

School of Occupational Therapy and Social Work

A Comprehensive Framework for Future Road Safety Strategies

Brett Peter Hughes

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Doctor of Philosophy
of
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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Candidate Signature:

A handwritten signature in blue ink, appearing to read "B Hughes", with a long horizontal line extending to the right.

Date: 15/6/2017

St Paul understood a system. Excerpts from 1 Corinthians 12:8

A body is not a single organ, but many. Suppose that the foot should say, "Because I am not a hand, I do not belong to the body," it does belong to the body none the less. Suppose that the ear were to say, "Because I am not an eye, I do not belong to the body," it does still belong to the body. If the body were all eye, how could it hear? If the body were all ear, how could it smell?...there are many different organs, but one body. The eye can not say to the hand, "I do not need you."

The New Economics, Chapter 3. Introduction to a System (Deming, 1994, p65).

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Brett P Hughes, 15 June 2017.

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Abstract

Road safety is a massive public health, social, economic and transport issue. More than 1.2 million people each year die in road crashes, and countless more are injured. Current road safety strategies lack a comprehensive, coherent set of components and policy tools underpinned by theoretically sound principles. Thus, the aim of the present thesis was to contribute to the improvement of road safety strategies to be more applicable, efficient, effective and responsive to different circumstances and futures.

The six papers included in the thesis address the overall aim from different perspectives. The review of models relevant to road safety in Paper I broadly and thoroughly reviewed the literature, to identify models that could inform the development of a comprehensive framework for road safety strategies. System theory, which emerged from the review and referenced in recent road safety strategies, was used as the basis for analysis of leading road safety strategies in Paper II. Paper III investigated the potential effects of four examples of government policies to demonstrate the economic context which affects road safety. Metrics for the outcomes of road safety strategies were investigated and developed in Paper IV and assessed against objective criteria. Based on the metrics and economic context component requirements, Paper V developed and applied data to demonstrate relationships between road safety and subcomponents from the economic and transport contexts. A single comprehensive framework for road safety strategies, comprised of nine mutually interacting components, with 75 subcomponents that contribute to crashes, and 10 generic policy tools consistent with system theory was synthesized in Paper VI, assessed against objective criteria, and supplemented with additional relevant concepts found in the course of the research.

It is expected that the developed framework, based in systems theory, can be applied to improve road safety strategies to reduce the social and economic burden of road safety on the community and industry.

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Preamble

Road safety is a massive public health, social, economic and transport issue. More than 1.2 million people each year die in road crashes, and countless more are injured (WHO, 2015). The economic and social consequences defy estimation (Peden et al., 2004). Reducing outcomes from road crashes is becoming increasingly more difficult since the significant and continual improvements made in the past are becoming more difficult to continue to be achieved (WHO, 2015). At the same time, new technologies, user preferences and transport systems are emerging that introduce unexpected challenges (Leveson, 2011a; Bennett and Lemoine, 2014) and are beyond the scope of even modern road safety strategies.

Developed countries have improved road safety since the very earliest times of road transport. Governments take a lead role in improving road safety on behalf of the community and industry. Since the early 20th Century, road safety has focussed on the application of engineering, enforcement and education (Damon, 1958) to improve roads, drivers and vehicles (HC Deb, 1939). A full description of factors and components contributing to crashes, and remedies to counteract them, has not yet been described (Wegman, 2017). Future changes, however, are beyond these existing policy tools and components. Further developments in road safety are required to continue to reduce road trauma, and applying systems theory offers considerable potential (Salmon and Lenné, 2015).

Road safety has been recognised as a complex field with multifaceted and interconnected factors, influences, interrelationships, components and countermeasures (Gordon, 1949; OECD, 1990; Peden et al., 2004), but road safety strategies take a very simple approach and do not reflect the complexity of contexts, causes and consequences. Road safety strategies need to recognise and address the full range of factors and influences that affect outcomes (Smeed, 1949; Peden et al., 2004). Road safety in future will be subject to dynamic contexts and technologies that are already evident, but very unpredictable, and different regions around the world are not the same (Wegman, 2017).

Several challenges have been raised about how road safety strategies can be improved. Approaches to road safety need to address the full range of factors and influences that affect it. New and comprehensive approaches offer the potential for improving road safety strategies (Benner, 1975 and 1985; May et al., 2008; Lundberg et al., 2009; Hovden et al., 2010; May et al., 2011). Systems approaches, in particular, have been successfully applied in other safety domains (Michaels, 1963; Kjellén and Larsson, 1981; Chapanis, 1996), but thus far not in road safety (Read et al., 2013; Salmon and Lenné, 2015), despite Smeed (1949) calling for greater appreciation of a wider range of factors affecting road safety more than 60 years ago. In doing so, he also called for greater integration of the individual actions of different professional disciplines to achieve complementary and synergistic road safety outcomes. These perspectives are consistent with including social and economic factors (Haddon, 1980a; OECD, 1990), and the systems approach that has been echoed several times (Peden et al., 2004; Racioppi et al., 2004). However, these perspectives are not particularly evident in current road safety strategies and have certainly not yet been thoroughly applied (Salmon and Lenné, 2015). Models have been used to summarise and describe road safety at several levels, including frameworks for road safety strategies. Such frameworks for road safety should be assessed for suitability for their purpose (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000). However, since road safety strategies, and the conceptual frameworks that underpin them, are rarely assessed, they have not been justified.

Road safety strategies have evolved rather slowly and incrementally over time, and are based on existing paradigms (OECD, 1990; OECD, 1997b; May et al., 2008). Existing components and influences further affecting road safety are not fully included in road safety strategies, such as the social and economic contexts that Haddon (1980a), Zein and Navin (2003) and others identified for road safety, or other safety domains (Hughes et al., 2016). Thus, a full description of the possible range of policy tools and components based on theory, research and practice that can be applied to guide the development of better road safety strategies, is lacking (Hughes et al., 2016).

Given the background that current road safety strategies may be limited and inadequate, a broad perspective and systematic research methodology (Hancock and Bezold, 1994; Voros, 2003), was adopted to overcome narrow thinking that was previously evident (Hollnagel, 2008; May et al., 2008; Lundberg et.al., 2009; Hovden et al., 2010; May et al., 2011).

The aim of this thesis was, therefore, to contribute to the improvement of road safety strategies by developing a comprehensive framework based on a broad approach with multiple perspectives grounded in theory, research and practice. The work identifies wider influences on road safety outcomes and other actions that could be applied, but not commonly included in contemporary road safety strategies. The framework describes nine mutually interacting components, with 75 subcomponents that contribute to crashes, and 10 generic policy tools that can be applied to reduce the outcomes of these crashes. Compared to previous road safety handbooks, guidelines, standards, research and strategy, this framework is more comprehensive than previous descriptions applied to improve road safety.

It is expected that applications of this framework can contribute to the improvement of road safety strategies with the result that the burden of road safety on the community and industry, both socially and economically, can be reduced.

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List of Publications

Paper I

Hughes, B.P., Newstead, S., Anund, A., Shu, C.C., Falkmer, T. (2015). A review of models relevant to road safety. *Accident Analysis and Prevention*, 74, 250-270. ISSN 0001-4575, <https://doi.org/10.1016/j.aap.2014.06.003>

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Paper II

Hughes, B.P., Anund, A., Falkmer, T. (2015). System theory and safety models in Swedish, UK, Dutch and Australian road safety strategies. *Accident Analysis and Prevention*, 74, 271-278.

ISSN 0001-4575, <https://doi.org/10.1016/j.aap.2014.07.017>

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Paper III

Hughes, B.P. (2010). *Government policy: the accidental effect on road safety*. Proceedings of Australasian Road Safety Research, Policing and Education Conference, Canberra, Australia. <http://acrs.org.au/files/arsrpe/R2010655.pdf>

Paper IV

Hughes, B.P., Hopkins, S. (2011). *Outcomes-based national road safety performance measures*. Proceedings of Australasian College of Road Safety Conference, Melbourne, Australia. <http://acrs.org.au/files/papers/8%20Hughes%20Outcomes%20Based%20National%20Road%20Safety%20Performance%20Measures.pdf>

Paper V

Hughes, B.P., Newstead, S., Shafei, S., Hopkins, S. (2014). Data foundations for relationships between economic and transport factors with road safety outcomes. *Journal of the Australasian College of Road Safety*, 25(3), 41-49. <http://acrs.org.au/wp-content/uploads/ACRSjournalVol25No3Aug14WEB.pdf>

Paper VI

Hughes, B.P., Anund, A., Falkmer, T. (2016). A comprehensive conceptual framework for road safety strategies. *Accident Analysis and Prevention*, 90, 13-28. ISSN 0001-4575, <https://doi.org/10.1016/j.aap.2016.01.017>

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Note 1: According to Google Scholar 15th of June 2017.

Note 2: According to Elsevier 15th of June 2017.

Note 3: All papers are peer reviewed and published. Reviewers' comments can be provided on request.

Terms Used in this Thesis

The language of high level documents about safety, and road safety in particular, can be confusing due to vague, inconsistent and ambiguous terminology. In this thesis, the following terms are mostly used with the meanings described below, as consistently as possible.

Other authors may use the same terms with different meaning. These terms are common in the literature; however they are often not used consistently and may have different common usage in different domains, as this thesis examined and explained in more detail. Terms may be used differently relative to geographic areas, cultures, contexts or languages. For instance, some fields, such as public health, use the term 'determinant', whereas 'factor' is widely used by analysts and economists. The context of the use of a term may also affect its meaning, or terms may change over time. For example, road safety now commonly uses the term 'crash' in preference to 'accident', but 'accident' has been used in safety for a very long time and remains in common use in other safety domains.

The definitions below commonly apply to the terms used in this thesis, unless required to be different due to the original context or use, where it is inappropriate to use the term as defined below.

Accident – an unplanned event with adverse consequences, such as injury, loss of life or other damage. Accident is common terminology for most safety domains besides roads, where it used to be the common term. The terms 'motor vehicle accident' or 'road traffic accident', or simply 'road crash', or 'car crash' have also been commonly used. 'crash' is normally used in this thesis for a motor vehicle collision, and 'accident' for other adverse events in other safety domains, although there are exceptions, mainly due to historical usage.

Achievement – successful improvements to safety (i.e. reduction in adverse consequences).

Actor – any individual or entity that has the capability to affect road safety, including government, agency, association, company or individual person. Sometimes categorised as users or stakeholders. This is further explained in Chapter 7.

Approach – a way of applying a theory to examining or improving a problem area, or a way of doing something from a certain perspective.

Component – a subordinate part of a system, e.g. drivers, vehicles and roads in the road safety system.

Concept – a general underlying basis, idea, rationale, approach to, or way of thinking about an issue, situation, description or thing.

Construct – a main subordinate part or idea of a model, description or theory, and can be defined by inclusion and exclusion criteria.

Crash – an accident on a road, a term more commonly used recently in road safety management, including strategies, research, analysis and programs.

Domain – a field of study or activity, e.g. economic, social or physical environment. See 'Safety domain' below for further description.

Economic – relating to financial transactions or wealth. Note this is a limited but common view of 'economic' that, in its pure sense, holistically relates to social, physical, environmental and other outcomes.

Factor – an intrinsic characteristic of a component, e.g. age of driver, colour of vehicle. In health prevention, factors are commonly called determinants to describe the prime causal or explanatory characteristics of events. However, determinants generally ignore other components and influences. Factor is commonly used in economics and sometimes in road safety the way component is used in this thesis.

Framework – a description according to a logical structure or underlying ideas, or a structure for thinking and ideas. In this thesis, framework is generally used as the basic rational arrangement at a high level that describes a strategy.

Influence – an external agent or action that changes a factor or component, e.g. increasing population or economic activity. Influence is often used in economics the way policy tool is used in this thesis.

Model – a representation of something in the real world used to help understand, communicate, organise ideas, analyse, investigate or research. In general, models may take different forms, such as physical, mathematical, visual, computer generated or conceptual (based on ideas). Models may be used for a variety of descriptive purposes including to organise and summarise ideas, problems or solutions. All models have inaccuracies or weaknesses, but can still be very useful, or even powerful in guiding thoughts and actions.

Natural environment – relating to the physical, real world environment.

Outcome – either beneficial or adverse consequences of a system when it is functioning, or something of value that is produced or as a result.

Performance measure – a quantification of a change in an outcome, according to a specification, often used for comparison, or to examine or describe achievement.

Perspective – a way of considering, examining, describing or analysing something.

Policy – a tangible and deliberate action by government that causes a change to a component. In other usage, policy can be a high level, general statement of intent or direction. However, in this thesis a policy is a specific action.

Policy tool – any specific intervention or countermeasure applied to improve safety including policies, programs and/or projects, e.g. pricing, education or regulation.

Principle – a general rule to be followed, or moral value to be used as a guide or put into practice.

Program – a group of policies or projects of similar type, e.g. the same action repeated in different locations.

Project – a tangible action that changes a component directly.

Relationships – the interactions between actors, policy tools, components and outcomes, which may be positive or negative, forwards or feedback.

Road safety management – the activities by which road safety is achieved including strategy development, design and selection of policy tools, implementation, evaluation and performance assessment.

Safety domain – safety in specific bounded circumstances, e.g. occupational safety, safety in hazardous industries, food safety, recreational safety, medical safety, safety in offshore operations, nuclear safety and mining safety.

Social – relating to communities, human activity and effects on humans.

Strategic – relating to the identification of overall aims or objectives and the development of means of achieving them. Strategic approaches are therefore ways of developing strategies to address problems or making improvements to something.

Strategy – a general overview of a group of policies, programs, projects that are applied to improve road safety for a particular domain. Road safety strategies are generally applied at the national or state level, but could be applied to a city, road user group or other defined sector. Strategies are above the tactical level of individual actions.

System – a network of interdependent components that work together to accomplish an objective.

Theory – an underpinning idea as a basis for understanding. In this thesis, theories have been demonstrated by scientific research, or are a confirmed explanation of observations or basis for practice.

Transport safety – generally aviation, rail, road or maritime safety, but excluding road safety which typically has different operating conditions and safety management.

Target – a specified and measured objective or aim.

Type of model – a type is a certain way of constructing, characterising, categorising or describing something according to a clear logic, form or format. Types of models are different ways of describing something. A researcher can easily relate to types of research (e.g. quantitative or qualitative); an analyst can similarly relate to types of charts (pie, column, bar, scatter, etc.). A mathematician can relate to types of mathematical model (e.g. linear or non-linear, ordinary least squares regression or time series analysis, etc.).

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Chapter 1. My perspective on this thesis

Many years ago, I remember standing at an intersection and looking at where blood had remained in the pavement after a crash. After several years of inaction at the site I wondered why the crash had happened and what could have been done to avoid it. Later when I was investigating the relationship between traffic volumes, intersection factors and crashes at traffic signals, I had a message on my office pinup board that simply read "*Statistics don't bleed*", reminding me about the outcomes and not to just rely on data analysis. While I was investigating intelligent transport systems, I realised that technology exists within a greater context of organisational and wider circumstances. When I wrote about rail transport challenges I described the greater government and commercial challenges that were at least as significant as the rail infrastructure, rolling stock and operator issues that are the normal focus for railway improvements. I also observed that transport had become much more complex and was likely to continue to do so. The level of regulation, application of technology, social operations and other changes are much more interconnected and are constantly making people's lives and business much more complicated.

Given this appreciation of a wide range of influences on transport systems, most recently I wondered why road safety strategies focused so narrowly on so few components. Engineering, enforcement and education had been related to vehicles, drivers and infrastructure, but I also knew there were many other factors that affected road safety. It was clear from industry, government and research reports that there were many other contributing factors and actions, but safety literature, and especially regarding road safety, almost entirely ignored these factors. I also noticed that many road safety strategies were extremely similar, employing a narrow range of countermeasures, such as enforcement, education and road engineering. I knew from my policy experience that there were other countermeasures that might potentially be deployed to reduce the massive worldwide human cost of the road toll, currently estimated at over 1.2 million lives

per annum, and 50 million injuries, with enormous financial cost that defies estimation. I also knew that my white, Western, aging, professional, male background was likely to limit my perspectives, so I tried to think about how other contexts and situations might be appreciated with regard to this unwanted waste of human lives, and unnecessary financial and social costs.

Apart from the technical content and scientific approach, there are underlying themes which this thesis takes on, to challenge and change the paradigms of road safety, viz.:

- the current perspectives of crashes that may be limited, by overcoming the *What-You-Look-For-Is-What-You-Find*, and *What-You-Find-Is-What-You-Fix* limitations (Hollnagel, 2008; Lundberg et al., 2009); and
- *What-Got-You-Here-Won't-Get-You-There* (Goldsmith, 2007), to explore new opportunities to improve safety.

To overcome these, Hollnagel (2008) describes the need to anticipate future threats and risks by having an idea about how they can happen. This requires a shift from extrapolations and analogies from the past, typical of a calculative culture that leads to reactive solutions that are often singular and incomplete. Such approaches are also often restricted by narrow scope of investigations and predicated by assumptions that therefore lead to inadequate conclusions, and impede learning in the process. Therefore, this thesis seeks to move to a proactive or developmental approach, that anticipates and plans, with learning as an essential element.

All of these perspectives led to this investigation of the whole range of factors and influences that affect road safety outcomes. The themes and thoughts about diversity and complexity from my background are the main influences that have guided the directions of this research. I believe that this knowledge opens the door to a greater understanding of the road safety system as a whole, so that all of the opportunities to improve road safety are maximised and that the goal to reduce the road toll can continue to be achieved. Hopefully then, generations that follow will see less blood on the pavement.

1.1 Background

Road trauma is recognised internationally as an important issue with significant public health, social, economic and transport consequences. Governments want to reduce this trauma, and have developed road safety strategies for many years to articulate how they intend this to be achieved (Mohan et al., 2006; OECD/ITF, 2008; FHA, 2013; OECD/ITF, 2016a). The burden of road trauma has reduced in many industrialised countries, but remains far from small (EU, 2015; WHO, 2015; BITRE, 2016; OECD/ITF, 2016b). Therefore, this thesis explores and develops potential improvements to road safety strategies so they can be more applicable, efficient, effective and responsive to different contexts and futures.

In response to the substantial personal and economic costs of road crashes, most developed countries have road safety strategies or plans¹ that summarise governments' overall approach to road safety (WHO, 2015; OECD/ITF, 2016a). The aim of such strategies is to guide implementation of individual actions that together comprise a cohesive and comprehensive approach to reduce road trauma (Mohan et al., 2006; OECD/ITF, 2008; FHA, 2013; OECD/ITF, 2016a).

Generally, national and state governments take a lead role in improving road safety, since improvements result in social and general economic benefits rather than private or commercial benefits (Mohan et al., 2006; OECD/ITF, 2008; FHA, 2013; OECD/ITF, 2016a). Governments also have more responsibility, authority, capacity and capability to affect road safety outcomes than their communities, businesses and industries which expect governments to act. Private companies, associations and others also contribute, sometimes with their own strategies, but take less responsibility unless significantly affected (Rasmussen 1997; Leveson, 2009; Salmon et al., 2016).

Road safety is a multifaceted problem (Gordon, 1949; Damon, 1958; Haddon, 1980a; OECD, 1990; Peden et al., 2004, Racioppi et al., 2004), with some 'wicked'

¹ Europe and Australia commonly use the term 'strategy' while the term 'Strategic Highway Safety Plan' is most common in the USA.

attributes (Di Stefano and Macdonald, 2003; APSC 2007; Head and Alford, 2013). While road safety strategies focus on drivers, vehicles and road infrastructure, there are many more direct and external factors that affect road safety outcomes (Gordon, 1949; Damon, 1958; Haddon, 1980a; OECD, 1990; Peden et al., 2004; Racioppi et al., 2004; Wegman, 2017). There are also a multitude of actors that contribute to road safety outcomes (Gordon, 1949; Damon, 1958; Rasmussen, 1997; Peden et al., 2004; Racioppi et al., 2004; Salmon et al., 2016). A great deal of effort has been applied over a long period of time to influence these factors as road safety strategies describe. Consequently, reducing road trauma is a somewhat intractable problem, so improvements are no longer simple or easy to implement (WHO, 2015; OECD/ITF, 2016b; Wegman, 2016). The rational-technical approaches that have been developed over decades, and remain reasonably the same today, seem unlikely to be able to meet the challenge to continue to improve road safety in the future (APSC, 2007; Leveson, 2009; Hovden et al., 2010; Larsson et al., 2010; Head and Alford, 2013; Hakkert and Gitelman, 2014).

While road safety strategies are developed and applied in nearly every developed country, the underlying theory and research on alternative models, styles, content or implementation of strategies as particular types of document or approach is very limited (Paper II, Hughes et al., 2015a; Paper VI, Hughes et al., 2016), typically relying on a paradigm based on the 3E's of policy tools (engineering, enforcement and education) to change three key components (drivers, vehicles and roads), as described below (Mohan et al., 2006; FHA, 2013). Some comparisons between different types of strategies are made in general terms (Wegman et al., n.d.; Koornstra et al., 2002; OECD, 2002; WHO, 2015; OECD/ITF, 2016b), but robustly researched comparisons are not evident in the literature.

Various frameworks, standards and guidelines have been developed to improve road safety, including:

- Strategic approaches (e.g. OECD/ITF, 2008 and 2016a);
- Strategies (e.g. those investigated in Papers II and IV);

- Guidelines and manuals (e.g. Mohan et al., 2006; Bliss and Breen, 2008; FHA, 2013 and PIARC, 2015); and
- Standards (e.g. ISO, 2012).

Given the multifaceted and complicated nature of road safety, it is not clear that these are all grounded in sound theory, or demonstrated to be robust in practice (i.e. complete and suitable according to a rational framework). While these have different purposes in improving road safety, they cover common components, actors or processes, and employ similar perspective, theories or models. So, research or activity in one of these areas may inform or be applicable to another of the areas.

This thesis focusses on government road safety strategies in developing countries, particularly Europe, North America and Australasia. The aim within this selected coverage is to continue the development that has occurred in the past, in order to improve the applicability, efficiency, effectiveness and responsiveness of road safety strategies and provide a foundation for strategies that will be required in the future, that will very likely be different from existing circumstances.

1.2 Statement of the problem

Road trauma is a leading cause of preventable death that is expected to worsen in the coming years (WHO, 2015). As mentioned, road crashes² are estimated to cost 1.2 million lives worldwide each year with possibly as many as 50 million people injured (WHO, 2015). In Europe, nearly 25,700 fatalities were reported in 2014 and more than 200,000 people sustained serious injuries (EU, 2015). In the USA more than 30,000 people die and more than a million more are injured in road crashes each year (Evans, 2014). Globally however, the number of road traffic deaths has

² The term 'crash' is used here, in its context of road safety, where the term 'accident' is used in some literature, and by the general public. According to Evans (1991, 2004) the term 'accident', despite its wide use, is considered less accurate, implying a degree of randomness which is inconsistent with analysis of the data, and inability to control which is inconsistent with safety management. While the term crash may be imperfect when describing a collision between say, a bicycle and pedestrian, it is considered the most appropriate term available. The term 'accident' is generally used in many other safety domains, which are relevant to this thesis, and therefore used when such contexts occur.

plateaued since 2007, while road safety has been deteriorating in many developing countries (WHO, 2015; OECD/ITF, 2016b; Wegman, 2017). The full extent of road trauma's economic and social consequences defies description or estimation, with the average cost to governments alone approximating 3% of Gross Domestic Product, and up to 5% in some cases (WHO, 2015).

To address this important issue, governments in developed countries generally prepare road safety strategies, as described in Papers II and VI (Paper II, Hughes et al., 2015a; Paper VI, Hughes et al., 2016), based on perspectives developed in the early 20th century (HC Deb, 1939; Damon, 1958), that have since evolved in style over time. In addition, Papers II and IV describe that while modern road safety strategies are often similar, they also have distinguished differences (Paper II, Hughes et al., 2015a). Therefore, a question arises as to what a comprehensive framework for road safety strategy would include, in order to inform and improve the development of any individual road safety strategy.

In 1997, OECD reported "*road safety policy has been a success story in most OECD countries*" because "*Overall, the risk of being fatally injured in a traffic accident has declined.*" (OECD, 1997a, p75). Nevertheless,

"A critical overall theory for road safety is lacking. If future policies and actions are to be fully successful, a comprehensive theoretical basis for road safety is needed." (OECD, 1997a, p90).

Notwithstanding this declaration of need, subsequent work focussed on four types of models: Descriptive Models, Predictive Models for Aggregated Data, Risk Models for Non-Aggregated Data and Accident Consequence Models (OECD, 1997b). Neither an underlying theory, nor generalised descriptive models were developed.

While road safety is improving in many developed countries, there are indications that the rate of improvement is declining (EU, 2015; WHO, 2015; OECD/ITF, 2016b; Wegman, 2017). It is possible that the advances in road safety that were achieved in the past cannot be achieved to the same degree in future, and new approaches may be required (Hollnagel, 2008; May et al., 2008; Lundberg et al., 2009; Hovden et al.,

2010; May et al., 2011; Salmon and Lenné, 2016). In other words, "*What Got You Here, Won't Get You There*" (Goldsmith, 2007). Furthermore, the future context for road safety is changing in ways that will dramatically affect outcomes (Rasmussen and Svedung, 2000; Leveson, 2011a; Hakkert and Gitelman, 2014), which is further explored in Chapter 7. If this is true, then the actions of past strategies will not be sufficient to achieve future road safety objectives.

Road safety outcomes vary greatly between different countries even though most developed countries have road safety strategies. EU (2015), WHO (2015), BITRE (2016) and OECD/ITF (2016b) describe the road safety situation and key issues in many developed countries, but there are substantial differences in road safety outcomes, and the results of road safety strategies as a whole remain unclear. The reasons for this are not understood since it is not a topic of research (Wegman, 2017). However, one potential reason is because the strategies developed for some jurisdictions are more applicable, efficient and effective than the strategies developed for others, whether by design, level of effort, or some other reason.

In spite of all of the efforts made by governments and others, and the improvements that have occurred, "*the road safety problem is far from being solved*" (Hakkert and Gitelman, 2014, p137). Road safety strategies need to be applicable to the future, because it will certainly be different to the past. It is evident that road transport, electronic technologies, user preferences, as well as wider social and economic systems, are changing and are doing so at an ever increasing rate (Rasmussen and Svedung, 2000; Leveson, 2011a; Hakkert and Gitelman, 2014; Deloitte, 2015; USDOT, 2016). Transport policy, including road safety, needs to be adaptable to the changing future. Therefore, future changes to the road safety context may be easier to respond to if there is a comprehensive framework to help them become more visible. The results of road safety strategies may be limited by the scope of the components that are targeted and the policy tools that are applied to effect improvements.

Road safety has been recognised as a complex field with multifaceted and interconnected factors, influences, interrelationships, components and countermeasures (Gordon, 1949; Damon, 1958; Haddon, 1980a; OECD, 1990). Peden et al. (2004) describe that "*of all the systems that people have to deal with on a daily basis, road transport is the most complex and the most dangerous.*" (p3).

"Any road traffic system is highly complex and hazardous to human health.

Elements of the system include motor vehicles, roads and road users, and their physical, social and economic environments. Making a road traffic system less hazardous requires a "systems approach" – understanding the system as a whole and the interaction between its elements, and identifying where there is potential for intervention." (Peden et al., 2004, p157).

While road safety strategies have been developed for decades, they have limited basis in theory and research (Paper VI, Hughes et al., 2016). Mostly they are based on a collection of individual policy tools applied to individual components, that generally have a basis in research individually, but not collectively, at a dynamic time in transport when new approaches are required (Hovden et al., 2010; Wegman, 2017). The style of road safety strategies as a whole is not based on theory, and has evolved over time without any apparent underlying research or rationale (Paper VI, Hughes et al., 2016). In addition, there is no evidence that the full range of potential policy tools and components have been considered for inclusion, to ensure any strategy is as efficient and effective as possible (Paper VI, Hughes et al., 2016). In contrast, other safety domains, such as industrial or occupational safety, have more robust theoretical and research basis that offers the potential to be applied to road safety (Paper I, Hughes et al., 2015b; Salmon and Lenné, 2015).

In the absence of a comprehensive framework that is based on theory and practice, there is no reliable description of the full possible range of policy tools and components that can be applied to guide the development of better road safety strategies (Paper VI, Hughes et al., 2016).

1.3 Road safety strategies

1.3.1 Overview of road safety strategies

In simple terms, road safety strategies are generally documents describing the actions a government will take in order to reduce the social and economic costs of road safety in their geographic region of interest (EU, 2015; WHO, 2015; BITRE, 2016; OECD/ITF, 2016b). Some road safety strategies may be written for certain sectors, such as a regional area, or mode of travel, such as heavy vehicles or cyclists. In other cases, road safety strategies may be prepared by interested associations, individual companies or others, for their own internal application or to influence others, such as governments.

Road safety strategies generally originate from a central government coordinating agency in conjunction with key contributing agencies, which assume the main responsibility for road safety outcomes (EU, 2015; WHO, 2015; BITRE, 2016; OECD/ITF, 2016a). Firstly however, there are many other actors inside and outside government who can make a contribution to improving road safety (Gordon, 1949; Damon, 1958; Haddon, 1980a; OECD, 1990; Peden et al., 2004; Salmon et al., 2016). Secondly, others, such as private companies, industry associations and workplace safety agencies, can develop their own road safety strategies to address their specific circumstances and needs. So, while governments assume a lead role, there are other actors who can make a significant contribution.

The outcomes of road safety strategies are difficult to determine (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013). Firstly, individual actions can occur without an overarching strategy document. Secondly, road safety is subject to many influences, so it can be difficult to determine the result of any action either individually or integrated with others, in isolation or the aggregate as the strategy. For instance, a strategy may summarise five years of activity, at the same time that population increases, vehicles improve and economic conditions change. In such cases it can be impossible to differentiate changes caused by the individual actions, the strategy as a whole or other exogenous contextual factors.

Road safety outcomes are affected by the wider context, including the transport system and broad economic and social contexts, but receive less attention than the key focus areas of drivers, vehicles and roads (Hughes, 2010; Paper VI, Hughes et al., 2016). Individual actions in road safety strategies typically include regulation and enforcement, education programs, funding for new facilities or activity and only target a few factors (Paper VI, Hughes et al., 2016). Other policy tools, such as economic incentives or subsidies, are rarely applied. Therefore, there is potential for other actions to be more widely applied to a greater range of components of the road safety system that contribute to road safety (Paper VI, Hughes et al., 2016).

It is claimed that many road safety strategies have been successful (Koornstra et al., 2002), although it is difficult to determine whether the strategy itself as an overarching document is beneficial (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013). Any analysis of individual actions in isolation or in aggregate is generally difficult, given the range of contextual factors that affect road safety outcomes (such as population increases) and other factors that are changing at the same time, such as continuing improvements in vehicle safety (Gaudry et al., 1995; Gaudry and Himouri, 2012).

1.3.2 Evolution of road safety strategies over time

Governments and others have developed and applied road safety strategies for at least 60 years. Prior to the 1950's the management of road safety occurred, but with the simplest of structure or strategic approach. A very common approach was the three E's – Enforcement, Engineering, Education (Damon, 1958; Nader, 1965; Booth, 1980; OECD, 1997b), attributed originally to Julien H. Harvey, director of the Kansas City Safety Council in 1923 (Damon, 1958). A fourth E – Emergency Management, was added later (FHA, 2013).

The next common approach developed was based on user-machine-environment which was translated to drivers, vehicles and roads for road safety management. The driver-vehicle-road construct was clearly evident in addressing road safety from the early years of motorised road traffic. In 1939, the British Minister for Transport,

Captain Wallace, during Parliamentary debate, referred to three factors that must be considered – the vehicle, the road, and the user (whether motorist, cyclist or pedestrian) while referring to the Alness Select Committee Report on the Prevention of Road Accidents for the British Parliament in 1939 (HC Deb, 1939) and noted there was no single or sovereign remedy. Much of the scientific and professional endeavour subsequently followed an epidemiological approach of host-agent-environment, particularly Gordon (1949) who considered accidents as an epidemiological problem. This approach was also broad enough to recognise wider categories of factors including physical environment, biologic environment and the socio-economic environment. The host-agent-environment construct migrated to driver-vehicle-road construct in road safety research analysis and strategy (Smeed, 1964), that became more widely used in research and practice following Haddon (1968).

Perhaps the most widely used logical approach was developed by William Haddon in several forms (Haddon, 1968, 1972, 1980a, 1980b, 1999). The Haddon Matrix, as it is commonly known, is still used frequently today and includes phases of a crash in time (pre-crash, crash and post-crash) and factors or components that affect crashes (e.g. drivers, vehicles, road environment, and social-economic environment), although there are several versions describing different components or factors as described below. The broader physical environment and socio-economic environment components did not, however, consistently and thoroughly continue after the 1970's.

OECD (1997a) summarised four road safety paradigms over the period from the inception of motorised vehicles according to 14 aspects (Table 1.1). The table shows that the various approaches to improving road safety can be considered from different perspectives, and have changed slowly and incrementally over time. These are pragmatic in nature, arising from practice and without an underlying theory or model.

Table 1.1. Evolution of road safety paradigms

ASPECTS	PARADIGM I	PARADIGM II	PARADIGM III	PARADIGM IV
Decennia of dominating position	1900 - 1925/35	1925/35 - 1965/70	1965/70 - 1980/85	1980/85 - present
Description	Control of motorised carriage	Mastering traffic situations	Managing traffic system	Managing transport system
Main idea and FOCUS	Use CARS as horse drawn carriages	Adapt people to manage traffic SITUATIONS	Eliminate risk factors from road traffic SYSTEM	Consider exposure of risks, regulate TRANSPORT
Motor vehicles / 1000 population	Less than 25	25-250	250-500	>500
Main disciplines involved	Law enforcement	Car and road engineering, psychology	Traffic engineering, traffic medicine, advanced statistics	Advanced technology, systems analysis, sociology, communications
Organisation of vehicle production	Craft-production, craftsmen's manufacturing	Mass-production workers assembling	Lean production, group assembly on sub-contracting	Recycling materials
Terms used about unwanted events	Collision	Accident	Crash, casualty	Suffering, costs
Role of persons using motor vehicles	Ownership of vehicles: "Car owner"	User of motor power: "Motorist"	Active part of the system: "Driver"	Social partnership: "Road user"
Attitudes towards automobiles	Fearful curiosity	Blind admiration	Prudent tolerance	Calm consideration
Premise concerning un-safety	Transitional problem, passing stage of maladjustment	Individual problem, inadequate morale and skills	Defective traffic system	Risk exposure
Data ideals in research	Basic statistics, answers on "What"	Causes of accidents "Why"	Cost/benefit ratio of means "How"	Multidimensional
Organisational form of safety work	Separate efforts on trial and error basis	Co-ordinated efforts on voluntary basis	Programmed efforts, authorised politically	Decentralisation, local management
Typical countermeasures	Vehicle codes and inspection, school patrols	The three E's doctrine, screening of accident prone drivers	Combined samples of measures for diminishing risks	Networking and pricing
Effects	Gradual increase in traffic risks and health risks	Rapid increase of health risk with decreasing traffic risk	Successive cycles of decrease of health risks and traffic risks	Continuous reduction of serious road accidents

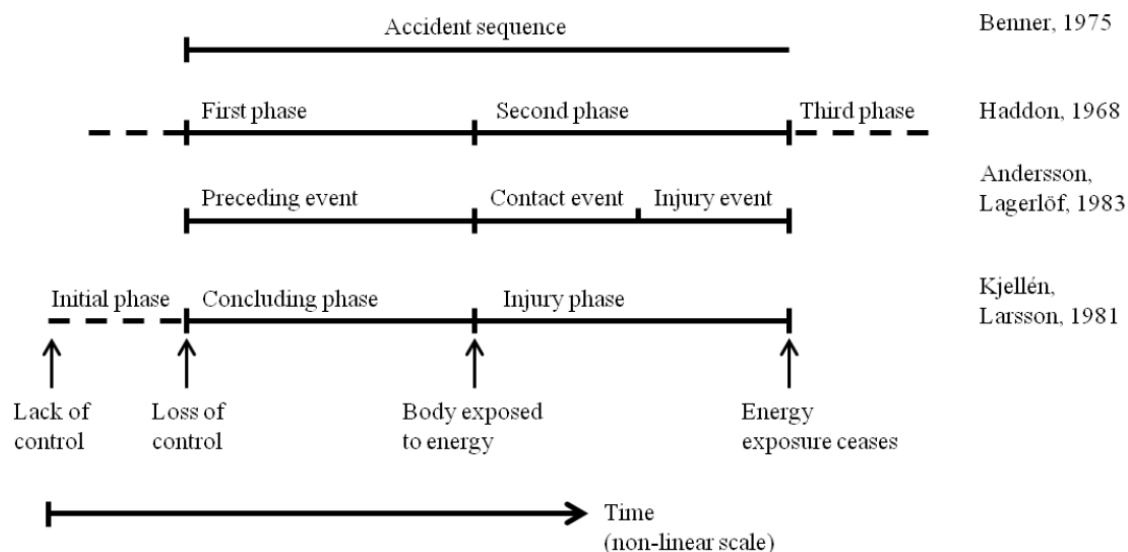
Hakkert and Gitelman (2014) described three perspectives on road safety strategies; management approaches, research paradigms and the causes of crashes and the changes on each of these over time (Figure 1.1, from Hakkert and Gitelman, 2014). This suggested an evolution of approaches to research over time, generally in five periods, and largely consistent with the practical approach, as described in Figure 1.1.

Figure 1.1. Periods of road safety research, according to various perspectives

	Time line →				
Perspective of consideration	Early years of motorisation	1950-1960s	1970-1980s	1990s	2000s
Road safety management (OECD, 2008)	n/a	Focus on driver interventions	Focus on system-wide interventions	System-wide interventions, with targeted results and leadership	Safe-system approach
Road safety research paradigms (OECD, 1997)	Vehicle control; descriptive research ("what")	Mastering traffic situation ("why"); research around the classical 3E's: Engineering, Education, Enforcement	Managing the traffic system ("how"); mathematical models; cost-benefit analysis	Managing the transport system; multi-dimensional analysis	Cross-disciplinary analysis; theory development
Main road crash causes (Wegman et al., 2007)	Crashes as a chance phenomenon	Crashes are mono-causal Crashes caused by the crash-prone	A combination of crash causes fitting within a 'system approach'	The road user is the weak link: more behavioural influence	Better implementation of existing policies; 'Systems' management perspective

Strandroth (2015) summarises the evolution of road crash models based on Kjellén (1984), as shown in Figure 1.2. Please note that these perspectives are generally about individual crashes, whereas the scope of road safety strategies is generally for all crashes in a region. Nevertheless, the concepts can be related to aggregate perspectives. This summary illustrates different descriptions of the sequence of a crash over time. While it recognises there may be contextual factors in the pre-crash period, there is no detailed description of the effect of context on crashes.

Figure 1.2. Relationship between the crash phases in early accident models



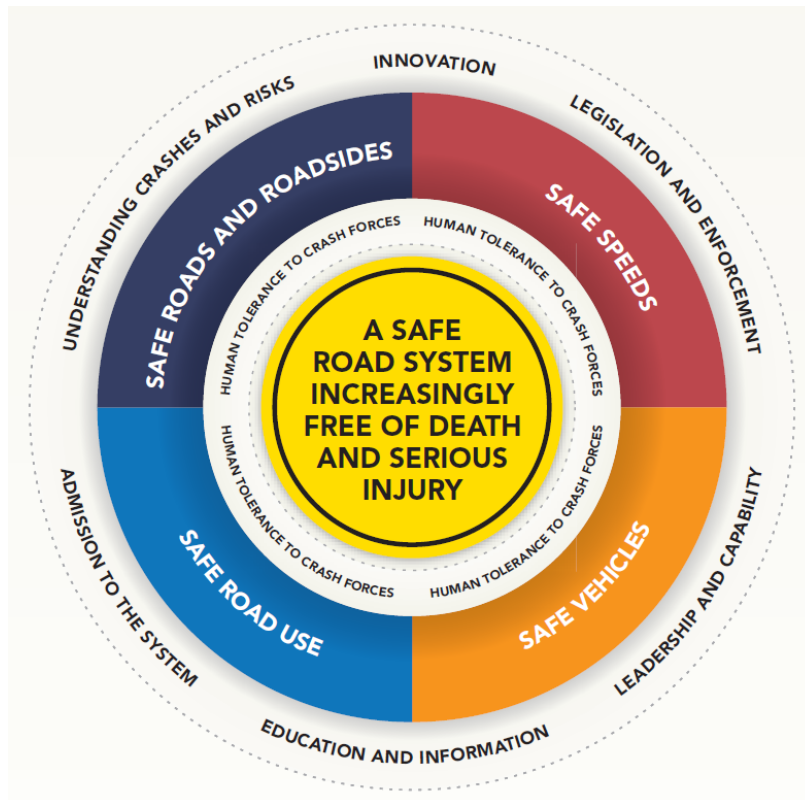
Different forms of overarching frameworks for road safety and other safety management generally are widely used and accepted, such as those described by Haddon (1980a), RRL (1963), Limpert (1978) and Baker and Fricke (1986). Guidelines have also been produced to inform the development of road safety strategies (ISO, 2012; FHA, 2013). Use of the frameworks indicates their acceptance, value and applicability for policy developers and practitioners in road safety. However, none of these include all the policy tools and components evident in road safety strategies.

Following the recognition that applying systems perspectives, such as integration, interrelationships and the roles of multiple actors had the potential to improve road safety strategies (OECD, 1990; Tingvall, 1997), attempts were made to reflect some of the nature of systems in road safety strategy development (Peden et al., 2004 Racioppi et al., 2004) that resulted in the first Safe Systems road safety strategies including a few systems characteristics (Tingvall, 1997; SRA, 2006; Wegman and Aarts, 2006; MOT, 2010). These particularly included appreciation of interactions between different parts of the system and the shared contributions of several actors that were intended to be complementary, so the strategies represent initial attempts to adopt aspects of systems. However, the links between the underlying rationale and the strategies to the systems concepts were tenuous, since they were

not thoroughly described or clearly based on systems theory or practice. As a result, for instance, the individual actors still appeared to operate independently, as did the application of the policy tools.

Road safety strategies have continued to evolve with the most recent in Europe and Australia being described as the 'Safe Systems' approach (Wegman et al., n.d.; Koornstra et al., 2002; MOT, 2010; Paper II, Hughes et al., 2015a), an example of which is illustrated in Figure 1.3 (MOT, 2010). These strategies are based on certain principles that vary quite considerably between versions, but include the limited capacity of the human body to absorb kinetic energy, that crashes are avoidable and drivers should not be blamed for crashes when other factors contribute. However, a comparison between the content of Safe Systems strategies and system theory (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a) reveals little in common. Contemporary road safety strategies are consistent with some of the key principles of systems theory, but do not recognise interactions between, or the interdependence of, the factors that affect road safety (Salmon and Lenné, 2015). Furthermore, while systems theory is based on other theory and research, the structure and principles underlying Safe Systems, or earlier types of road safety strategies, do not have the same proven foundations (Paper I, Hughes et al., 2015b). Indeed, as Larsson et al., 2010, p1170) points out, "*There are very few references to systems theory and road safety found when a literature research is carried out*". Therefore, this thesis investigates the application of systems theory that has the potential to improve road safety strategies.

Figure 1.3. New Zealand 'Safe System' approach to road safety



Contemporary road safety strategies continue to recognise basic components (such as drivers, vehicles and roads), and individual subcomponents (such as size of the vehicle or age of the driver), that contribute to the road crashes occurring and their outcomes. They also describe the policy tools (such as programs and projects) by which the components are changed, in order to improve road safety. However, each strategy is slightly different in response to the specific road safety issues, the situational context and preference for responding to the challenges and the manner of description. Given that different strategies need to include different actions, it is possible that some strategies do not include all of the actions that can improve road safety as efficiently and effectively as possible. It is also not clear that all possible actions have been considered in the development of the strategy. Elvik (2014) further recognises that assessment of interdependencies between road safety measures is very weak, in which case it poorly reflects systems theory.

Consequently, a comprehensive conceptual framework, thoroughly based on systems theory, has the potential to provide information on the full range of

components and policy tools during the development of road safety strategies to assist in ensuring they are complete, effective and efficient.

1.3.3 Current position of road safety strategies

Most road safety strategies describe policy tools (actions, projects or programs) that are applied to specific components that contribute to road safety, in order to improve road safety outcomes. Over the years, road safety strategies have been quite similar for the era in which they were written. However, despite these similarities, a few road safety strategies include either policy tools or components that are not common across all. This leads to the question as to whether any road safety strategy has included all policy tools and targeted all components that would improve road safety to the greatest degree.

It can be seen that the evolution of road safety strategies has been incremental rather than by step changes or dramatic divergence from previous concepts - more 'shallow change' than 'deep change' as May et al. (2011) describes. The approach of changing drivers, vehicles and roads by engineering, enforcement and education has been consistent for decades. More recently, an approach based on principles has become the underlying construct that the Safe Systems approach has followed. Even this approach has a long history (May et al., 2011), and incorporates many older concepts, as evidenced by the content of earlier strategies described in the previous section.

Systems perspectives have been recognised at least since the mid 1960's as being important in crash investigations.

"We have repeatedly emphasized the importance of viewing accidents in their broad ecological context and of avoiding disciplinary parochialism and an overemphasis on narrow classes of variables." (Michaels, 1963, p366).

Compared to viewing accidents as operational 'defects', that had dominated safety approaches up to that time, Michaels (1963, p372) concluded that *"the system approach appears to hold far more promise, especially when we bring modern technology to bear on transportation system design."*

While these systems concepts were identified, they had not been informed by a thorough theoretical foundation that only developed later (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a). A thorough systems approach has not been evident in road safety strategies, which have independent elements and tend to be simplistic, not reflecting the complexity of the factors, influences, interrelationships, components and countermeasures (Van Emmerik, 2001). Road safety problems required a sophisticated systems based response because the "*simplistic representations of traffic safety disregard the dynamic interactions among the road environment, the vehicle, and the road-user*" (Zein and Navin, 2003, p1).

Another example is the 'human tolerance to crash forces', that is commonly included in the Safe Systems approach. Yet this concept can be at least traced back to research in aviation injuries in the middle of the last century by De Haven (1942) and Stapp (1957), both reprinted in Haddon et al. (1964),

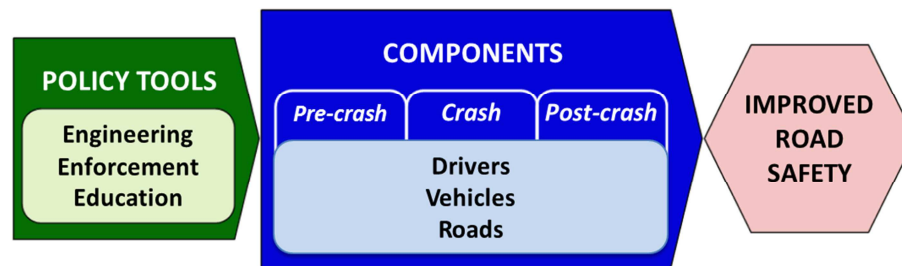
"Without exception, all of the forms of energy which may reach the human body can produce injury if either their amounts or their rates of application exceed the corresponding local or whole-body tolerances." (Haddon et al., 1964, p537).

This concept has been implemented in traffic engineering and reflected in road and intersection design standards. The design of roundabouts and merging lanes is preferred to high-angle intersections. The simple underlying basis is that vehicles colliding at acute angles result in less transfer of kinetic energy that result in forces more tolerable to vehicle occupants in the event of a crash.

The most commonly used framework in road safety management for many years, which remains predominant today, is summarised in Figure 1.4:

- three or four E's for countermeasures, or policy tools (engineering, enforcement and education plus emergency management);
- three components (drivers, vehicles and roads); and
- three phases of the crash sequence (pre-crash, crash and post-crash).

Figure 1.4. Typical application of policy tools to components to improve road safety



In conclusion, while there have been several evolutions of types of road safety strategies based on different perspectives, there is little justification for any individual type, nor comparative analysis to differentiate them. There is little description as to why road safety strategies have evolved or the basis for the next evolution. Lastly, there is little research into road safety strategies as a type of document, their theoretical foundations, efficiency or effectiveness, and potential alternatives or improvements.

1.4 Criticisms of safety models and potential for further development of road safety strategies

1.4.1 Development of models

Previous sections have described that road safety has been the subject of considerable research, strategy and practice. As a specific sub-topic, road safety strategies should be improved, if possible, in order for road safety to be improved. However, research that compares and analyses different road safety frameworks and the rationale and theory that underpins them, is rare. Road safety has been recognised as a complex field with multifaceted and interconnected factors, influences, interrelationships, components and countermeasures (Smeed, 1949; Peden et al., 2004;), with vague, inconsistent and ambiguous terminology that is confusing. Yet, as described above, this complexity is not reflected in road safety strategies over a long period of time. Furthermore, the future of road safety is subject to changing contexts and technologies, that are very uncertain, and different regions around the world are not the same (Wegman, 2017).

Road safety is a limited area of the broader domain of accidents and safety, so there is potential to learn from other domains. Crash investigations have many similarities and interconnections with road safety strategies. Investigations identify crash causes and factors, while road safety strategies develop countermeasures to address them, often summarised under key themes. So, analysing safety strategies, as well as learning from other safety domains and the field of crash investigations, offers potential to improve them.

This section discusses weaknesses and potential improvements in approaches to understanding safety from a variety of diverse perspectives and the potential for improvements that have been identified in other domains that could be applied to road safety. The intention here is to not be restricted by road safety approaches and perspectives, as Lundberg et al. (2009) and Benner (1975, 1985) describe, but to adopt a broad method that is open to other possible opportunities as Hancock and Bezold (1994) and Voros (2003) suggest, and Hovden et al. (2010) illustrate.

Benner (1975) criticised transport accident investigations on several grounds including delineating the beginning and end of the accident, methods of investigation and presentation of findings. He noted that approaches to investigating accidents were diverse, and concluded that there was no generally acceptable approach to accident investigation and analysis. Hence, there were unnecessary barriers to understanding crashes and transferring knowledge, popular misconceptions about the nature of accident phenomena and inefficiencies in the development of safety countermeasures. The same criticism can be applied to road safety strategies specifically, where Benner's requirements and outcomes are not demonstrated.

Lundberg et al. (2009) describes that a model is a set of assumptions about how events – in this case crashes – happen, and what the important contributing factors are. He argued that more sophisticated crash models are needed today to deal with events in more complex systems and new kinds of crashes that have emerged. Reflecting on Hollnagel's (2008) principle *What-You-Look-For-Is-What-You-Find*

(WYLFIWYF), Lundberg et al. (2009) analysed eight accident investigation methodologies from diverse hazardous industries (including road safety), all of which described similar complex and linear representations of accidents. Application of these models emphasised data collection, analysis, and report writing with only limited coverage of planning, design of recommendations, implementation, and follow-up. The result was "*a preoccupation with parts and a lack of focus on the whole*" (Lundberg et al., 2009, p1310). The nature of the models naturally and unnecessarily limited the scope of interest, so some causes and factors were inherently more likely to be found than others (or WYLFIWYF). Importantly, Lundberg et al. (2009) also concluded that the investigations manuals and models researched were diverse when it came to the design of recommendations. In other words they were not consistent, nor was any individual manual complete, so there was potential for each investigative process to learn from others. Lundberg et al. (2009) therefore concluded that a more systemic (i.e. consistent with systems theory) and comprehensive model was required. Thus, investigation of the scope and style of road safety strategies may improve their efficiency and effectiveness. Zein and Navin (2003) similarly argued that models for road safety were too simplistic because they resulted from police reports attributing more than 90% of all road traffic accidents to driver error, leading to the incorrect conclusion that the only effective road safety strategy is to improve driver behaviour.

One example of WYLFIWYF that occurs in road safety analysis is identification of where the system failures are, so that countermeasures can be prepared to mitigate them. Wegman (2017, p2) describes this identification as "*go fishing where the fish are*". However, doing so either inherently internalises research bias into the analysis or otherwise relies on an analysis framework that can identify all the locations where the 'fish' can be. So, if the search framework (that represents the whole system) is biased or limited, then the opportunities for improvement must equally be biased or limited. This approach then has two weaknesses: 1. key failures may not be identified and therefore remain uncorrected, and 2. contexts, that may be

changeable, may not be taken account of, which is an example of treating symptoms rather than causes.

In discussing occupational accident prevention, Hovden et al. (2010) questioned whether the current knowledge base was satisfactory, or whether there were opportunities to learn from other fields of risk research. They also questioned whether there was a need for radical changes or modification of traditional approaches and knowledge bases. They argued that most accident models and theories applied in the field of occupational accidents were still based on the domino model ideas of the 1930's, or epidemiological models of the 1960's, and were using a "*closed system safety mindset with mechanistic metaphors to describe the conditions, barriers and linear chains of an accident process*" (Hovden et al., 2010, p351). The focus in the 1960's and 1970's moved to technical faults and human errors, while accident modelling developed in the 1980's. This evolution appears similar to the changes in the way road safety has been approached.

While occupational safety continued to mature in the 1990's with the development and application of safety management and safety culture (Zohar, 1980; Glendon 2006; Hale, 2006; Leveson, 2011a; Hart, 2013; Atchley et al., 2014), the same is not evident in road safety management (Johnston, 2010). Approaches to improving occupational safety had moved from a socio-technical perspective – still evident in road safety approaches today – to performance management and organisational behaviours that are attributed to proactive responses to changing external factors, also relevant to road transport:

"Organisations today are under stress from a number of dynamic factors in their environment, such as technological changes, globalization, and market conditions. Modern socio-technical systems are characterized by increased complexity and coupling, and are as a consequence increasingly intractable."

(Hovden et al., 2010, p955)

Hovden et al. (2010) questioned whether new models and approaches could supplement and improve current approaches to safety and concluded that theories,

models and approaches to high-risk complex socio-technical systems from other perspectives and domains have the potential to enrich occupational safety management activities. Furthermore:

" there is a need for further discussions and research on the development of new tools to be added to the occupational safety management toolkit. Examples are... improvements of accident models and approaches to accident investigation."

(Hovden et al., 2010, p955)

Therefore, further developments in road safety strategies similar to the way other safety management has developed, possibly applying similar new models and approaches, may be advantageous.

May et al. (2008) argued that road safety strategies and programs have been limited by thinking within existing cultural arrangements and institutional responses, whereas a fundamental redesign of safety culture is required. This necessary change could occur by holistically linking and integrating policy and practice, which is essentially a systems approach (described further below). While *Vision Zero* represents a paradigm shift in its radical objectives, yet *"The Vision Zero framework is still tied to a mindset of 'drivers, vehicles, and roads' "* (May et al., 2011, p1425). 'Deep change', represented by fundamental redesign of the systems involved, is required to integrate road safety with health, transport, natural environment and other outcomes.

It has been argued that current road safety strategies are simplistic, employing reductionist analysis with a narrow focus that ignores many components, factors, influences and alternative potential countermeasures (Racioppi et al., 2004; Salmon et al., 2017). There may be also an underlying conviction that a structured, rational, planned approach to road safety strategies will result in successful outcomes. However, other conditions may be required for public policy success, such as political will (Bugeja et al., 2011). Furthermore, it is not clear how innovation occurs in road safety management, where the majority of change appears to be operational and incremental, rather than strategic. Besides good management, it

seems that success could also depend just as much on contextual factors such as timing, opportunity, perceived need and capability to act (Bugeja et al., 2011).

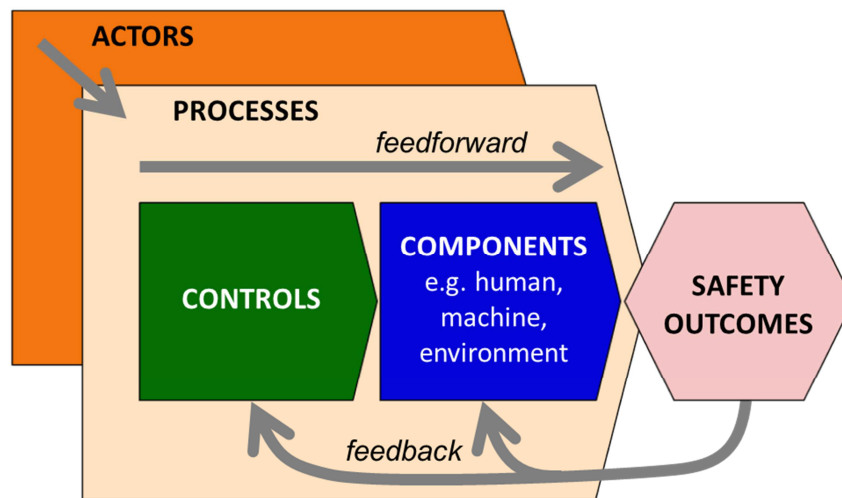
1.4.2 Systems approaches

The potential importance of systems concepts in safety was identified by Michaels (1963), while Kjellén and Larsson (1981) observed systems theory starting to be applied to occupation safety. Growing out of the complexity of man-machine interface problems in World War II and applications in road safety, Michaels (1963) described the potential importance of systems concepts. Kjellén and Larsson (1981) subsequently observed that several aids to accident investigation in occupational safety, including models and checklists, were emerging based on systems theory. However, Larson et al. (2010) found that a literature search revealed very few references to systems theory and road safety, as previously mentioned.

A system has been described as "*a network of interdependent components that work together to try to accomplish the aim of the system*" (Deming, 1994, p50). According to the theory, a system comprises interdependent and interrelated components that achieve a valued pre-set objective, purpose or function (Perrow, 1984; Leveson, 2004; Wilson, 2014). The fundamental constructs of a system are components, relationships, joint purpose and interdependency (including feedback interaction) that may be complemented by other descriptive principles or dimensions, such as time (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a). Systems theory describes interdependence where the best outcomes are achieved with the best operation of the individual components working together. Conversely, failure or suboptimal performance of any individual components reduces the best purpose of the whole system being achieved. A systems approach can improve understanding and consideration of the whole subject, providing a deeper knowledge on how dynamic, complex behaviour contributes to outcomes (in this case road crashes and their consequences) (Underwood and Waterson, 2013). Systems approaches are comprehensive, rigorous, founded in theory and proven in practice across several safety domains, over a long period of time (Waterson, 2009; Leveson, 2011a).

The systems approach has been thoroughly applied to occupational and industrial safety (Rasmussen, 1997; Leveson, 2004, 2009, 2011a) by applying main constructs of systems theory *actors* that employ *processes* to apply *controls* to *components*, while recognising *interrelationships* to produce the intended *outcomes*, as summarised in Figure 1.5.

Figure 1.5. General systems approach applied to safety management



Adoption of a systems approach is essential for effective road crash injury prevention (Peden et al., 2004; Racioppi et al., 2004), which would require a number of factors affecting the probability of a road traffic injury to be considered, including economic and demographic (or social) factors. Such a tool would assist in identifying problems, formulating strategy, setting targets and monitoring performance:

"While progress has been made in many highly-motorized countries, the practical realization of the systems approach remains the most important challenge for road safety policy-makers and professionals." (Peden et al., 2004, p13); and

"A scientific, systems approach to the problem of road safety is essential, though it is not yet fully accepted in many places." (Peden et al., 2004, p25)

Application of systems theory offers the opportunity to overcome the limitations of traditional, reductionist approaches that are often based on overly simplistic and

linear cause-and-effect rationale of crash factors (Zein and Navin, 2003; Racioppi et al., 2004; Larsson et al., 2010).

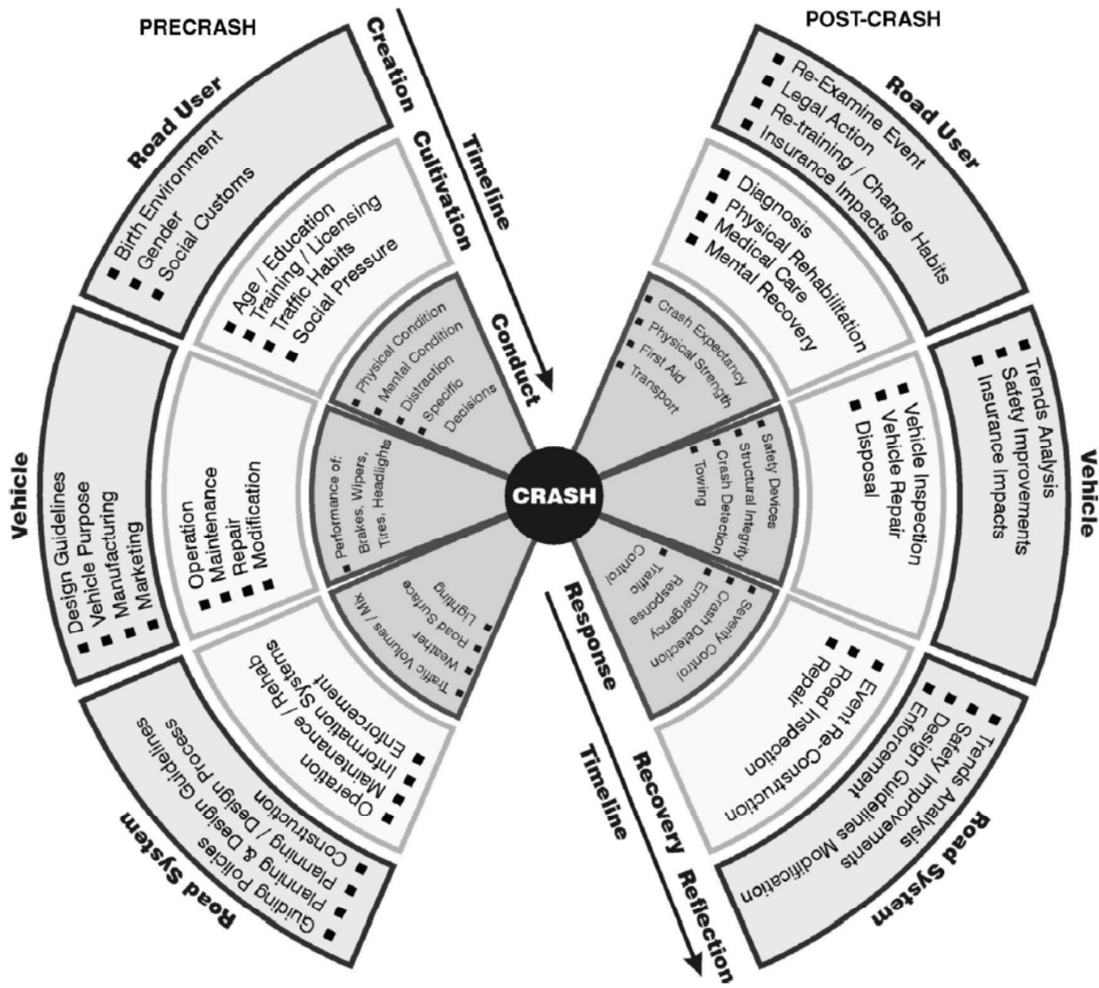
Waterson (2009) and Wilson (2014) identified that systems concepts lack proper conceptualisation and application, while Waterson (2009) found that systems concepts are influential in safety management, and that they are widely, but inconsistently used. Salmon and Lenné (2015) identified the global challenge to improve road safety, but questioned whether it can be achieved by a series of small, incremental improvements and instead favoured a paradigm shift to achieve greater road safety gains based on 'systems thinking' successfully applied previously in other safety domains. Systems thinking is a philosophical approach that regards safety, and indeed accidents, as emergent properties arising from non-linear interactions between multiple components across complex sociotechnical systems. Therefore, contemporary road safety strategies are fundamentally different to systems thinking approaches, but future road safety strategies may benefit if systems theory and approaches were to be incorporated and applied. As editorial comment in the *Accident Analysis and Prevention* Special Section: Systems Thinking in Road Safety, Salmon and Lenné (2015) noted that most papers and contemporary road safety strategies apparently used systems approaches, but they were often confused in road safety, primarily by incorrectly using the language and improperly applying the concepts. While road safety strategies contain elements of systems thinking and its language, they are not underpinned by systems theory, nor do they adopt systems thinking models and methods during implementation. Salmon and Lenné (2015) noted that proper application of systems theory is beginning to be recognised in road safety research, and its application has the potential to significantly advance road safety knowledge. However, they ultimately questioned "*whether systems thinking research has yet been implemented in road safety circles*" (Salmon and Lenné, 2015, p248).

A systematic or integrated approach has been called for, to tackle the challenge to rapidly improve road safety (OECD, 1990; Tingvall, 1997; OECD, 2002; Peden et al., 2004; Racioppi et al., 2004; Mohan et al., 2006; Stigson et al., 2008; Lie 2016). Road

safety strategies have evolved over time, been approached in different ways and included different content. Given Kjellén and Larsson's (1981) requirements for conceptual safety models and the criticisms raised by Benner (1975, 1985), May et al. (2008), Lundberg et al. (2009), Hovden et al. (2010), May et al. (2011) and Salmon and Lenné (2015), it is appropriate to adopt a methodology that initially considers a wide perspective regarding road safety, whether it be research, investigation analysis, countermeasures or strategies. The perspective should not be limited to road safety but include other safety domains, as Lundberg et al. (2009) described. Hancock and Bezold (1994) and Voros (2003) suggest five types of future that are described in Chapter 2: Potential, Possible, Plausible, Probable and Preferable. Voros's approach systematically narrows the scope from the widest range in order to focus on and develop desirable outcomes. Doing so potentially offers the greatest opportunity to learn from, and apply, any available knowledge.

Perhaps the most sophisticated approach to road safety based on systems theory is an elaboration on the Haddon Matrix (Zein and Navin, 2003). They argue that representations of road safety are simplistic because they ignore the dynamic interactions among the road environment, the vehicle, and the road user, so a more sophisticated systems approach is required to respect the interrelationships between factors. The model subsequently developed expands on the pre-crash phase to describe creation, cultivation and conduct sub-phases. It similarly expands on the post-crash phase by describing response, recovery and reflection phases, as shown in Figure 1.6 (Zein and Navin, 2003). This model, however, has several weaknesses; it does not describe the greater economic context, land use and other components and it does not clearly differentiate between different types of content (bullet points), that include components or factors (e.g. weather), policy tools (e.g. enforcement) and activities (e.g. planning). Furthermore, it also continues to rely on a limited description of relationships between components based on time sequence, without any feedback or other interconnection.

Figure 1.6. Systems approach applied to traffic safety



1.4.3 Assessment of models

Kjellén (2000) describes that models exist for several purposes, including assisting in creating a mental picture, facilitating questioning and information, establishing rules, checking, evaluation, analysis, identifying and assessing countermeasures and communication. Analytical models that are developed should meet their intended objective. These concepts can be similarly applied to frameworks (which are themselves models) for road safety strategies.

Benner (1985) identified the lack of assistance for managers or accident investigators:

" little guidance exists in the accident investigation field to help managers or investigators identify and choose the best available accident models and accident investigation methodology." (Benner, 1985, p105).

Furthermore:

"No comprehensive lists of choices, criteria for their evaluation and selection, or measures of performance emerged to help accident investigators or program managers choose the "best" accident model and investigative methodology." (Benner, 1985, p105).

Kjellén and Larsson (1981) identified several types of different models or views of industrial accidents, such as systems theory, the energy model, the process model, and information-psychology theories. They proposed criteria to test their suitability for investigation of occupational accidents, and described that models should be suitable for the purpose and different types of accidents, easy to understand, relevant, complete and suitable for prevention of future accidents. However, they found that it is difficult to find one model that meets all the requirements.

By analysing fourteen model types, such as the Haddon Matrix, Benner (1985) identified accident models and investigation methodologies that were compared and ranked according to 10 evaluation criteria, described in Chapter 7 (Realistic, Definitive, Satisfying, Comprehensive, Disciplining, Consistent, Direct, Functional, Noncausal and Visible). He concluded that the diversity in the number of accident models was unnecessary and some had severe shortcomings. Importantly, he also found that accident investigations were inefficient and ineffective because of inadequacies in the underlying accident models.

It has been suggested that a comprehensive framework for road safety strategy, based on theory, research and practice, and suitable for the future would be valuable. However, such a framework is yet to be described. Given that road safety is subject to numerous external influences beyond the control of any road safety

strategy, it is extremely difficult to prove that a road safety strategy is effective in itself in achieving objective and measurable performance criteria (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013). Such strategies tend to be discussed in relation to the subsequent levels of road trauma over time, but demonstrating causality between a strategy and road safety outcomes is at best extremely difficult. However, an alternative proxy for testing a road safety strategy is to assess it against model criteria (Kjellén, 2000).

1.5 Thesis outline

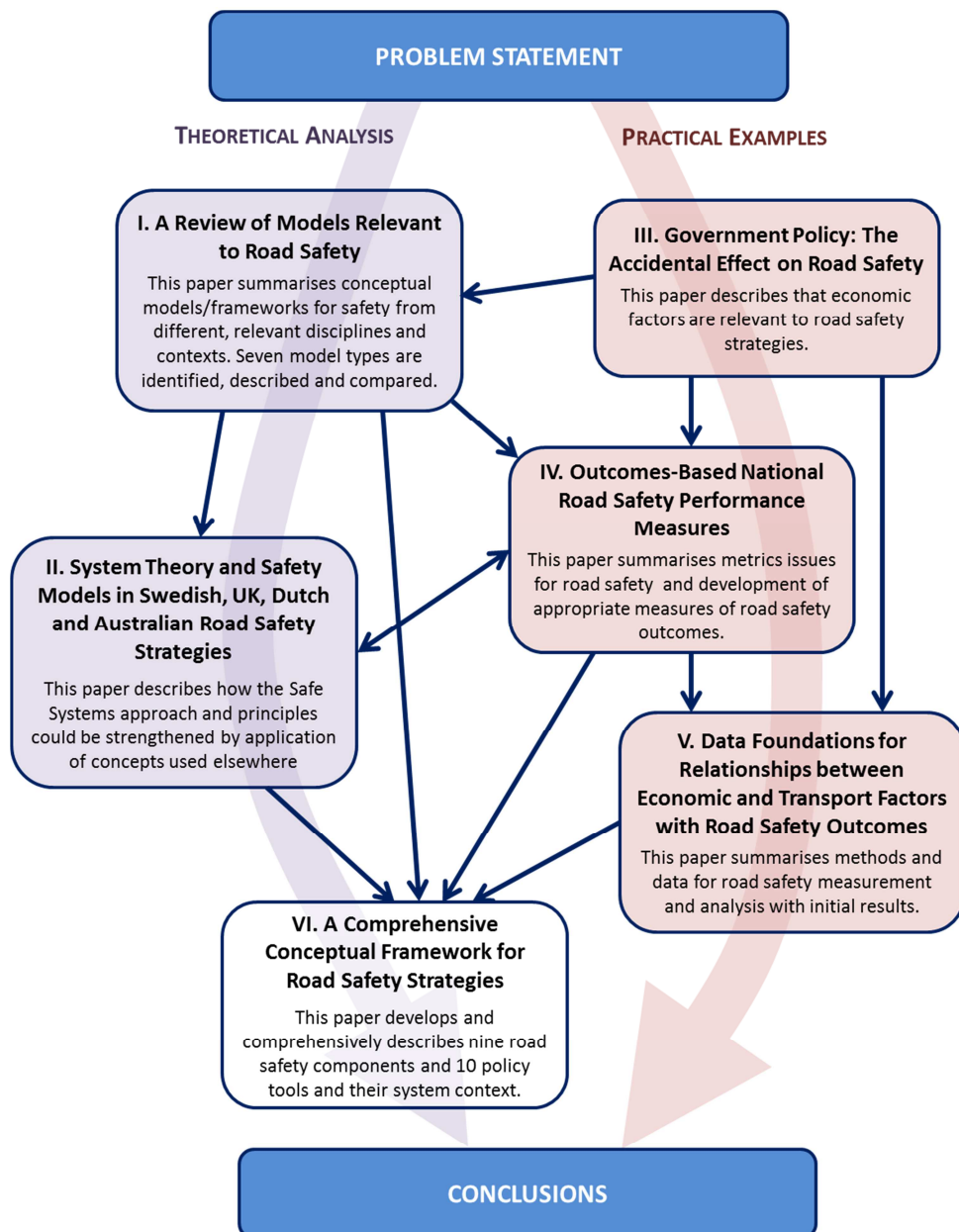
The objective of this thesis is to propose improvements to road safety strategies to reduce the burden of road trauma on society. This thesis addresses the weaknesses in road safety strategies identified in the literature. The aim is to improve the applicability, efficiency, effectiveness and responsiveness of road safety strategies by:

- expanding the full breadth of content;
- describing the integration and interrelationships across the full range of components;
- incorporating contemporary safety research and practice, including alignment with systems theory; and
- providing justification for conclusions based on road safety theory and practice, since these have been lacking in previous road safety strategies.

The thesis has its starting point in the use of system theory, together with evidence from research and practice. A comprehensive framework for road safety strategies will be developed, incorporating all components, policy tools by which they can be changed, and the interactions between them. The thesis wrestles with the challenge to integrate theory with practice, and which one should come first. In the end, neither theory nor practice should necessarily precede the other, since both need to inform the other, and it becomes an interactive process with feedback, rather than a linear or sequential process.

This thesis comprises six papers that describe a theoretical analysis and practical examples, as shown in Figure 1.7. The information from these themes contributes to the logical development of a comprehensive approach for road safety strategies – the conceptual framework. The theoretical analysis commences with a broad overview of models used for safety management that is successively narrowed in subsequent papers to specifically define the road safety strategy framework. The practical investigation highlights economic issues in particular, that are relevant to road safety and relevant measurement of outcomes.

Figure 1.7. Overview of thesis structure and relationship between papers (Roman numbers refer to the included papers).



The underlying rationale behind the framework developed in this thesis is that policy tools (such as policies, programs and projects) are applied to components, in order to improve road safety outcomes (i.e. to reduce road trauma), as shown in Figure 1.8. While this approach is consistent with road safety strategies in the past, it is further developed based on system theory, policy theory and evidence of components and policy tools in road safety research and practice.

Figure 1.8. General application of policy tools to components to achieve road safety outcomes



In Paper I, the thesis commences with an overview assessment of models applicable to safety management that are potentially relevant to road safety strategies. In addition, this paper also describes that economic policy tools (such as taxation), have the potential to affect road safety outcomes. The second paper provides examples illustrating the effect of the economic context and economic policies that can affect road safety outcomes. In doing so, these papers introduce one component affecting road safety (the economic context) and policy instruments (such as taxation), that could be applied to affect road safety outcomes but are not normally recognised, targeted or utilised. These two perspectives – components and policy tools – are the concepts that are investigated, developed and refined through the whole thesis until they are fully described in the final paper.

1.6 Significance of the thesis

Since it is not clear that road safety strategies are as efficient and effective as possible, they may not be sufficient to continue the improvements to road safety that have been achieved in the past, or to address future road trauma. The value of this thesis is to extend the scope of interest (component) and actions (policy tools) to provide opportunities for governments to develop and apply new initiatives to

improve road safety. Importantly, this thesis describes for the first time the full range of both components of road safety and policy tools by which they can be changed to improve road safety. It also provides a framework for others including private individuals, companies, consumer or industry groups or researchers to consider what should be taken account of for their own areas of responsibility, or in collaboration with others.

1.7 Theoretical basis

While there have been several styles of road safety strategy over several decades, the theoretic and research basis for them is weak. Road safety strategies typically include many individual actions that commonly have a basis in research, at an individual level. In most cases there is evidence from other applications (such as other jurisdictions), or similar applications (such as other types of vehicle), or trials by which it can be deduced that the proposed action is likely to be effective. Notwithstanding the benefit of experience regarding individual actions, the underlying rationale for the structure of the strategy is not founded in theory or research.

1.7.1 Frameworks for safety management

The framework developed in this thesis was informed by general safety models from other relevant domains. In this situation, a 'model' is a simplified description or representation to aid understanding (Kjellén, 2000).

Different types of safety models are used for different safety domains with varying purposes, characteristics or perspectives. Different types of model individually and separately describe component parts, sequences of events and activities, individual interventions used to improve safety, mathematical representations, processes, safety management systems, risk assessment processes or systems approaches.

Early safety models in other domains focussed on the components contributing to activities or safety, but evolved to emphasise interventions, quantitative analysis, work processes and failure sequences, while the most recent models adopted

systems perspectives (Leveson, 2009, 2011a). While road safety strategy frameworks also evolved, they followed a different and simpler path, not recognising the information or adopting the conclusions from research and application in other domains.

1.7.2 Road safety frameworks

The four E's approach (Damon, 1958; Nader, 1965; Booth, 1980) and Haddon's matrix are based on observation and deduction, without an underlying theory justifying the individual elements. Basically, this type of strategy is based on an assumption of cause and effect – certain factors or components 'cause' crashes to occur. Some causes occur in a temporal sequence – before, during or after a crash. In response, governments apply policy tools to the components that 'cause' road safety to improve. Observation and investigation of crashes over many years lead strategy developers to focus on specific issues, such as types of crash, vehicle, road or driver. While these approaches are rational, they are not explicitly based on research or an underlying theory.

While the Haddon Matrix is widely known and frequently used, it is not without its difficulties. Firstly, while it apparently has a rational basis in observation, it has no theoretical or research basis, and is reported without particular justification. Secondly, there are several versions of the matrix reported, as shown in Table 1.2, each without explanation regarding the underlying rationale or theoretical basis. This could suggest that even simple strategic perspectives for road safety management are difficult to describe completely, singularly and accurately, and indicates room for improvement in clarity. This could be one reason why the Haddon matrix is widely applied at the tactical and operational level of road safety programs and projects, but not at the level of road safety strategies. The Haddon approach incorporates the underlying concept of events that occur in sequence over time. A preceding event contributes to a subsequent event. However, this approach fails to recognise the interdependence of phases and components in contributing to crashes as a true systems approach would.

Table 1.2. Different versions of the Haddon Matrix

Paper	Phases (Time)	Parts	Results
Haddon (1968)	Precrash Crash Postcrash	<i>Components:</i> Driver Passengers Pedestrians Bicyclists Motorcyclists Vehicles Highways Police	Driver injury and death Passenger injury and death Property damage
Haddon (1972)	Pre-Crash Crash Post-Crash	<i>Factors:</i> Human Vehicle and Equipment Environment	<i>not stated</i>
Haddon (1980a)	Precrash Crash Postcrash	<i>Factors:</i> Human Vehicle and equipment Physical -environment Socio-economic environment	Damage to people Damage to vehicles and equipment Damage to physical environment Damage to society
Haddon (1980b)	Pre-event Event Postevent	<i>Factors:</i> Human Vehicle Environment	<i>not stated</i>
Haddon (1999)	Precrash Crash Postcrash	<i>Components:</i> Driver Passengers Pedestrians Bicyclists Motorcyclists Vehicles Highways Police	Driver injury and death Passenger injury and death Property damage

In conjunction with the matrix, ten ‘general strategies’ for injury prevention were described to guide actions to control injury generally (Haddon, 1980b, p418), some of which are relevant to road safety including:

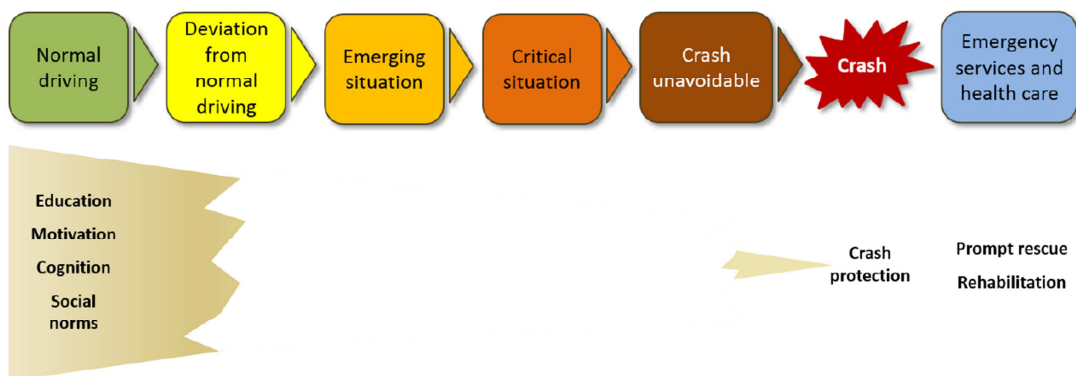
- *prevention in the creation of the hazard in the first place;*
- *to reduce the amount of hazard brought into being;*
- *to separate, in time or space, the hazard and that which is to be protected;*
- *to separate the hazard and that which is to be protected by interposition of a material barrier;*
- *to modify relevant basic qualities of the hazard;*

- to begin to counter the damage already done by the environmental hazard; and
- to stabilize, repair, and rehabilitate the object of the damage.

Some concepts incorporated in the Haddon matrix and the ten strategies are useful in developing road safety strategies and frameworks that better incorporate systems approaches. The ten general strategies provided guidance in the development of subsequent road safety improvements, and some are clearly reflected in contemporary road safety strategies and principles.

Rizzi (2016) described a model that integrated a chain of events, including feedback paths to prior events, as shown in Figure 1.9, based on Lie (2012) that is consistent with systems theory (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a). In applying this to motorcycle safety, Rizzi (2016) describes a traditional approach to motorcycle safety, summarised as the integrated safety chain model. Rizzi (2016) recognised that for motorcycle safety there were traditionally no safety interventions between rider training and the protective clothing being worn, that was effective after crashes occurred. He argued that further countermeasures in the chain of events needed to be investigated so that the system could be understood. This perspective illustrates that road safety policies may be employed to intervene in any part of the sequence to affect the ultimate outcome.

Figure 1.9. The traditional approach to motorcycle safety, seen with the integrated safety chain model



Various descriptions of road safety components have been developed for research (RRL, 1963), crash analysis (Baker and Fricke, 1986) or individual road safety measures (Elvik et al., 2009). While these different perspectives are valid, they are limited and do not cover all of the components that apply to road safety. The common, but limited, descriptions of road safety can be considerably expanded to include wider economic, transport, land use and social contexts, together with more detailed stages of crash response, other road infrastructure, the natural environment and road safety management.

The most recent versions of road safety strategies are based on the Swedish road safety strategy *Vision Zero* (Tingvall, 1997; SRA, 2006). Lie (2012) summarises *Vision Zero* as the five clauses in the Tylösand Declaration (Vägverket, 2008, p6):

1. *Everyone has the right to use roads and streets without threats to life or health*
2. *Everyone has the right to safe and sustainable mobility: safety and sustainability in road transport should complement each other*
3. *Everyone has the right to use the road transport system without unintentionally imposing any threats to life or health on others*
4. *Everyone has the right to information about safety problems and the level of safety of any component, product, action or service within the road transport system*
5. *Everyone has the right to expect systematic and continuous improvement in safety: any stakeholder within the road transport system has the obligation to undertake corrective actions following the detection of any safety hazard that can be reduced or removed.*

These principles describe the basis of other contemporary strategic approaches to road safety (Peden et al., 2004; Racioppi et al., 2004; SRA, 2006; Wegman and Aarts, 2006; MOT, 2010; ATC, 2011).

1.7.3 System theory

Systems generally describe the processes of transforming input to output for a purpose, that is, produce something of value (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a; Underwood and

Waterson, 2013). Systems theory is a scientific exploration of wholeness, covering the essential components and the relationships between them (von Bertalanffy, 1968; Ackoff, 1971; Leveson, 2011a). The fundamental constructs of a system are components, relationships, joint purpose and interdependency that may be complemented by other descriptive principles or dimensions, such as time. While these characteristics are used to describe a system (or model), other models may also exhibit characteristics evident in other systems.

Chapanis (1996) defined a sociotechnical system as

“an interacting combination, at any level of complexity, of people, materials, tools, machines, software, facilities, and procedures designed to work together for some common purpose”. Chapanis (1996, p22).

This model of sociotechnical systems for analysing and designing organisational structures was developed from a psychological perspective in the late 1940's and 1950's. This theory applies a systems approach to sociotechnical issues in workplaces (De Greene, 1973, 1993; Badham et al., 2006; Hendrick, 2006). The model suggests that work system design and processes are interdependent with three major subsystems: 1) personnel, 2) technology, and 3) external environments that affect the organisation. It is then implicit that any change to some aspect of one subsystem, will impact on at least one of the others and affect the outcomes. If these changes are not planned for, it is likely to impact the work system producing unanticipated and sub-optimal solutions (Hendrick, 2006). Given that there are sociological factors affecting road safety outcomes, the application of sociotechnical system theory and practice is appropriately relevant to this thesis.

In contrast to road safety models, system theory has an extensive theoretical basis, and has demonstrated substantial benefits to improving safety in other domains over more than 40 years. Systems theory and techniques have successfully been applied to improve safety in the most complex and hazardous operations and situations (Waterson, 2009; Leveson, 2011a), such as nuclear power plants, aviation and industrial operations.

While road safety tends to describe crashes with cause-effect accident³ models, system theory views accidents as the result of unexpected, uncontrolled relationships between different components (Underwood and Waterson, 2013). Systems approaches analyse whole entities, rather than considering their parts in isolation (Waterson, 2009; Underwood and Waterson, 2013). The systems approach is comprehensive and rigorous, founded in theory and proven in practice. It improves understanding and consideration of the whole subject, providing a deeper knowledge of the contribution of dynamic, complex system behaviour to accidents (Underwood and Waterson, 2013). Road safety strategies tend to be more reductionist and simplistic in assessing individual components in isolation, ignoring complementary effects and interdependence (Racioppi et al., 2004), and their value is not necessarily evident.

As described above, systems theory and approaches have been recognised as being important in safety management (Michaels, 1963; Kjellén and Larsson, 1981; Chapanis, 1996) but have not been well applied in road safety (Zein and Navin 2003; Salmon and Lenné, 2015). In contrast to system theory, road safety strategies generally include a collection of independent specific policy tools applied to individual components without taking account of interactions and interdependencies between components or policy tools.

One example of system and its failure is the manufacture of a machine with engine and transmission components, by different sections of an organisation (Deming, 1994). In this machine, both the engine and transmission had electrical components in them. Because of his understanding of both components, an engineer devised a new design for the engine's electrical components that eliminated the electrical components in the transmission. By considering the components as part of the system as a whole, significant cost could be saved in production of the machines. However, the redesign was rejected by the financial people controlling the engine

³ While the term 'crash' is appropriate for road safety, the term 'accident' is used here since it is generally used in most other safety management for an unplanned event with unacceptable consequences.

manufacturing, because it increased the costs of engine manufacture and therefore decreased the profit for their section. This example illustrates the attributes of a system having a prescribed purpose (that fails in this case), interdependency between components, inappropriate performance measurement and a failure of people to work together. Deming (1994) further argues that systems cannot be managed internally by themselves, but require an external perspective and action:

"Any system needs guidance from outside. Again a system can not understand itself." (Deming, 1994, p54).

1.7.4 Policy tools

An underlying generalised approach or rationale for actions applied to improve road safety is not evident in the literature. The underlying premise of this thesis is that components that contribute to road safety outcomes can be influenced by policy tools, in order to improve the desired outcomes (i.e. reduced road trauma). Early Engineering (or non-interacting) or Economic (or utility maximising, or danger compensation) policy tools to improve road safety, are described. The theory is then developed that policy tools were applied to improve road safety outcomes, but are affected by human behaviour responding to the results of applying the tools based on risk homeostasis (Evans, 1985), which implies a feedback mechanism.

One broad approach is based on the premise that human action (or behaviour) is a component in all aspects of road safety, not only as the road user, but should include those involved in decision making, design, planning, regulation, and so on. Therefore, policy tools can be categorised as detectors (tools for collecting information about target behaviour) and effectors (sanctions or rewards for changing or modifying the behaviour detected) (Durant and Legge, 1993). Policy tools have been broadly described in a threefold typology; economic means (carrots), regulations (sticks), and information to elicit changes in behaviour (sermons). Leveson (2009) described control mechanisms that generally can be applied to improve safety in systems in five levels: managerial, organisational, physical, operational, or manufacturing-based.

Policy tools have been further elaborated in considerable detail, such as the 63 individual tools listed by Vedung (2003). In road safety, Elvik (2003) found 132 potential road safety tools for Norway that could potentially be applied to other contexts. Bliss and Breen (2012) described institutional management functions for the road network as a whole to improve road safety.

1.8 Conclusions

Road safety strategies have evolved rather slowly and incrementally over many decades. However, road safety strategies' contribution to continuing to reduce road trauma is challenged for several reasons:

- weakness in existing approaches to road safety strategies (such as *What-You-Look-For-Is-What-You-Find*), even as they have matured;
- the potential to incorporate new concepts, particularly those already proven from other safety domains; and
- the rapidly changing external context that is becoming increasingly dynamic, unpredictable and complex, making improvements more difficult unless new approaches are found and used (or *What-Got-Us-Here-Won't-Get-Us-There*).

This thesis addresses several problems and criticisms identified in the literature regarding road safety management:

- the complexity and diversity of road safety factors, influences, components interrelationships, and countermeasures (Smeed, 1949; Peden et al., 2004; Racioppi et al., 2004);
- new and comprehensive road safety approaches required to manage and achieve road safety outcomes (Benner 1975, 1985; May et al., 2008; Lundberg et al., 2009; Hovden et al., 2010; May et al., 2011);
- incorporation of proper systems approaches as applied in other safety domains (Michaels, 1963; Kjellén and Larsson, 1981; Chapanis, 1996; Salmon and Lenné, 2015);
- development and assessment of road safety models to ensure suitability for their purpose (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000);

- development of suitable performance measures for assessment of road safety management (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013); and
- broadening the limited scope of road safety management (Hollnagel, 2008; Hovden et al., 2010) by using a systematic research methodology (Hancock and Bezold, 1994; Voros, 2003).

Research from other safety domains and criticisms of approaches to improving safety have identified opportunities for continuing the evolution of road safety strategies. Therefore, this thesis adopted a thorough, systematic and broad research method, to provide a robust and comprehensive description of applicable policy tools based on research and practice to improve the efficiency and effectiveness of road safety strategies and contribute to future reductions in road trauma.

Chapter 2. A Review of Models Relevant to Road Safety – Paper I

2.1 Introduction

The evolution of road safety strategies and the variety of approaches raises many questions for research, policy and practice. A researcher could ask, "What is the theoretical basis of the underlying framework of each of the strategies?" Someone who develops policy could ask "Which of the strategic approaches works best and why?" Those who implement strategies could ask "How could I put this type of strategic framework into practice given my particular context and road safety history?" These are complex questions, and there are many others, each worthy of investigation. The specific questions raised in this thesis are discussed in each of the papers, but the first paper concerns the range of alternative strategic descriptions that are possible.

The history of road safety strategies illustrates that the path of progress has mainly been based on incremental improvements to previous strategies. As Lundberg et al. (2009) described, the initial risk is to fall into the trap of looking internally within road safety without appreciating and incorporating knowledge from elsewhere or *What-You-Look-For-Is-What-You-Find* (Hollnagel, 2008; Lundberg et al., 2009). Therefore, the approach here was to investigate broadly across other safety domains and learn from the available knowledge from other domains.

Some studies have been conducted that summarise and compare road safety strategies but do not investigate the underlying types or frameworks of these road safety strategies (Wegman et al., n.d; OECD, 1990; Koornstra et al., 2002). For instance, OECD (1990) investigated 'integration' within 41 road safety strategies. Comparisons between the types of strategies were limited to location of interest (cities, highways and regions), types of policy included, appraisals conducted, goal and objective setting and program design. The comparison between the road safety strategies of Sweden, the UK and the Netherlands by Koornstra et al. (2002) was limited to characteristics of each country and specific problem areas. OECD (1997b)

compares different descriptive, predictive, risk and accident consequence models. The different applications, or purposes, of these different types of model are described, but they are not compared in any way. Wegman et al. (n.d.) identify different policies that have been applied, and contextual factors, such as the transport system, but focus the comparison on the analysis of the road safety outcomes achieved.

The basis of road safety strategies is therefore questionable, since few strategies or research describe any underlying theory or analysis of the underpinning framework for the road safety strategy. While individual actions are well grounded in theory and practice, the same cannot be said for the strategies as a whole that are an aggregation of individual actions without a justifiable structure. Therefore, the aim of Paper I is to improve the knowledge base regarding types of strategic framework available that could be applied as road safety strategies.

Systems generally involve the processes by which inputs are transformed to output(s) for a purpose, but the concepts still lack proper conceptualisation and application in road safety (Waterson, 2009; Wilson, 2014). Waterson (2009) found that while systems concepts are influential in safety management, they are widely, but inconsistently used. While soundly based and proven to be useful in practice, the term 'system' is not specifically defined, but variously described, as:

1. system (an operating entity);
2. systems theory (an underlying rationale for definition of systems characteristics);
3. systems approaches (a process to analyse and understand a system); and
4. systematic processes (a manner of application).

A systems approach to safety views crashes as the result of unexpected, uncontrolled relationships between different parts of the system, compared to the traditional cause-effect accident models that are much more limiting (Underwood and Waterson, 2013). Considering and understanding the whole subject, offers the opportunity to deepen knowledge on how dynamic, complex system behaviour

contributes to accidents (Underwood and Waterson, 2013). The term 'Safe System' has been used as a most recent form for road safety strategies (Wegman et al., n.d.; Koornstra et al., 2002; MOT, 2010; Paper II, Hughes et al., 2015a⁴). The understanding of systems theory and its application in road safety strategies is not common despite its potential to overcome the limitations of traditional and reductionist approaches. Therefore, the term 'system' was specifically chosen as a search term.

Many models have been used in several safety domains to understand issues and contributing factors. In situations reported in the literature, models simply describe or represent a road safety situation and are useful to create a mental picture, enable further questioning, inform, establish rules and facilitate checking, evaluation, analysis, identification and assessment. Investigation of alternative types of model provides the potential to learn from, further develop and apply alternative models (Kjellén, 2000). Models are not perfect but can still be useful, especially when augmented by additional actions, such as more detailed analysis (Underwood and Waterson, 2013). Alternative and potential models were therefore investigated in this paper to understand:

- alternatives and choices;
- all outcomes (other beneficial outcomes) and conflicts (undesired adverse outcomes); and
- synergies (complementary outcomes when activities occur at the same time).

2.2 Objective

The objective of Paper I was to survey the full range of safety models that could potentially be used to improve road safety strategies. A broad approach, similar to the 'futures cone' (Hancock and Bezold, 1994; Voros, 2003), was taken in order to

⁴ In conjunction with publishing Papers I and II in a Special Section of *Accident Analysis and Prevention*, Salmon and Lenné (2015), summarised the papers with a commentary. In doing so they supported the research and conclusions in Hughes et al. 2015a and Hughes et al. 2015b. Despite wide interest in the application of systems thinking to road safety, the editors only included 11 papers in the Special Section, including two presented in this thesis. The editors described the paper in this chapter as "*the perfect opening contribution to this special issue ... providing essential background to the papers which followed.*" Salmon and Lenné (2015, p245).

not limit the perspective. Doing so resulted in a large amount of literature to consider. The wide range of possible models found were categorised into types to appreciate their content, and to be compared to determine which may offer the best prospect for informing the development of comprehensive road safety strategies in future.

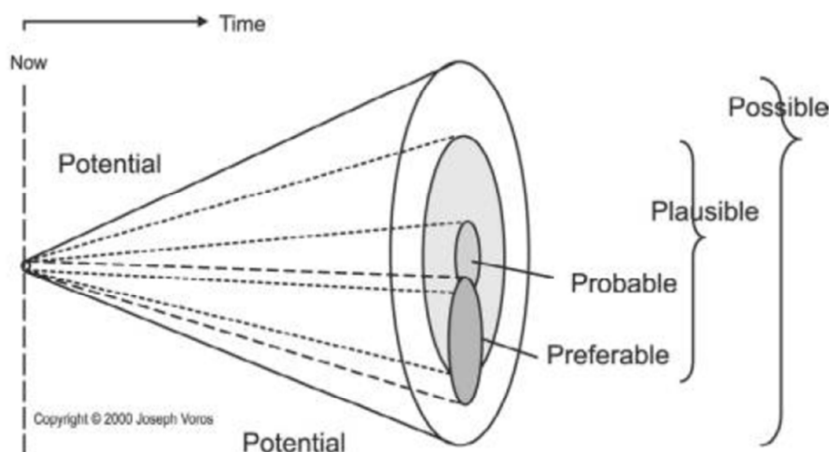
Clearly, a range of alternative strategic approaches to road safety are possible, so a method needs to be devised as to how to choose which approach is desirable.

Hancock and Bezold (1994) and Voros (2003) posit five types of future:

1. *Potential* futures: alternative futures in general, including those we cannot even begin to imagine;
2. *Possible* futures: all the kinds of futures we can possibly imagine;
3. *Plausible* futures: futures that could happen according to our current knowledge;
4. *Probable* futures: futures that are considered likely to happen;
5. *Preferable* futures: what we want to happen based on subjective value judgments.

This approach, which is based on Hancock and Bezold (1994) and illustrated in Figure 2.1 (Voros, 2003), systematically narrows the range of all possible solutions to the solutions that are desirable or need to be taken account of, and has been used in several fields (Habegger, 2010; Ortegon-Sanchez and Tyler, 2016). This first paper adopts this basic approach to identify the full range of possible approaches to road safety strategies, based on models that have been described previously, that are subsequently refined in following papers.

Figure 2.1. The 'futures cone' — arrangements of alternative scenarios

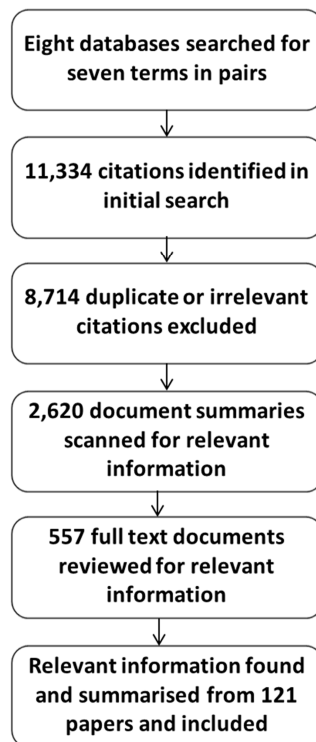


A systematic stepwise method, similar in principle to a systematic review (NHMRC, 2000; Petticrew, 2001; Lefebvre et al., 2009) was used to identify different models. Common search terms relevant to strategies and frameworks in safety domains, were chosen. Either 'safety' or 'strategy' was always searched in conjunction with 'model', 'system', 'strategy', 'policy' or 'framework' across eight literature databases. The search was not restricted by year of publication or contexts, such as industry, health transport or recreation. The search terms were necessarily general, that resulted in an extremely large body of literature to consider, so the search was narrowed by eliminating terms that were too common. While a large number of papers were found, narrowing the search further by combining terms, revealed too few papers for broad review.

The initial search, as summarised in Figure 2.2, focussed on models that were most relevant to road safety strategies, resulting in 11,334 results. Duplicate papers and those not considered relevant or useful according to criteria, were eliminated. These criteria excluded papers that were either too general or too specific or vague. Additionally, some terms had alternative but irrelevant meanings that took careful attention to eliminate. For instance, apart from use in safety to mean interventions to improve outcomes, the term 'policy' also frequently applied to insurance policies and actions by police agencies (policing).

Summary information from 2,620 documents was scanned to select those that contained either model types, or factors or influences not previously identified. This resulted in 557 full text documents being sourced and reviewed. Finally, 121 models describing different content were summarised. The types of model were then aggregated into broad categories or types of model that exhibited similar overall structure. Some literature described additional information that was also captured.

Figure 2.2. Flowchart of the literature search process



2.3 Findings

The review identified seven different types of safety models, all of which had been applied to road safety. Amongst other domains, these models were found in other major modes of transport, general industry, hazardous industries, health and recreation. While these occurred in different safety domains, some had been developed for various purposes or uses according to alternative perspectives, or otherwise included specific characteristics. Some models related to very specific circumstances, such as an individual recreation centre, while others were broad in scope, such as for a whole country or industry. Furthermore, it was found that the models had evolved and changed over time.

While the models describe the situation in a certain way, additional supporting information often supplemented the main model description. These included definitions, principles, objectives and targets, and other framework concepts or information. Concepts beyond the intended scope of this thesis emerged, such as systems approaches, risk management and safety culture.

The terminology used in models was often vague, inconsistent and ambiguous which was confusing, and terms were not often defined thoroughly or clearly. Therefore, the same terms were found in different discussions, but without consistent meaning. Lack of clear definition and consistent use of terms in the literature resulted in ambiguity and confusion, which reduced the value and application of research and information.

A few particularly important concepts emerged from the investigation. The term 'safety culture' (Glendon, 2006; Hale, 2006; Leveson, 2011a), describing the underlying nature of an organisation's approach to safety, was found to be strongly supported. Safety culture and safety climate are similar concepts, often used interchangeably (Zohar, 1980; Hart, 2013) which have been systematically reviewed and applied in other safety domains (e.g. Reichers and Schneider, 1990; Hofstede, 2001; Schneider et al., 2013). Based on evidence from previous literature, organisational climate may, for example, be defined as:

" the shared perceptions of and the meaning attached to the policies, practices, and procedures employees experience and the behaviors they observe getting rewarded and that are supported and expected" (Schneider et al., 2013, p362).

This is differentiated from organisational culture:

" the shared basic assumptions, values, and beliefs that characterize a setting and are taught to newcomers as the proper way to think and feel, communicated by the myths and stories people tell about how the organization came to be the way it is as it solved problems associated with external adaptation and internal integration" (Schneider et al., 2013, p362).

For most common practice in safety management, the differentiation between organisational culture and climate is more theoretical than useful. This distinction is probably completely irrelevant for road safety where neither concept has gained any use.

The term 'system' was similarly identified in the study, and was used very widely, but loosely and differently without clear definition. 'Safety Management Systems' (SASNZ, 2001) was widely applied and strongly supported in several safety domains, but not evident in road safety strategies. Risk management is a process of hazard identification, assessment, evaluation and mitigation, but was also absent from road safety (Glendon and Waring, 1997; Rasmussen, 1997; Kontogiannis et al., 2016). These important concepts, with strong theoretical, research and practical foundations were clearly found to offer potential to be incorporated into road safety strategies.

The seven different types of model used in safety were identified, described and compared according to purpose, use, characteristics, strengths, weaknesses and relevance to road safety. Table 2.1 summarises the most important information, characteristics and use, which were used to guide subsequent stages of the thesis.

Table 2.1. Different types of models relevant to road safety

Model Type	Characteristics of Model Type	Model Use
Component Models	Identifies all the individual contributing parts or units.	Used in safety strategy development. Provides a structure for general safety information. Provides general descriptions.
Sequence Models	Based on a specific series of events resulting in incident(s) (e.g., event chain, energy transfer and fault tree analysis).	Used for individual incident/accident analysis.
Intervention Models	Identifies activities or countermeasures which improve safety (e.g., engineering, enforcement).	Used to analyse specific policy or strategy.
Mathematical Models	Based on quantitative analysis of data and relationships.	Used for quantitative analysis of effects of specific policy or strategy.
Process Models	Identifies sequences of, and relationships between, work and/or activities.	Used to develop and prioritise countermeasures: identify and assess potential risks and causes to develop and assess countermeasures.
Safety Management Models	Identifies management components, system, relationships and outcomes. Describes the manner and process by which safety is managed (e.g., Safety Management System or Risk Management System).	Used for management assessments: organisation, procedures, resourcing, reporting.
System Models	Describes purposes, components, relationships and interdependency.	Used to analyse systems including effects of countermeasures, influences and consequences.

2.4 Conclusions

The investigation of the full range of models possibly useful for road safety strategies revealed a few key alternative types of model. However, a wide diversity of the content of alternative models was also evident. Therefore, it appears plausible that a more integrated, complete and holistic model may also be developed, by incorporating parts of different previous models.

It was found that systems theory, Safety Management Systems, the risk management approach or safety culture, while widely used in other safety domains, were not commonly or thoroughly applied to road safety, so application of these approaches may improve road safety strategies. Consequently, subsequent research in this thesis focussed on applying systems approaches more clearly and completely to the component models that are commonly and currently used in road safety strategies.

However, neither the study nor the literature compared the value of different types of model, or their applicability to specific situations or purposes. It was not evident that any particular type of model was superior, or whether certain content of any model was either valuable or unnecessary. These aspects therefore offered the opportunity for further research to improve the application of models.

The study results supported the conclusions of Read et al. (2013) that:

“The existing research has not applied a systems approach, and thus has not identified, described or explained emergent phenomena, variability in system functioning, dynamic aspects of the system and how influences at different system levels interact.” (Read et al., 2013, p773).

Other safety domains, including transport, have applied systems theory, models and approaches, to thoroughly and comprehensively understand and successfully improve safety. Therefore, the same would be appropriate for the road safety system, and strategies to reduce road trauma.

At this stage, the attributes of different types of road safety strategy, compared with the models of safety found, were not clear. Therefore, it was decided to comparatively review the most contemporary and well developed road safety strategies to investigate the consistency and differences between the strategies to determine what might be learned to develop road safety strategies in general.

The analysis also broadened the scope of the road safety system that is commonly narrowly described as comprising drivers, vehicles, and road infrastructure. The

models found clearly identified further factors and influences, including economic, social and natural environment, as well as the wider transport system and post-crash activities. This is an important finding that leads to the question as to the full content of a complete description of a road safety strategy that is developed in the final paper. However, the next paper investigates an intermediate question as to how modern road safety strategies compare with the models and approaches found in the literature.

Chapter 3. System Theory and Safety Models in Swedish, UK, Dutch and Australian Road Safety Strategies – Paper II

3.1 Introduction

The Introduction to this thesis describes certain weaknesses in road safety investigation and analysis that can be considered, in order to improve road safety strategies. This includes the theoretical basis of contemporary road safety strategies, whether they are systematically developed, broadly based or to avoid the narrow thinking previously evident (Hollnagel, 2008; Hovden et al., 2010). Therefore, there is potential value in researching the leading contemporary road safety strategies by investigating them using these weaknesses as considerations.

Paper I investigated types of safety frameworks that have been applied in different safety domains. That paper's key conclusions are regarding the potential use of systems theory (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a; Underwood and Waterson, 2013) that could potentially improve road safety strategies. Paper I identified several safety frameworks that have been applied to road transport that have changed and developed over time.

The Introduction and Paper I identified five leading road safety strategies in Sweden, the Netherlands and the UK that are reported as the most successful. Together with the Australian road safety strategies, these are also described as being the most modern, following the 'Safe Systems' approaches (Wegman et al., n.d.; Koornstra et al., 2002; MOT, 2010; Paper II, Hughes et al., 2015a). The most recent comparative reports on road safety analyses differences in outcomes and the policy focus of individual road safety strategies (OECD, 2014; OECD 2016b). However, as per previous studies of this type there is no comparison between the underlying frameworks for the different strategies. These analyses compare

outcomes based on broad explanatory factors, such as population, vehicle use and numbers of registered vehicles.

Paper II aimed to address the gap in knowledge identified above, regarding comparative strengths and weaknesses of different types of road safety strategies. It builds on the information from Paper I, by analysing these most successful road safety strategies against system theory and against each other to identify similarities and differences to determine whether they suggested any inherent advantages or specific strengths, as illustrated in Figure 3.1.

Figure 3.1 A model to analyse road safety strategies



3.2 Objective

The objective of this paper was to understand the underlying theoretical foundations by which the best contemporary road safety strategies are developed and structured. Doing so offered the potential to identify the important common features of the strategies that would be essential. At the same time other features that were not common either may not be essential, could potentially strengthen other strategies, or may only be applicable in certain circumstances. Considering the information from Paper I also gave the opportunity to identify other features that could be applied to these leading strategies, to result in even greater benefits to road safety. Furthermore, this analysis offered the potential to develop and apply a higher level of road safety strategy practice to new strategies to be developed in future.

The starting point for the study was firstly the types and content of system models while the second perspective was system theory, both of which were investigated in Paper I. These two clear 'lenses' described and applied in the literature formed the assessment criteria to review the five modern strategies. This analysis was based on

systems theory concepts, and an understanding of the full range of models that have been applied to safety domains. Each of the strategies were assessed against systems criteria, key components, relationships, objectives and interdependency. Two additional supporting descriptors were noted for each; principles and theoretical basis. The content of each strategy was then described and compared.

The analytical criteria identified in this paper were:

- **Key Components** – the constituent parts that comprise the systems, essential for the system to operate and to make a contribution to achieving the intended purpose or outcome of the system;
- **Relationships** – the connections between key components, how each individual component affects, or is affected by other parts, and how the key components interact;
- **Objectives** – what is intended to be achieved; and
- **Interdependency** – 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.

In addition,

- **Principles** – the fundamental propositions that underlie the rationale behind the strategy; and
- **Theoretical Basis** – the strategy is grounded in a thoroughly proven rationale supported by evidence.

The five strategies were considered according to the seven model types found and described in Paper I:

1. Component or unit models;
2. Event chain or sequence models;
3. Intervention models;
4. Work, activity or process models;
5. Quantitative analytical (or mathematical) models;
6. Safety or risk management system or process models; and
7. System models.

The five strategies were analysed to identify and describe similarities and differences between each. The consistency with and divergence from systems theory for each strategy were also described. These descriptions suggested potential implications, alternative safety models and improvements that could be made to these and other future road safety strategies.

3.3 Findings

These five leading strategies had been described as systems approaches, or descriptions, and had some similarities with systems theory and models in terms of component type model structure and objectives.

The strategies all exhibited aspects of Component or unit models, Intervention models, and Quantitative analytical models. However, there were distinct differences between these amongst the different strategies, particularly in the detail of components, interventions and principles. These strategies all exhibited attributes from different types of model, particularly Component, Intervention and Quantitative analytical models.

None of the strategies described the full complement of attributes according to system theory. All five of the strategies identified Key Components and Objectives. However, these components were of quite different types. None of the strategies described relationships between key components and while interdependency was implied, it was not explicitly described in any way. The thorough and scientifically based analysis of complex systems provided by systems theory had not been well applied in these strategies, which in turn means the potential strengths of applying systems theory were not realised.

None of the strategies described a rigorous and clear theoretical basis, although individual interventions are evidently based on strong science and analysis (Koornsta et al., n.d.; Wegman, 2017). All of the strategies, with the exception of Sweden's *Vision Zero* (SRA, 2006), were developed from road safety theory, observation and analysis, and research, at least to some degree. All of the

strategies, with the exception of United Kingdom's *Tomorrow's roads: safer for everyone* (DOTUK, 2000), described principles that underpinned the strategies.

3.4 Conclusions

The considerable inconsistency of content amongst the five strategies investigated raised the question as to the universal validity of the Safe Systems approach in road safety being a clear and comprehensive guiding approach. The five strategies were inconsistent with system theory lacking uniformity, theoretical basis, or similarity of application. This suggested that further refinements and development of the content of these strategies offered potential for their improvement. Furthermore, the application of the features of these road safety strategies to other jurisdictions was obviously problematic. The diversity offered little guidance as to a comprehensive framework that was widely applicable.

While the form and content of the road safety strategies investigated were inconsistent, there was considerable consistency in terms of the major components, particularly roads, vehicles and drivers that have been evident in road safety strategies for several decades, as described in the Introduction. Therefore, these strategies represented an incremental evolution on road safety strategies rather than the new and comprehensive approaches that Benner (1975, 1985), Lundberg et al. (2009) and Hovden et al. (2010) suggested offered the potential for improving road safety strategies. Consistent with road safety strategies over a long period, the strategies investigated were limited in scope and did not relate to the complex and multifaceted nature of road safety with its interconnected components, influences, interrelationships, components and countermeasures. The challenge to recognise and address the full range of factors and influences that affect outcomes that Smeed (1949) and Peden et al. (2004) identified, has not been met with these strategies, and the limited perspectives previously evident, remain (Hollnagel, 2008; Hovden et al., 2010).

The study did not assess the *degree* to which the five strategies were consistent with systems theory, or the type of model (von Bertalanffy, 1968; Ackoff, 1971;

Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a). Objective measures for these are difficult to define, but some strategies are evidently stronger and clearer than others.

Since the study did not investigate whether the strategies were suitable for the purpose as several authors (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000) suggest, further research offered the potential for improved understanding of the utility of these leading strategies. The study did not investigate whether the strategies were effective, *in themselves*, in improving road safety (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013), or whether other factors were important, such as levels of government commitment or extent of resourcing. It may be that the interventions in the road safety strategies in the study could be applied in isolation of the high level road safety strategy description and still achieve the desired outcome, especially if high levels of resourcing were applied to countermeasures.

The strategies analysed in this paper focussed on the outcomes of road safety, such as deaths and serious injuries. The focus of comparison was on broad explanatory factors, such as population, as opposed to the underlying frameworks for the strategies. The outcomes must certainly be recognised as being the ultimately important objective of any road safety strategy. Therefore, the measurement of outcomes and key broad explanatory factors was the topic of further investigation in Paper IV.

Papers I and II indicated certain features, factors and influences of safety and its management that are not normally included in road safety strategies. Taking those that are economic in nature, Paper III investigated examples of government policy, which are not evident in leading strategies, to illustrate the potential effect on road safety outcomes. The system and model issues highlighted in this paper are investigated further in Paper V to inform the development of the comprehensive framework.

Chapter 4. Government Policy: The Accidental Effect on Road Safety – Paper III

4.1 Introduction

Economic theory and concepts relating to transport are the technical basis of the following three papers (III, IV and V). Therefore, an extended introductory background and foundation is provided here, but is relevant to all three papers. Paper I describes that economic factors and influences affect road safety outcomes, the relevance of which are explored in these three papers.

As far back as Smeed (1949, 1968) economic issues⁵ have been considered important in road safety,

"It is still not generally realized that in addition to the cost of road accidents in human suffering, the economic cost to the community is very great." (Smeed, 1949, p12),

"it must be assumed that as economic conditions improve there will be a considerable growth in the number of private cars, so increasing congestion and tending to increase accidents." (Smeed, 1949, p29).

The review of models in Paper I identified several components that affect road safety, but not always accounted for in road safety strategies. For instance, Haddon (1980a) had previously identified socio-economic factors that are rarely included in contemporary road safety research, analysis and strategies. Other components include parts of the economic, transport contexts (Boyer and Dionne, 1987; Gaudry et al., 1995; Gaudry and Himouri, 2012), as described below.

⁵ The terms 'factor' and 'influence' are used in the economic and health literature (although imprecisely and inconsistently), and therefore in Paper III as published. However, an economic 'factor' is a Component in the terminology used throughout this thesis, and an 'influence' is generally a Policy Tool. Therefore the term Component in this chapter has the same meaning as factor in Paper III and the term Policy Tool in this chapter has the same meaning as influence in Paper III. Haddon also uses 'Component' (Haddon, 1968, 1999), and 'Factor' (Haddon 1972, 1980a, 1980b).

Various authors have identified and categorised a diversity of components that can affect systems. Peden et al. (2004) noted that:

"Any road traffic system is highly complex and hazardous to human health. Elements of the system include motor vehicles, roads and road users, and their physical, social and economic environments. Making a road traffic system less hazardous requires a "systems approach" – understanding the system as a whole and the interaction between its elements, and identifying where there is potential for intervention." (Peden et al., 2004, p157).

Spengler (1957) classified economic components under three headings:

- i) *"(1) the main physical agents of production — labor force, reproducible wealth or capital, and provisionally nonreproducible wealth (land and natural resources) — and (2) applied technology";*
- ii) *"mechanisms and other circumstances which dominate the allocation of agents of production and finished goods and services (price system, extent of market, division of labor, intersector balance and aggregate demand, etc.)";* and
- iii) *"(1) the major economic decision-makers and (2) the environment of economic decision."* (Spengler, 1957, p42).

Kindleberger (1965) described several non-economic components, including:

" the orientation of the individual in his society, family, class, race, and religion, rural-urban differences, national character, size of social unit, effect of culture on institutions, and interaction of cultural values and economic change."
(Kindleberger, 1965, p20).

For road safety, Mohan et al. (2006, p35) defines the term 'determinant' as a *" factor which contributes to or explains the occurrence and prevalence of a phenomenon."* The main components that affect exposure to risk include: economic factors, demographic factors, land-use planning, mixture of motorised traffic with vulnerable vehicles, and road design (Mohan et al., 2006). Crash involvement is affected by specific driver, vehicle and road characteristics including speeding, fatigue, age, and road or vehicle defects. Factors affecting crash severity include seatbelt use, speed, alcohol and drugs, and protection within vehicles and with road

side objects. Postcrash outcomes are mainly affected by health care and crash incident response factors.

The difference in endogenous components, particularly the economic context, is the reason why road safety performance is reported by rate to compare countries according to a consistent base. For instance, OECD/ITF (2014 and 2016b) report against population, vehicle use and the number of registered vehicles that are all macro-economic factors. Building on this concept, a rational basis for estimating the number of road crash victims based on economic and transport system parameters, – the DRAG Framework, was described and developed (Gaudry, 1984; Gaudry et al., 1995; Gaudry, 2002).

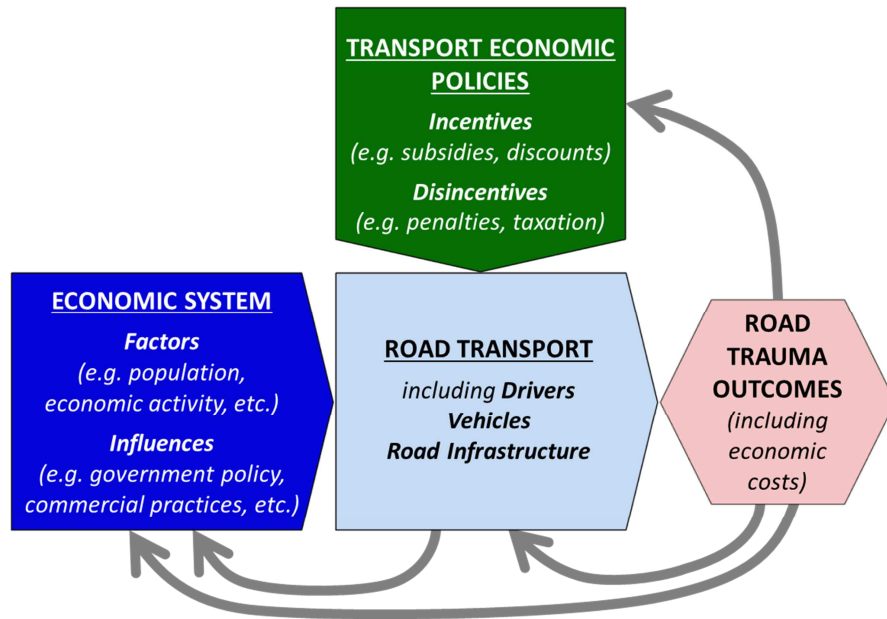
4.1.1 General economic concepts

Based on Paper I, there are therefore several economic considerations to bear in mind when considering road safety (Smeed, 1949 and 1968; Boyer and Dionne, 1987; OECD, 1990; Gaudry et al., 1995; DETR, 2000; Preston, 2001; Headicar, 2009; Gaudry and Himouri, 2012), as summarised in Figure 4.1:

1. economic effects of road crashes (costs and benefits of road safety and interventions);
2. effects of economic factors on the transport system that in turn affect safety performance (levels of road trauma);
3. effects of economic policies that change economic factors and transport; and
4. economic policies that can be applied to improve road safety.

Both the road transport operations and road trauma outcomes have economic costs and benefits that in turn affect and become part of the economic system. This feedback loop is a normal feature of systems (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a) and recognised in road safety (Kjellén, 1984). As part of a proper management process, policies are evaluated for utility (efficiency of and effectiveness in achieving change), and changed as required (e.g. revise, reduce, increase or cease) in order to continue to achieve outcomes.

Figure 4.1. Economic relationships relevant to road safety



4.1.2 Economic activity and transport demand

Based on transport being a derived demand, industry and government strategy literature suggests that economic activity and population are underlying drivers of passenger and truck movement (OECD, 1990; DETR, 2000; Preston, 2001; Headicar, 2009). The literature regarding relationships between a national economy and transport is described by Preston (2001) who concludes:

"The links between transport and income are obvious. In fact, so obvious that they are rather under-researched." (Preston, 2001, p14).

"Socio-demographics may be more important than we previously thought." (Preston, 2001, p21).

"We must resist the temptation to view transport in glorious isolation." (Preston, 2001, p21).

While the effect of the transport system on road safety has been acknowledged and identified, the relationships between macroeconomic factors and road safety are not commonly recognised or researched. Studies have identified the need to take the macroeconomic and transport contexts into account in road safety strategy, policy, planning and practice. The effect of economic factors and influences on road safety is complex, but cannot be ignored. A single individual factor, such as

increasing fuel price, could result in a transfer of car trips to public transport that would benefit road safety. On the other hand, it could also increase motorcycle travel which is more dangerous, thereby having an adverse effect of road safety. In addition, as Kveiborg and Fosgerau (2007) imply, global financial conditions may change the structure of economies, which affect transport, and hence road safety.

Gaudry and de Lapparent (2013) suggest that economics is the fourth significant dimension that must be taken into account in road safety research in addition to drivers, vehicles and roads. Transport, and consequently road safety outcomes, can be affected by macroeconomic factors, such as economic activity (e.g. Gross Domestic Product – GDP), economic structural factors (e.g. population) and economic policy (e.g. carbon tax). As a consequence, road safety can be variously affected by change in the macroeconomic or transport system to different degrees. Therefore, the expected external economic context and influences that affect the future outcomes are important to understand and take into account when investigating changes to road safety.

Several authors have reported similar relationships between transport demand, travel and underlying economic factors. Early models used simple and readily available factors, such as population, size of the labour force and unemployment (Partyka, 1984). Blum et al. (1988) report that Foos (1986) found a positive effect of income, the number of employees, real retail sales, and total stock of cars on transport demand, while fuel price has a negative effect. Ramanathan (1999) found that an increase in GDP significantly increases demand for fuel in both the long and short run. Scuffham and Langley (2002) found significant and important relationships between crashes and unemployment rate, GDP per capita, and alcohol consumption in the short-run. Kveiborg and Fosgerau (2007) found total production, handling factor, the truck size, the average load and the average length of haul were important factors explaining growth in freight traffic (vehicle km). Enoch and Warren (2008) analysed the factors affecting car use (mobility) in 45 small island developing states (SIDS). The factors with the strongest impact on mobility included fuel economy, fuel consumed per person, urban population,

population density, GDP per person, road length, vehicle ownership (per person), vehicles per kilometre of roads and fuel price. Liddle (2009) found short and long run relationships between two measures of transport demand (vehicle-miles and fuel use) with GDP, gasoline price, and vehicle ownership in the USA for 1946 to 2006. González and Marrero (2012) found demand for road transport increased with lane-km and the vehicle fleet, while per capita GDP and fuel prices reduce road traffic mobility. Gaudry and de Lapparent (2013) note the variety of, and close relationships between, economic growth and transport demand in terms of person-km/day and tonne-km/year. These relationships are typical of other studies that find clear relationships between certain economic components and transport demand.

4.1.3 Relationships between economic activity and road safety

The first and primary determinant of traffic safety is 'exposure' which is the key link between transport activity and road safety (Peden et al., 2004; Van den Bossche and Wets, 2003). Exposure represents the amount of opportunities for crashes to occur, so increasing exposure (such as number of trips, number of vehicle-kilometres or trip duration) increases the number of crashes. The DRAG approach is a rational mathematical based framework developed for estimating the number of road crash victims based on demand for road use (DR – 'exposure risk'), crash frequency (A – 'frequency risk') and crash severity (G – 'severity risk'), (Gaudry, 1984; Gaudry et al., 1995; Gaudry, 2002). Further specific factors are useful for more detailed analysis, and other explanatory factors may be incorporated as appropriate, particularly for more detailed analysis or more specific outcomes. DRAG has provided theoretical foundations and practice for estimating, forecasting, analysing and assessing in road safety performance (Page, 1997; Gaudry and de Lapparent, 2013). In doing so, DRAG describes mathematical relationships between economic activity and road safety outcomes.

The relationships between road safety outcomes and diverse economic factors may be complex. Kopits and Cropper (2005) demonstrated an inverted U-shape relationship between per capita income and traffic fatality risk. Other relevant

economic activity factors have been identified that affect road safety outcomes including index of industrial production (Joksch, 1984), employment factors (Wagenaar, 1984; Reinfurt et al., 1991), disposable income and income (Keeler, 1994). Zlatoper (1991) investigated a wider range of factors and found income, the ratio of urban to rural driving, highway police and safety expenditure, motor vehicle inspection laws, and adult seatbelt use laws with enforcement reduced motor vehicle road fatality rates. The amount of driving, speed, speed variance, driving density, alcohol consumption, and temperature, were positively correlated with fatality rates.

Gaudry et al. (1995), Gaudry and Himouri (2012) and others researched a wide range and number of economic, social, safety policy influences, physical factors and human factors to determine effects on several measures of road safety outcomes. Distance travelled, fuel price, weather, speed limit legislation, seatbelt use, alcohol consumption, retail sales, vehicle maintenance costs, motor cycle and moped use, drivers' ages, unemployment and other independent variables were used to explain transport measures including distance travelled by vehicle types. As noted with exposure above, the total distance travelled typically resulted in more crashes. Increases in fuel price showed a significant negative effect on the distance travelled (or exposure) and crashes. An increase in retail sales related to a significant increase in the distance travelled and crash outcomes, while the opposite effect occurred with increases in unemployment.

Santos et al. (2010) investigated economic theory and policy implementation regarding negative economic externality impacts of transport, one of the most important of which was crashes. These can be influenced by governments through command-and-control policies (including mandatory vehicle standards, restrictions to vehicle ownership or use, and parking restrictions). Alternatively, governments may employ incentive based policies, including 'quantity control' (e.g. for vehicle use by schemes, such as cap-and-trade allowances or rationing) and 'fiscal policy instruments' (such as taxes on vehicle ownership or use, subsidies for preferred types of vehicles, or pollution taxes (e.g. fuel tax), congestion charges, parking

charges or pay-as-you-drive insurance. They conclude there are many different types of government financial policy instruments which provide economic incentives (or disincentives) that influence behaviour, by changing the cost of certain activities. Of the OECD countries investigated, Australia has the fourth lowest petrol price (including taxes) and the third lowest fuel duty as a percentage of fuel prices. They concluded that, except in specific circumstances, regulations and standards are not efficient policy instruments from an economic perspective. Alternatively, incentive based policies are economically efficient, provided certain circumstances exist, particularly to change user behaviour. Finally, there are a variety of good policy instruments available to reduce negative externalities, but governments may find that taxes are more practical and administratively easier to implement than permits, in the case of road transport.

4.2 Objective

As economic factors and influences have the potential to affect transport demand or safety behaviour, this paper investigated examples of these that were not included in the most modern and successful road safety strategies, such as those described in Paper II. As also noted in Paper II, the most recent comparative reports on road safety compare outcomes, but based only on broad explanatory factors, such as population, vehicle use and numbers of registered vehicles (BITRE, 2016; OECD/ITF, 2016a).

From a systems perspective, economic 'factors' are intrinsic or endogenous, and therefore integral to the whole safety system (OECD, 1990). For instance, as found in Paper I, economic factors include population, levels of economic activity (such as GDP) or disposable income – factors that always exist in the economic system. Particularly in public health, these are called 'determinants' (Peden et al., 2004) and readily recognised in analysis and strategy. On the other hand, 'influences' are discretionary, voluntary or preferences that can come or go according to independent choice. These typically include consumer choices and industry or government policy tools. Governments use various policy tools to achieve outcomes, some of which are applied to improve economic outcomes. However,

since economic factors are intrinsic to the transport system as a whole, government economic policy may result in road safety consequences.

Economic policies also affect pricing, funding supply and demand for transport components and their use, and other financial aspects. Policies that increase the cost of transport decrease the amount of transport and vice versa. In doing so, based on the rationale described in the literature above, road safety would be expected to change. Therefore, this paper sought to illustrate the gap in policy and road safety understanding regarding the relationship between, and effects of, economic policies and road safety. The effect of emissions trading schemes, industry policy, taxation policy, road pricing and charging schemes were examples of economic influences investigated. These economic influences were found to affect road safety, illustrating gaps in knowledge regarding the content of modern road safety strategies. Industry participation and broader stakeholder advocacy for road safety were also investigated to appreciate their role in development of industry policy. Finally, the further potential for applying economic policies to improve safety were described.

4.3 Findings

Global climate change is a major focus of international and national policy. Transport is generally identified as a primary target for reducing greenhouse gas emissions that contribute to climate change. The proposition is that by changing to more fuel efficient modes of travel (or more correctly CO₂ equivalent efficient) and reducing the amount of travel, then climate change will be mitigated. So, governments are attracted to introduce policies that affect the transport system by employing various forms of financial disincentive (such as emissions trading schemes or carbon taxes). In doing so, road safety would be expected to be affected in some way. Potentially, if the cost of road transport increased due to an emissions pricing scheme, then car use would decrease and other modes, such as public transport, motorcycling and active transport (walking and cycling) would increase. Some of these effects would be expected to improve road safety (such as public transport), while others would be expected to reduce road safety (motorcycling).

However, the effect of schemes to reduce emissions on road safety is uncertain and has not been investigated in the development of such policies.

Taxation policy is fundamental to national revenue and expenditure, including transfers of funds between different groups, in order to achieve broad or specific social and economic outcomes. An extensive review of the Australian taxation and transfer system found several effects of taxation on transport including the amount of use of roads and distortions to consumer choices between car and public transport use. The review found that one particular taxation policy (Fringe Benefits Tax applied to individuals for company employment benefits) artificially increases road use. Therefore, road crashes are likely to have been elevated unnecessarily and inadvertently.

Road pricing and charging is a complex issue regarding efficient road use and generation of revenue. There are several different types of schemes that can have diverse purposes, such as reducing congestion, and generating funds for road investment, operations and maintenance. If road charging increases the cost of road use or becomes more transparent, it could be expected that some travel would no longer occur and some car travel would transfer to public transport, so road safety would be expected to improve.

Governments may develop and apply policies to various industries for a variety of purposes, such as to stimulate economic development, increase employment and sustain social equity. Doing so can affect transport provision or use (and therefore exposure) that can have consequences for road safety. Policies for the motor vehicle industry can affect the type or quality of vehicles that can also affect road safety outcomes. The example investigated here is the review of the Australian automobile industry. Changes to vehicle manufacturing can affect price or quality of cars, resulting in improvements to safety with newer (and therefore safer) vehicles in the transport system, and/or the introduction and increase of vehicle safety features. If the review promoted vehicle safety as a policy outcome, it could have achieved road safety outcomes at the same time as supporting the local motor

vehicle industry. Several private submissions to the review raised road safety as a major issue, but none were raised by governments. Half of all submissions raised road safety as an issue for the review, but it was not included in the conclusions and recommendations.

4.4 Conclusions

As expected from the introductory literature, this paper demonstrated that government economic policy affects road safety outcomes. Therefore, economic, social or other policy needs to form part of any road safety system description. Previous research into economic effects on road safety, described above, has focused on macro-economic factors, such as population, and economic activity. This paper demonstrated that economic influences, such as government policy, go beyond the previous scope of economic factors that influence road safety.

Traditionally, social and economic 'determinants' were included as factors or components affecting health outcomes, and also recognised in road safety. However, these are limited because they assume 'steady state' situation. In practice, these too can be changed by policy, thereby affecting road safety outcomes, either intentionally or not. Consequently, such economic policies can be used to improve road safety, if they are changed in ways that do so.

The examples in this paper illustrated that outcomes from economic policy have the potential to reduce travel demand, encourage one mode of transport over another, discourage particular vehicles and encourage safer vehicles. Potential changes to transport that could result in improved road safety outcomes include:

- car travel transferred to rail or bus public transport;
- trip lengths reduced by accessing closer facilities (e.g. shopping centres);
- reduced travel (trips not taken);
- travel substituted by teleworking, telecommunications, or working from home;
- trips reduced by multiuse (i.e. amalgamating purposes into a single trip); and
- trips reduced by trip chaining (i.e. several trips joined into a single journey).

This paper also introduced some broad concepts regarding analysis of general economic factors to demonstrate their effect on road safety. Given that economic factors and influences affect road safety, Paper IV further investigated how road safety outcomes are measured. Paper V subsequently investigated data requirements in order to analyse the road safety effects of economic factors and influences. The potential for applying economic policies illustrated in this paper informed the investigation of the data required and the more detailed introductory analysis between economic factors and road safety in Paper V. This paper also contributed to the clarification of policies to improve safety that were researched in the development of the final comprehensive framework developed in Paper VI.

Paper III confirmed that broader economic influences affect road safety than those factors typically researched in the past. Appreciation and inclusion of these influences would better reflect the complexity of road safety that Smeed (1949, 1964), OECD (1990), Peden et al. (2004) and others identified. It would also bring some aspects of systems thinking that Peden et al. (2004) and Salmon and Lenné (2015) suggested were required. Doing so may overcome the narrow thinking that Hollnagel (2008) and Hovden et al. (2010) described and offer the potential for improving road safety strategies that Benner (1975, 1985), May et al. (2008), Lundberg et al. (2009), Hovden et al. (2010) and May et al. (2011) suggest.

Chapter 5. Outcomes-Based National Road Safety Performance

Measures – Paper IV

5.1 Introduction

Road safety has been observed and considered probably as long as there have been motor vehicles, with crashes and fatalities dating back to the 19th century (Damon, 1958). Such observations slowly formed into data for information and analysis and eventually road safety management by the 1930's with routine statistical analysis occurring by the 1940's (Smeed 1949).

The outcomes (or consequences) of road safety are diverse. Haddon (1980a) identified crash consequences as damage to people, vehicles and equipment, physical environment and society. Peden et al. (2004) note that merely counting crashes is simplistic and inadequate, since the consequences of road crashes include health, social, economic and other outcomes. Furthermore, these outcomes are inconsistently spread, affecting people non-uniformly (such as by age or socio economic status) or by context (such as the high crash rates in developing countries). Data for road safety originate from diverse sources including police, health institutions, insurance companies, government departments, special interest groups and other public and private sources, with a diversity of approaches to collecting, analysing, reporting and comparing (Peden et al., 2004).

Many countries have set targets to improve road safety based on data about outcomes (Gitelman et al., 2010). The aim of targets is to increase the efficiency and effectiveness of road safety programmes to improve road safety performance (Elvik, 1993; Peden et al., 2004). Holló et al. (2010, p1142) note the concept of measuring performance is tied to its purpose with historical attributions to Lord Kelvin, "*If you cannot measure it, you cannot improve it*", and Kaplan "*One can't manage what one can't measure*". The concept is often attributed to Deming, as "*If You Can't Measure It, You Can't Manage It*". Interestingly, this is a misquote of "*It is wrong to suppose*

that if you can't measure it, you can't manage it – a costly myth" (Deming, 1994, p35) – two totally opposite views. These perspectives suggest that quantitative performance assessment is valuable, but it is not sufficient and should be in conjunction with qualitative performance assessment. The purpose of performance measurement is to enable management of activities and processes (designing, planning, implementing, monitoring and reviewing) to achieve outcomes efficiently and effectively. Whether performance assessment should be quantitative and/or qualitative is an interesting issue worthy of further consideration, but is beyond the scope of this thesis.

Indicators have been used for decades in industrial process performance management and in safety, including maritime, rail and aviation transport (ETSC, 2001). Safety performance is defined as:

"Changes over time in the level of transport safety, with a reduction in the number of accidents or the number of killed or injured people defined as an improvement in safety performance" (ETSC, 2001, p11).

Safety performance indicators are defined as:

" any measurement that is causally related to crashes or injuries, used in addition to a count of crashes or injuries, in order to indicate safety performance or understand the process that leads to accidents" (ETSC, 2001, p5).

Performance measures are considered an essential element of safety management, in order to understand the process that leads to crashes and to inform the development of effective countermeasures. The authors describe that road safety outcomes may be measured in many ways, but not all are equally useful, so they need to be designed and selected carefully. The objectives of road safety performance measurement have been summarised as reporting on (real) underlying performance; accurate reporting, understanding crash causes, informing the development of effective countermeasures, early identification of problems, demonstrating the effectiveness of countermeasures and programs, monitoring progress and improving performance (ETSC, 2001).

Measurement of road safety performance at the strategic level is commonly quantitative, dating back at least to Smeed (1949). The concept has been consistently used over time (Smeed, 1968; Evans, 1991; Allsop, 2000; Broughton and Knowles, 2010; Broughton et al., 2010; FHA, 2013; BITRE, 2016). Recent examples extend to international comparisons that often use rates (comparing outcomes against population or number of vehicles or amount of vehicle travel) as normalising factors (Gitelman et al., 2010; EU, 2015; WHO, 2015; BITRE, 2016; OECD/ITF, 2016b). Measurement of outcomes (or performance measurement) road safety management, analysis and reporting is now common (Wegman, 2004; Peden et al., 2004; Racioppi et al., 2004; OECD, 2008; Gitelman et al., 2010; OECD, 2016a; BITRE, 2016).

Peden et al. (2004) argues that reliable information is essential to prioritise road safety programs, but available performance measures have major gaps, such as health outcomes. Hakkert et al. (2007) describe a safety management system model based on ETSC (2001), where performance indicators measure the success of policy tools employed (safety measures and programmes). These measures are important to enable targets to be set that describe policy intentions and monitoring of progress for strategies as a whole. On this basis, performance measures are an essential and integral part of road safety strategies (OECD, 2016a).

Despite the widespread use of safety performance measures, it is not clear that the measures developed and used meet any objective or defined criteria to ensure they are suitable for the purpose intended, as Kjellén and Larsson (1981), Benner (1985) and Kjellén (2000) describe is required. In addition, neither do the reports describe how the performance measures are used, nor do they make a difference to achieving transport outcomes.

5.2 Objective

Transport management and strategic planning background of this sort led the National Transport Commission (NTC) to commission the development of national road and rail transport performance measures for Australia (Hughes et al., 2011;

Hughes and Hopkins, 2011). If wider components, such as those from the economic, social, physical or transport systems contexts are included as part of the road safety system to be managed, then some measures of performance should relate to them. Paper IV formed a component of wider research that developed and applied performance criteria for three outcome themes (productivity and efficiency, environment and safety) and two organisational themes (regulatory efficiency and organisational strategy).

To understand current practice and incorporate contemporary concepts, best practice and requirements, Paper IV reviewed transport and management literature, government reporting requirements from relevant agencies and current practice in transport performance measurement. Based on this information, selection criteria and specifications for performance measures were prepared to guide the proposed performance measures that were finally developed.

Paper IV was conducted in close cooperation across the multidisciplinary study team to ensure a consistent approach and results. The performance measures were also consistent across land transport modes – road and rail, as required. In addition, the study involved close cooperation with the NTC staff to ensure the outcomes met the purpose intended. This dual academic and quasi-government participation ensured robust conclusions that met management needs.

5.3 Findings

The survey of agencies reported in this study demonstrated that agencies can and do measure activities (that translate inputs into outputs), outputs (the means produced by agencies that achieve outcomes) and outcomes (results that have value to others). In transport, intermediate consequences exist, such as the amount of travel, asset value, mode share or financial values of consequences (benefits and costs). However, in practice, there is a predominance of activity, output and intermediate measurement compared with outcomes which are measured less frequently.

The criteria for selecting performance indicators was based on use of the measures and was consistent with recent best practice (Doran, 1981; Diamond, 2005; Dwyer and Hopwood, 2010; FHA, 2013), as shown in Table 5.1 (Hughes et al., 2011).

Table 5.1. Criteria to select performance measures

Criteria	Description
Policy relevance	<p>The indicator is relevant and important to governments, private sector and consumers, e.g. there is a high benefit-cost ratio</p> <p>The indicator monitors issues where there is a clear gap between the actual and desired outcome, e.g. high impact factor in transport reform outcomes</p> <p>The indicator has a high probability of being influenced by policy reform in the transport sector</p>
Accessibility	<p>The indicator is currently available and is available in a timely fashion. If not currently available, future collection is proposed</p> <p>The data on which the indicator are based is nationally comparable, e.g. intranationally, internationally and between all modes of transport</p> <p>The cost or burden of measurement, either current or proposed, is not unreasonable or unrealistic</p> <p>There are either no ownership issues or they can be easily resolved</p>
Representativeness and validity	<p>The indicator actually measures what it is intended to measure – it correlates well with other indicators of the same aspects and captures meaningful aspects of performance</p> <p>There is policy-focussed evidence to support the indicator's choice</p>
Reliability	<p>Data are of high quality, accessible and regularly updated</p> <p>The indicator provides stable results across various populations and circumstances, including time</p>
Simplicity	<p>The indicator is able to manage and reduce complex relationships</p>
Outcomes focussed	<p>The indicator focuses on desired outcomes of transport reform, not inputs, processes or outputs</p>

The safety performance measures were developed with consistent specifications for all five transport and organisational measures of performance, as shown in Table 5.2 (Hughes et al., 2011).

Table 5.2. Specification of performance measures

Specification Item	Description
Title	Name of the indicator
Purpose	Why it is being measured
Object	What is being measured
Metric and direction	Definition of the indicator (e.g. dimensions) and in which direction progress measured
Data requirements	What the input data are
Data collection methods	How the data is collected
Timing	Whether a short or long-term indicator, any delay in reporting and any timing issues
Ownership	The source of the data and the agency that reports it
Reliability	Consistent across states, modes, internationally, etc.
Relationships	Links between the performance indicators and other proposed indicators
Future developments	Including improving accuracy, reduced cost, improving consistency, etc.
Other information	Any other issues, comments, problems, opportunities, other information, etc.

Applying the selection criteria and specifications resulted in nine road safety performance measures being proposed, the major descriptors of which are shown in Table 5.3 (Hughes et al., 2011).

Table 5.3. Road safety performance measures

Performance Measure	Purpose	Object	Metric
Fatalities and Serious Injuries	To measure human impacts on individuals in society	Number of people killed and seriously injured	1. Number of people killed 2. Number of people seriously injured
Safe Vehicles	To indicate the improvements in passenger vehicle safety that are occurring	Level of vehicle safety quality of new passenger cars	Percentage of new passenger car sales that are 5 star ANCAP rated
Safe Roads	To indicate the improvements to road infrastructure to improve safety that are occurring	Level of safety quality of roads	Traffic weighted percentage of state road length that meets AusRAP standards
Safe Drivers 1. Seatbelt use 2. Alcohol and drugs	To indicate the level of driver safety	Driver safety	1. Percentage of vehicle occupants using seatbelts 2. Percentage of drivers not exceeding drug and alcohol thresholds as assessed by test
Safe Speeds	To indicate the level of safe road use	Safe speed of road use	Percentage of vehicles not exceeding the speed limit
Fatality and Serious Injury Rates for Passenger Travel	To understand relative levels of passenger safety between modes and related to travel	Number of people killed and seriously injured in passenger vehicles compared with the amount of passenger travel	Number of people killed and seriously injured divided by the passenger kilometres of travel
Fatality and Serious Injury Rates for Freight Travel	To understand relative levels of freight transport safety between modes and related to travel	Number of people killed and seriously injured in crashes involving freight vehicles compared with the amount of freight travel	Number of people killed and seriously injured in crashes involving freight vehicles per freight tonne kilometres of travel
Social Costs of Transport Crashes	Economic costs are an important measure for governments and for comparisons with other sectors	Total cost of crashes to the community	Annual dollar costs
Signal Violations 1. Traffic Control Signal violations 2. Railway Level Crossing Signal violations	To measure the compliance of drivers to control signals and therefore the level of risk that occurs	Proportion of red control signals that are passed by drivers	Proportion of signals that are passed by road drivers

5.4 Conclusions

The performance measures developed met the functional objectives of the organisation responsible, consistent with principles for useful performance measures and met specific selection criteria. Therefore, the performance measures developed were consistent with the objective to aid safety management (Benner, 1985), road safety management (ETSC, 2001; Peden et al., 2004; Racioppi et al., 2004) and comparisons between jurisdictions (Gitelman et al., 2010).

The study recognised the complex, multifaceted and interconnected factors and components that affect road safety outcomes that Smeed (1949) and Peden et al. (2004) describe as being important. The measures described transport and social outcomes across road and rail, freight and passenger transport, in addition to driver, vehicle and road components. The performance measures developed recognised a wide range of factors and influences that affect road safety outcomes, with the aim to use them for road safety management.

The study resulted in road safety performance measures that related to the systems nature of road safety (Michaels, 1963; Kjellén and Larsson, 1981; Chapanis, 1996; Salmon and Lenné, 2015). Firstly, the performance measures were directly aligned with the Safe Systems approach to road safety (Wegman et al., n.d.; Koornstra et al., 2002; MOT, 2010; Paper II, Hughes et al., 2015a), notwithstanding this approach has limited consistency with systems theory. Secondly, the performance measures recognised the much wider transport system, given the development of performance measures for productivity, efficiency and environment outcomes at the same time. One of the safety performance measures developed also represented social outcomes.

The results were consistent with the difficulties that Gitelman et al. (2010), Holló et al. (2010) and Papadimitriou and Yannis (2013) described. This study also found differences in data and methodology between jurisdictions that are difficult to resolve, consistent with Gitelman et al. (2010). This study has properly designed a

set of basic safety performance indicators according to requirements that Gitelman et al. (2010) suggested.

The major challenge for the outcomes of this study is implementation that requires several steps. It is noted that the NTC included the performance indicators developed in this study in its forward strategic planning (NTC, 2011) that indicates a high level of acceptance of the results and the intention to implement. Further engagement with cooperating jurisdictions is essential, since the NTC does not collect most of the data required. Further work is also required to develop procedures for collecting high-quality and comparable data for the indicators, as Gitelman et al. (2010) suggested. Finally, following implementation, the use of the performance measures should be tested to ensure they contribute to achieving the outcomes required as Kjellén and Larsson (1981), Benner (1985) and Kjellén (2000) proposed.

A fundamental characteristic of systems is that the outcome being achieved is greater than the sum of the individual parts operating in isolation. With respect to measuring performance, there are two specific and difficult challenges regarding management of safety of systems. The first is how to measure performance in a way that recognises the inherent integrated and interdependent nature of systems, as opposed to the aggregation of individual actions or components. The second is similar; the measurement of the value of management, strategies or their underlying foundational frameworks as a whole, as opposed to the consequences of the individual actions which the strategy contains.

Traditional analytical techniques, such as quantitative modelling, can be useful for measuring specific performance characteristics, as described. However, analysis to determine system performance or its management is more difficult. This paper suggests that specific or intermediate aspects of the system need to be analysed (e.g. speeding, impairment, not wearing seatbelt, safe vehicles), and near miss events. It may be that other measures would be advantageous, such as impairment (e.g. fatigue), number of blackspots or safety-related issues reported. Such

performance measurement may also require different and new analytical techniques, such as system dynamics, to inform the management of road safety systems, while other new techniques may be required to evaluate road safety strategies or frameworks. For instance, the effect of individual policy tools or relationships could be analysed as independent occurrences then compared with an analysis of the policy tools or relationships operating together in a system. Another method of performance measurement could be to analyse the interactions between individual components, actors or policy tools. At the level of strategies as a whole, proxy measures could possibly be used, such as the number of interactions between any individual component, actor or policy tool and others, where greater numbers of interactions signify greater system interdependence or vice versa.

Measurement of performance is at the heart of road safety strategies, since it represents the achievement of the objectives. Therefore, performance measurement needs to reflect the countermeasures in road safety strategies and the strategies themselves. At the same time, the success of the countermeasures and road safety strategies is assessed according to the measures of performance. New performance assessment techniques are required to take account of the systems nature of road safety. Such performance measurement may also require new and different analytical techniques, such as system dynamics, to more usefully inform the management of road safety systems.

This paper follows on from Papers I and III by proposing measures based on relevant safety models and government responsibilities, policies and actions. It relates to the strategies investigated in Paper II, and the comprehensive framework developed in Paper VI by describing the type of performance measures that road safety strategies should be reporting against and how such measures may be developed, and implemented. Such performance measures need appropriate data to be valid and useful, as is further investigated in Paper V.

Chapter 6. Data Foundations for Relationships between Economic and Transport Factors with Road Safety Outcomes – Paper V

6.1 Introduction

This paper builds on the concepts described in Papers I, III and IV, particularly in regard to macroeconomic factors that affect road safety. The paper also reflects requirements for appropriate and valid data implied by Paper III and identified in Paper IV, in order to provide useful information for road safety analysis and strategy development, particularly in relation to development and assessment of policy tools and performance assessment. Since road safety strategies are at a high level (e.g. for a country as a whole representing all users, vehicles and roads), the factors relevant to them are also broadly based and are generally understood and described as macroeconomic factors. Paper IV described the concepts and literature regarding relationships between economic activity and road safety.

Economic factors have been recognised as part of the complexity of factors and influences affecting road safety. Therefore, these factors need to be taken account of in road safety analysis, and the development of road safety strategies (Smeed, 1949; OECD, 1990; Gaudry, 1984; Peden et al., 2004). Any models for analytical purposes or for performance measurement must be fit for purpose — valid and useful (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000). Several macroeconomic factors representing economic activity have been correlated with road safety outcomes in multiple ways. Commonly used measures of economic activity include: real gross domestic product (GDP) or real gross national product (GNP) (Gaudry, 1984; Hakim et al., 1991; Zlatoper, 1991; Van Beeck et al., 2000; Granados, 2005). OECD (1990) summarised the road traffic and transport system, in three levels, as shown in Table 6.1, which result in the outcomes of travel costs and benefits.

Table 6.1. The road traffic and transport system

Level I		Land Use
		Location of persons and goods (housing, employment, etc.)
		Supply and demand Planning Logistics Activities
		Trip origin and destination Trip purpose Arrival/departure time Transport mode/car availability Traffic direction (peak vs off -peak period direction)
Level II		↓ Transport Demand
		Road Network Traffic control
		Travel behaviour Traffic process (macroscopic)
		Clustered routes Classes of road users Volume, speed and density
Level III		↓ Traffic flows
		Design and layout of streets
		Traffic behaviour Encounters
Benefits:		Accessibility Comfort and recreation
Costs:		Noise and air pollution Traffic delays Parking problems Conflicts and accidents
Travel costs and benefits		

Some aspects of road safety have been subject to considerable analysis at the strategic level, but not necessarily road safety strategies themselves. Several methodologies have been employed over time, with early techniques being simple regressions models (Smeed, 1949) that have developed and improved over time to the most recent sophisticated times series analysis, such as Auto-Regressive

Integrated Moving Average (ARIMA) (Wagenaar, 1984; Reinfurt et al., 1991), and the more general Structural Time Series Modelling (STSM) (Scuffham and Langley, 2002).

Mathematical models can inform development of analytical tools for road safety analysis, research, performance measurement and strategy development. Conceptually, this requires an understanding of the context and previous research. Statistically, development of mathematical models in this case requires:

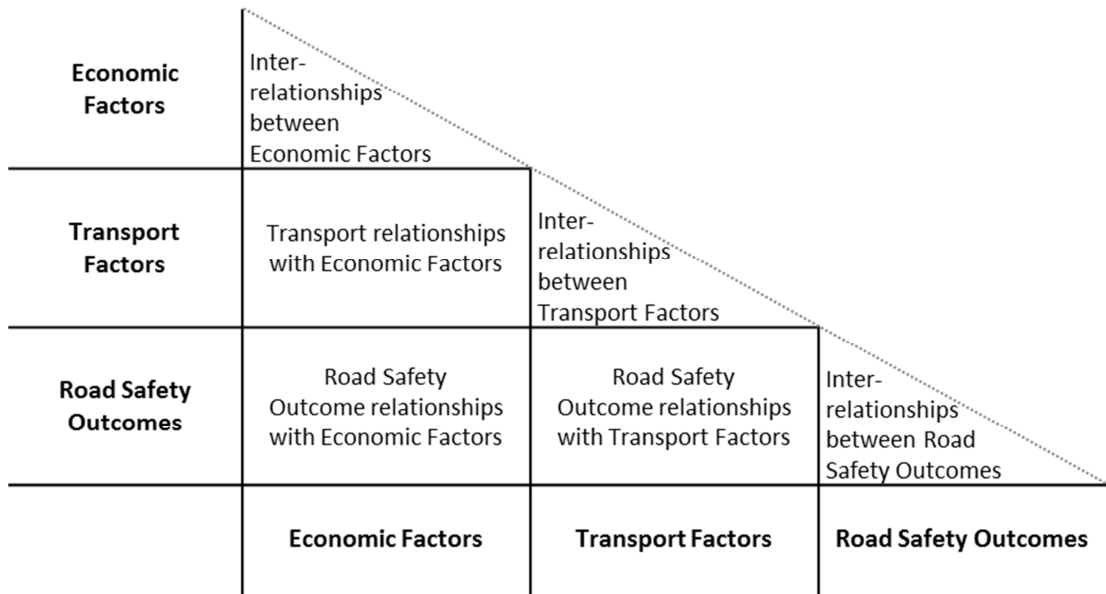
- suitable data regarding relevant economic parameters and road safety outcomes;
- use of appropriate explanatory or associated parameters; and
- valid mathematical relationships between economic parameters and outcomes (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000).

Consistent with analysis described in the background to Paper IV, the underlying rationale for this analysis is similar to the DRAG models (Gaudry, 1984; Gaudry et al., 1995; Gaudry, 2002). It was intended that the model proposed be further developed in subsequent studies, to enhance the estimate of the amount of travel based on economic activity and provide additional detail by segregating crashes by road user type. As described in Paper IV, road safety outcomes are a function of economic and community activity that produces travel, resulting in crashes that, in turn, result in damage and injury. Previous strategic and detailed analysis describes that the relationships are complex in road safety terms, due to the multiplicity of factors and influences. Such models are also challenging in terms of data, statistics, modelling and interpretation. However, in the simplest linear form, the form of this model would be described as:

Road safety outcomes = economic activity
x travel per economic activity (\rightarrow *amount of travel*)
x crashes per travel (\rightarrow *number of crashes*)
x severity (*injury*) per crash.

Accordingly, three types of data are required to estimate the relationships required to achieve this macro model, as illustrated in Figure 6.1.

Figure 6.1. Data and relationships for a macro model of crashes



This approach is usually simplified at the highest level of road safety management, viz. strategies and performance measures, as road safety outcomes are related to macroeconomic factors, such as population, economic activity and transport. The economic parameters collected were reduced to economic activity, employment, populations and fuel variables. The road safety outcomes were reduced crash numbers (including by type) and consequence (fatalities and injuries). Relationships between road safety outcomes and macroeconomic parameters were investigated for the preliminary analysis undertaken in this study.

Paper V was devised as a first stage to a larger assessment and models of factors affecting road safety. The aim was to collect and prepare the data prior to modelling in a similar way to the DRAG approach.

6.2 Objective

The aims of Paper V were to:

- identify important relevant information from previous research regarding the association between changes in economic factors and road crashes;
- investigate and describe the association between economic variables of the Western Australian economy and serious casualty crash outcomes; and

- describe the preparation of data and estimates suitable for further research, policy and strategy development and analysis, including forecasting.

Paper V comprised three analytical steps:

1. data collection and assessment;
2. investigation of alternative model forms; and
3. investigation of alternative explanatory economic activity factors.

Paper V collected data on economic factors and transport system variables, to research relationships between these underlying factors and road safety outcomes. An important part of this paper is ensuring the data are mathematically and statistically suitable for the purpose for which they are to be used (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000), something that is not generally considered in road safety analysis at the strategic level of performance analysis or strategy development.

Data for 16 economic factors, 12 transport system variables, and 17 road safety outcome measures were collected from public and restricted sources, for the period 1985 to 2009, as shown in Table 6.2. Other scaled measures often used in road safety management, such as travel per capita, could be derived from the measures collected to enable further analysis.

Table 6.2. Economic, transport and safety data for strategic analysis

Economic Parameter	Transport Parameter	Road Safety Outcomes Parameter
Population	Vehicle km travelled (VKT)	Fatalities
Gross State Product	VKT by car	KSI's (Killed or seriously injured)
GSP/capita	VKT by motor cycle	Crash – passenger vehicle
Gross State Income	VKT by light commercial vehicle	Crash – heavy vehicle
Gross State Income/capita	VKT by rigid truck	Crash – motorcycle number
Gross Disposable Income	VKT by articulated Truck	Crash – bike number
Industrial Value Added	VKT by bus	Crash – pedestrian number
State Final Demand	VKT by passenger vehicle	Crash number
Retail Turnover	VKT by heavy vehicle	Crash fatal number
Net International Export	Random breath test	Crash – KSI
Employment	Speed camera use	Crash Hospital number
Unemployment	Media expenditure on road safety	Number of crashes – someone received medical treatment
Unemployment rate		Number of crashes – major property damage only
Petrol sales		Number of crashes – minor property damage only
Petrol price		Road Injury by motor vehicle
Fuel consumption		Road Injury by pedal cyclist
		Road Injury by pedestrian

The assembled data were subjected to visual assessments, descriptive statistics and statistical tests. The statistical diagnostic tests included correlation, multicollinearity, normality and stationarity. These tests ensured that subsequent analysis avoids problems, such as misspecification of models or invalid analysis that results in misleading conclusions.

Simple and more complex model forms were investigated using ordinary least squares regression. Both linear and non-linear models were investigated. Models that were simple, statistically valid, and with closer levels of fit to the observations were preferred.

6.3 Findings

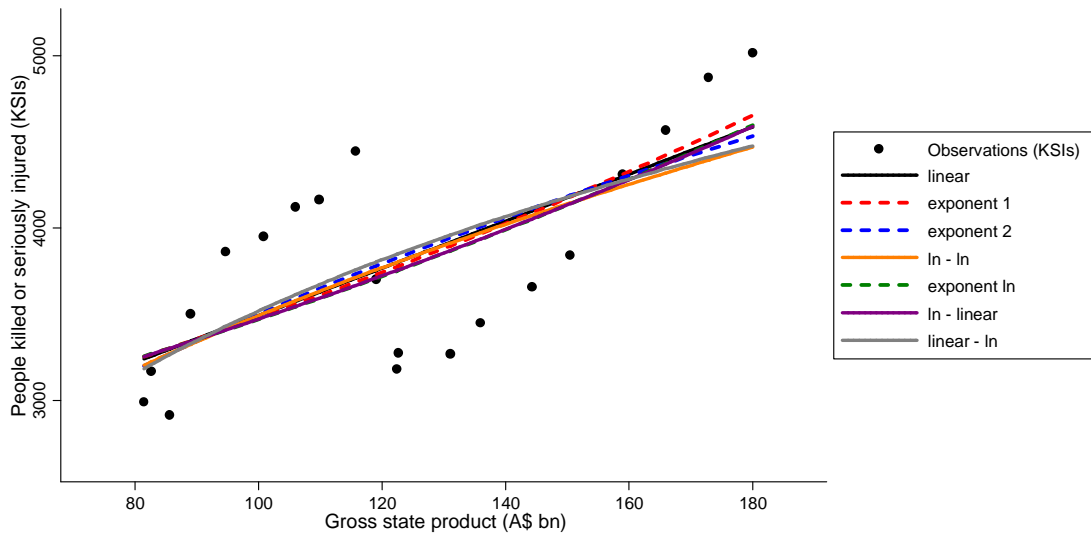
The data collected were generally found to be suitable for the purpose, with some cautions. As could be expected, the data assessment revealed that there were many correlations between the potential explanatory variables within the three groups of data (economic, transport and road safety outcomes). For instance, most measures of economic activity were strongly correlated, so they could not be used together for multivariate analysis. Using these parameters individually was found to be acceptable. While data were collected for both quarterly and annual time periods, the annual data were found to have fewer problems in terms of normality. The annual data were, in fact, generally acceptable in terms of normality for statistical purposes. The tests for stationarity revealed some weaknesses in the data, so care must be taken in subsequent analysis to ensure time series effects are taken into account in the modelling.

Seven linear and non-linear models were investigated, using Gross State Product (GSP) as the representative measure of economic activity. Relationships with the number of people killed and seriously injured (KSI's) and total numbers of crashes were valid, while relationships with the number of fatalities or the number of KSI crashes were generally not valid. The model preferred was an exponent model of the form:

$$y = b_1 \cdot b_2^x$$

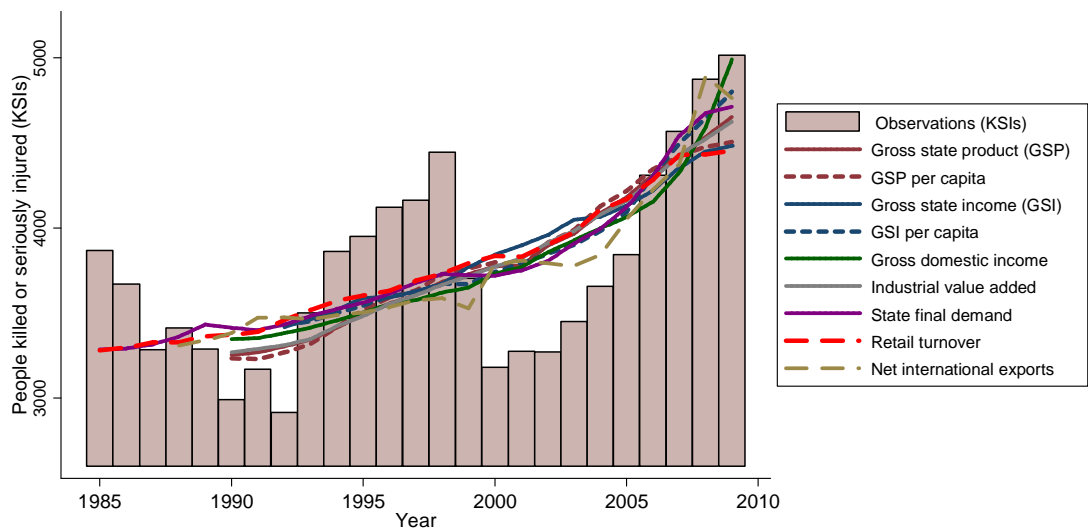
where 'y' represents the road safety outcome (in this case the number of KSI's) and 'x' represents the economic parameter (in this case GSP). Plotting of the results, shown in Figure 6.2, illustrates that there were little difference between the different model forms compared to the observations.

Figure 6.2. Investigation of alternative explanatory economic activity models



Nine alternative economic parameters were investigated as explanatory factors; Gross State Product (GDP), gross state income, gross domestic income, industrial value added, state final demand, retail turnover, and net international exports. The first three of these were divided by population to form per capita parameters. Relationships between the road safety outcomes and all economic parameters were found to be valid with similarly high explanation of the outcomes. Following determination of the relationship, an estimate was made for each year, using the economic activity for that year, which was compared with the observation for that year, as shown in Figure 6.3.

Figure 6.3. Investigation of alternative explanatory economic activity factors



GSP is preferred as an explanatory variable due to it being a broad measure, frequently used, commonly understood and widely available. GSP exhibits a higher correlation with KSI's, and is a simple single parameter not incorporating another factor that the per capita measures do. The preferred model is then:

$$\text{KSI} = 2420 \times 1.000004^{\text{GSP}}$$

6.4 Conclusions

The analysis in Paper V has confirmed that, for estimates of relationships with road safety outcomes:

1. suitable data are available;
2. appropriate economic explanatory parameters exist; and
3. valid mathematical relationships can be developed between economic parameters and road safety outcomes.

As a result, valid relationships between economic parameters and road safety outcomes were determined.

The model developed has been informed by economic constructs identified in the literature (Paper I), and economic parameters reported in the literature (Papers III and IV). The model results are consistent with previous analysis that linked economic activity with road safety outcomes (Gaudry, 1984; Hakim et al., 1991; Zlatoper, 1991; Van Beeck et al., 2000; Granados, 2005).

The results of Paper V met the requirements for appropriate and valid data and models for road safety analysis and strategy development consistent with Benner (1975, 1985), Lundberg et al. (2009), Hovden et al. (2010), Kjellén and Larsson (1981) and Kjellén (2000). Paper V demonstrated that the macroeconomic context provides important contextual parameters that influence road safety outcomes. In particular, the approach is suitable to inform development and assessment of policy tools (Peden et al., 2004) and performance assessment (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013).

The data and initial information investigated in Paper V provided a solid foundation for further investigations of relationships between economic and transport factors with road safety that can be used to inform further analysis, research, performance measurement and strategy development. This result was important for the comprehensive framework developed in Paper VI, since it provided the opportunity for future thorough analysis of factors relevant to road safety outcomes, and the opportunity to inform analyses of any policies developed and proposed in a strategy.

Chapter 7. A Comprehensive Conceptual Framework for Road Safety Strategies – Paper VI

7.1 Introduction

The Introduction to this thesis described the incremental development of road safety strategies and potential opportunities to make improvements. Guidance for developers of new road safety strategies is currently provided by previous strategies, guides to practice (Mohan et al., 2006; ISO, 2012; FHA, 2013) and a multitude of potential policy tools (Elvik et al., 2009). However, this guidance material has been found to have little theoretical basis for their underlying frameworks and are limited in scope, partly for this reason. This chapter brings together the learnings from the developmental papers in previous chapters of this thesis, based on theory and practice, to propose a comprehensive framework for future road safety strategies.

Road safety outcomes are the result of the complexity and multiplicity of components, influences, interrelationships, and countermeasures (Smeed, 1949; Peden et al., 2004; Racioppi et al., 2004). Components have been broadly described in categories including roads, vehicles and drivers that operate within the broader economic, social, natural environment and transport contexts, resulting in postcrash actions, such as emergency response and medical treatment. Policy tools, or countermeasures, used to reduce road safety outcomes are not logically categorised, or classified. Therefore, any comprehensive framework developed must be broad enough to cover the full range of components and policy tools that affect road safety outcomes. Such a more advanced framework may be required to improve road safety strategies (Benner, 1975, 1985; May et al., 2008; Lundberg et al., 2009; Hovden et al., 2010; May et al., 2011).

With a similar objective in mind, Lundberg et al. (2009) examined different approaches to safety investigations in organisations over time that progressed from

management control of workers, to line managers and operators (the 'sharp end'), then later to management and regulators (the 'blunt end'). The most recent models combine both factors and events, such as Reason's (1997) model of organisational accidents. For safety within organisations, seven factors were usually found to be important by authors in the safety community and among practitioners (while acknowledging there were many others): Social, Technological, Organisational, Human, Safety culture, Information and Economy vs. production. Such a broad view was needed in order to overcome the 'preoccupation' on individual parts in isolation, and lack of focus on the whole activity, process or organisation, to overcome the likelihood of narrow conclusions or *What-You-Look-For-Is-What-You-Find* (Hollnagel, 2008; Lundberg et al., 2009).

There is a specific opportunity to improve road safety strategies by incorporating systems approaches into road safety frameworks (Michaels, 1963; Kjellén and Larsson, 1981). Systems theory (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Chapanis, 1996; Rasmussen, 1997; Leveson, 2004, 2009, 2011a) has been successfully applied in other safety domains, but not commonly or thoroughly in road safety (Salmon and Lenné, 2015), as Papers II and III confirmed.

In researching accident models, Benner (1985) found there was little guidance for managers and investigators to identify and choose the best available accident models. No comprehensive lists of models or criteria for evaluation and selection existed for that purpose, a point that can be extended to road safety strategies. After identifying accident models and investigation methodologies, Benner (1985) compared and ranked accident investigation models according to 10 evaluation criteria – Realistic, Definitive, Satisfying, Comprehensive, Disciplining, Consistent, Direct, Functional, Noncausal and Visible – to identify those that were most suitable and effective. After applying these criteria to 14 different types of model, he concluded that since some models were clearly better than others, not all should be used. He further concluded that more exhaustive research into accident models should occur. Criteria, such as those Benner (1985) developed, are informative and useful for evaluating, selecting and comparing road safety strategies or frameworks.

This paper builds on the theory and practical examples of the previous papers in this thesis. The models identified in Paper I provide opportunities to guide the directions of a new comprehensive framework, particularly with respect to comprehensive content and systems theory and practice. Information and experience from other safety domains can be incorporated into a road safety framework. The review of modern and successful road safety strategies in Paper II suggests certain ways that even the leading, modern and successful strategies can be improved. Thus, it could reasonably be expected that road safety could be improved as a result, not only in these jurisdictions but perhaps even to a greater degree if applied elsewhere. The macroeconomic factors and influences illustrated in Paper III should be incorporated into a generic model since they clearly affect road safety outcomes. The outcomes for road safety described in Paper IV can form a clear objective required for a system approach to be applied. Finally, the data foundations in Paper V suggest some specific content that would be valuable to be included in a generic framework, and also indicates that data is available for use in applying more comprehensive strategies.

7.2 Objective

The specific objective of this final paper was to develop a comprehensive framework for future road safety strategies, incorporating all components, policy tools by which they can be changed, and the interactions between them. Development of the framework was based on criticisms and weaknesses of road safety management described in the Introduction of this thesis, the preceding papers, and opportunities identified in this thesis. If the objective is achieved, it is expected that road safety strategies can be improved, with the result that the burden of road safety on the community can be reduced.

Frameworks are widely used in road safety, and elsewhere in safety management generally (RRL, 1963; Limpert, 1978; Haddon, 1980a; Baker and Fricke, 1986). Perhaps the most commonly recognised framework is the matrix developed by Haddon (1968, 1972, 1980a, 1980b, 1999) that he called a *Logical Framework*, based on three constructs; phases (the crash event sequence), parts (called factors

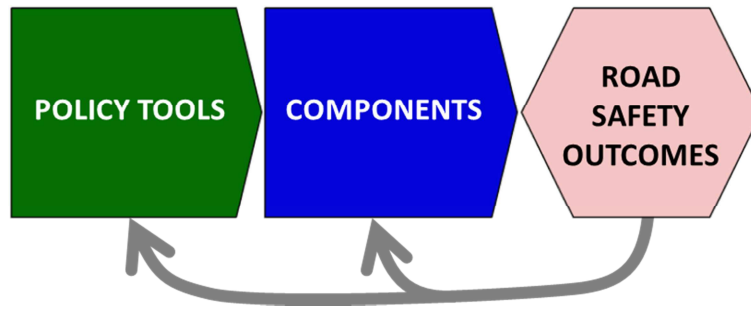
or components) and types of outcomes (called results). In fact, this matrix is a development of the earlier and even more commonly used threefold construct of vehicle, roads and drivers (Damon, 1958; Nader, 1965; Booth, 1980) that dates back to the 19th Century (Peres, 1895) and clearly stated by the 1930's (HC Deb 1939).

Identification and description of policy tools were informed by those previously identified for general use (Vedung, 2003), in road safety (Elvik et al., 2009) and in road safety management (Bliss and Breen, 2012). Vedung (2003) described several different possible taxonomies based on economic theory, but the simple threefold typology of public policy instruments – regulations (sticks), economic means (carrots) and information (sermons) – was adapted in this study.

The road safety frameworks discussed in the Introduction of this thesis did not clearly and fully describe all the possible components that could comprise a road safety strategy, since some components were included in one but not in others. In the same way, no one list of policy tools is complete, since some policy tools were included in one list but not in others. While there are frameworks describing components and several lists of policy tools, they lack an underlying rationale (or theoretical foundation) and coherent arrangement. Even if the lists were complete, they did not conform to systems theory, and approaches that offer opportunities to improve road safety strategies that would require clear descriptions of relationships.

The objective of this research was to fully populate the policy tools and components illustrated in the diagram presented in the Introduction of this thesis (Figure 7.1), based on an underlying rationale and coherent arrangement, including interactions.

Figure 7.1. Applying policy tools to components in the road safety system to achieve outcomes



7.3 Findings

The research was based on the models found in Paper I that suggested frameworks, interactions, *types* of policy tools and components, as well as *specific* policy tools and components. In particular, the much broader range of individual policy tools and components found in Paper I were specifically identified, categorised and incorporated.

The primary relationship (or sequence of interactions) regarding crashes occurring is described in this framework as context → crash → consequence. The framework categorises policy tools as incentives, disincentives and influence. The components are categorised as transport and land use, economic, social, natural environment, safety management, road infrastructure, vehicles, human, and response system.

Fundamentally, two types of incentive policy tools, two types of disincentive policy tools and six types of influence policy tools were identified, as illustrated in Figure 7.2 and detailed in Table 7.1.

Figure 7.2. Types of policy tools to achieve outcomes

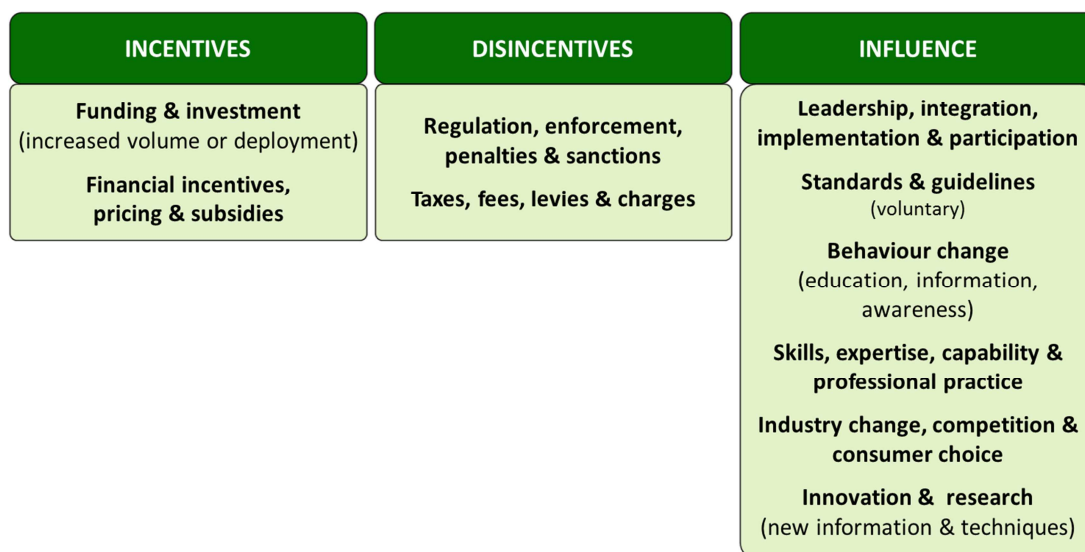


Table 7.1. Description of policy tools

Policy Tool	Description
INCENTIVES	
Funding & investment	Application of finances to increase the amount of facilities, services, assets, product or level of deployment
<i>Includes:</i>	Purchasing of vehicles, tools, systems and equipment, infrastructure investment, services delivery, deployment of staff, engineering production, maintenance and product delivery
Financial incentives, pricing & subsidies	Voluntary monetary or in-kind payments, costs and rewards to encourage desired behaviour or practice Financial transfers and cross subsidies
<i>Includes:</i>	Disincentives or penalties for poor behaviours and inducements or rewards for good behaviours Taxes and charges that provide road safety benefits (e.g. alcohol excise) Discounts for insurance and registration, payments to service providers
DISINCENTIVES	
Regulation, enforcement, penalties & sanctions	Activities to develop and apply a legislative authority
<i>Includes:</i>	Legislation, rules, orders, enforcement, penalties, sanctions, mandatory application of standards
Taxes, fees, levies & charges	Financial charges applied to discourage undesirable behaviour or practice
<i>Includes:</i>	Payments for costs incurred, fees to encourage behaviour change, levies to fund policy tools

Policy Tool	Description
INFLUENCE	
Leadership, integration, implementation & participation	Desktop, office, personal and relational activities regarding the planning and delivery of policies, programs and projects to optimise safety outcomes – excludes actual delivery of a policy
<i>Includes:</i>	Leadership – advocacy, campaigning, general background information, strategic planning, development, assessment, selection of effective and efficient policies, programs and projects, outcomes monitoring Integration – coordination, optimisation, information exchange, output management Implementation – planning, programming, timing, impact assessment Participation – dialogue with stakeholders, negotiation, agreements, engagement
Behaviour change	Activities that encourage people to behave more safely – separate from, but may be linked to incentives, pricing, subsidies and regulatory mechanisms
<i>Includes:</i>	Education, information, awareness, rational encouragement, individualised information, mass campaigns
Skills, expertise, capability & professional practice	Development of personal capacity, competency and fitness to undertake a task Development of professional skills and practice
<i>Includes:</i>	Training, experience, knowledge, skilling Medical, physical and intellectual fitness for duty
Standards & guidelines	Voluntary application of written authoritative agreements or references with respect to design and practice
<i>Includes:</i>	Formal and informal standards and guidelines for good practice – may be recommended, desirable or minimum
Industry change, competition & consumer choice	Application of strategic advantage to provide a market advantage – influences in markets that result in a desired outcome
<i>Includes:</i>	Performance enhancement, lower costs, improved service, provision of market information (price, performance or quantity)
Innovation & research	Investigation and development of new information with respect to behaviour, practice, product or operations and initial deployment to prove and refine applicability
<i>Includes:</i>	Basic and applied research, pilots, trials, evaluations, new general and specific information, continuous improvement

Within these policy tools, there are numerous examples of specific policies, projects, programs that can be deployed and a distinction is not always clear between them. For instance, development of skills (influence) may be a

requirement of legislation (disincentive), come with a penalty for non-compliance (disincentive), require funding for training (incentive) and benefit from application of standards and guidelines (influence).

The number and diversity of components was considerably greater than for policy tools, and more difficult to be comprehensive, but are summarised with subcomponents in Table 7.2. Four different subcomponents of transport and land use were found, four different subcomponents of economic context, eight different subcomponents of social context, four different subcomponents of natural environment, nine different subcomponents of safety management, 11 different subcomponents of road infrastructure component, 20 different subcomponents of vehicle component, 11 different subcomponents of human component, and four different subcomponents of response system.

Table 7.2. Types and descriptions of components in road safety

Component	Subcomponent Description
Transport and Land Use Context	Transport alternatives, other modes, company operations Spatial Arrangement, co-location Accessibility – remoteness, location, service levels Transport integration
Economic Context	Economics, finance, funding Population, employment structure Environment, energy, climate change Legal – regulation, liability, privacy, insurance, courts, corrections
Social Context	Politics and government Law – role and response Social norms, nurture, background, traditions, rituals Ethnic practices Spiritual beliefs Literacy, intellect, education Employment – practices, demands, restrictions Activities, travel purposes
Natural Environment	Daylight, dawn, dusk, night, sun Weather and atmospheric conditions – rain, fog, snow, smoke, wind, temperature Adjacent environment – topography, trees, grass, water Wildlife
Human	Participants – driver, passenger, witness, acquaintance, occupant, road workers Age and sex Impairment – alcohol, drugs, medicines, carbon monoxide, drowsiness, sleep, disablement (seizures, pain, blackouts, disabilities), fatigue Driving process – strategy, tactics, perception, alertness, reaction, attention, distraction, error correction, response to incidents and conditions Abilities – physical, vision, hearing, mental state, injury, illness, disability, health Capability – natural, learned, skill, intelligence, education, experience Attitude, motivation, demeanour, emotion, psychological state, behaviour Time (day, week, month, season), type of trip Driving capability – licence, restrictions Helmets, clothing and other protection Clothing – visibility, protection, interference
Vehicles	Type – car, truck, trailer, motorcycle, bicycle, bus, farm machinery, other Design* – standards, maintenance, damage, modifications, inspections Wheels and tyres* – size, type, tread, pressure, condition, chains Brakes* Controls* – steering, pedals, levers, switches Body type* and mass Seatbelts, child restraints and other protection Lights* – external, internal, type, performance, colour, reflectors Cargo – type, characteristics, mass, strength, shape, hazardous Structure* – frame, doors, panels, safety features, crashworthiness, fittings, mirrors, mountings, flammability Suspension

Component	Subcomponent Description
	<p>Engine, transmission, fuel type Instruments Electrical components and circuits Colour Glass – colour, type Movement – speed, direction, angle, acceleration, coasting, deceleration, turning, overtaking, reversing, force, vibration Liquids and fluids Type of impact – speed, angle, physical dimensions Active safety and other technology – antilock brakes, electronic stability control, adaptive cruise control, speed control, etc. <i>Note: * Generally applicable to motor vehicles, but may be applied to others</i></p>
<p>Road Infrastructure</p>	<p>Surface – friction, colour, smoothness, cracks, edges, shoulders, unsealed, pothole, concrete, asphalt, seal, manhole, drain, repair, cycle facility, drainage, grit, spills, footpaths – wet, dry, snow, ice, other Geometry – alignment geometry, curve, crest, dip, gradient, level, lanes, crossfall, physical dimensions, dual carriageway, passing lane, shoulder, median Signs, regulatory, advisory, pavement marking, signal, manned, speed limits, active/passive, reflectors, colour, illumination, reflectivity, access control, street design, bus lanes, roadworks Lighting – roadway, features and adjacent Obstacles – pylons, gutter, kerb, culvert, bridge, pole, other street furniture, safety barrier, tunnel, building, overpass, tree, bus facilities Intersection type – intersection, junction, roundabout, grade separation, merge, railway crossing, crosswalk or crossing point, angled, pedestrian crossing, island Road type – freeway, highway, city street, residential, rural, bridge, tunnel Miscellaneous – driveway, midblock, parked cars, stopped buses, lighting, glare, road debris, previous collision, landslides, work zones, tram / light rail Traffic volume, type, interaction Safety devices – guardrail, barrier, rest stop, fence, service area, route guidance, landslide protection Maintenance</p>
<p>Crash Response</p>	<p>Emergency and rescue services Crash reporting and incident management Health treatment – first aid, emergency treatment, injury treatment, Rehabilitation, permanent care and adaptation</p>
<p>Safety Management</p>	<p>Risk management – identification, assessment, countermeasures, revision Information – research, data, investigations, benchmarking Capability – skills, knowledge, experience, of all participants Capacity – financial, human, system, technology Systems – processes, structures, procedures, standards Integration – collaboration, coherence, synergy, co-ordination, optimisation Implementation – policy, planning, design, installation, maintenance, monitoring, revision Communication – content, contact, medium Culture – attitudes, beliefs, values, commitment</p>

The framework was applied to analyse both the components and policy tools identified and described in 58 road safety strategies from 22 countries dated from 2000 to 2015 that revealed the following:

- more than 90% of strategies focussed on road infrastructure, vehicles, human and safety management components;
- more than 90% of the strategies analysed included a leadership approach, integration, implementation, participation, funding, investment, regulation, enforcement, behaviour change, skills, expertise and capability, innovation, research, standards and guidelines;
- more than 50% of strategies included some actions regarding the social context, transport and land use context or response system;
- 25% or less of the road safety strategies engaged in changing the economic context, the natural environment, or the social context; and
- policy tools such as financial incentives, pricing, subsidies, industry change, competition and consumer choice were not commonly used, while taxes, fees and charges were only identified in three strategies.

Analysis revealed that road safety strategies have been increasing in complexity and diversity over time as more policy tools are being applied to more components. A few recent strategies either affect all components and/or employ all types of policy tools.

7.4 Additional potential approaches, techniques and concepts

As the Introduction to this thesis describes, frameworks for road safety have been used as a basis for road safety strategies for decades. However, successful achievement of road safety outcomes requires much more than a well-founded and described strategy, and new approaches may be required (Hovden et al., 2010; Wegman, 2017). Due to the broad research approach adopted in this thesis, several potential topics (approaches, techniques and concepts) became evident during the

course of this thesis that could complement the framework developed⁶. Each of these offers some potential for improving road safety and is therefore worthy of further research to determine whether it may be usefully applied. However, each of these would require extensive research as separate, significant and thorough investigations to determine potential applicability in road safety. Therefore, it is beyond the scope of this thesis to do so. Nevertheless, some of these topics warrant noting or further elaboration, albeit only at an introductory level.

The following general topics have been regularly and extensively applied in other domains with useful results, and are included in the final comprehensive framework in Chapter 9:

- **Actors** – individuals or entities with the capability to affect road safety, including government, agency, association or company (Rasmussen, 1997; Racioppi et al., 2004; Hollnagel, 2008; Stigson et al., 2008; Leveson, 2011a; Salmon et al., 2016);
- **Relationships** – interconnections between actors, components and/or policy tools that affect outcomes (Rasmussen, 1997; Ackoff, 1971; Leveson, 2004, 2011a; Racioppi et al., 2004; Stigson et al., 2008)
- **Principles** – to guide road safety improvements (OECD, 1997c; Tingvall, 1997; Peden et al., 2004; Racioppi et al., 2004; SRA, 2006; Vägverket, 2008; OECD/ITF, 2016a); and
- **Processes and management** – to ensure efficient and effective safety activities (particularly regarding strategy, planning and implementation) (OECD, 1990; OECD, 1997c; OECD, 2002; Zimolong and Elke, 2006; OECD/ITF, 2008; Holló et al., 2010).

The following more specific or detailed topics have also been regularly and extensively applied in other domains with useful results, and are noted here for further reference and potential research and application in future:

⁶ Note that Section 7.4 and 7.5 include further information and research that extends the results beyond that included in Paper VI.

- **Risk management** – a way of managing safety (Glendon and Waring, 1997; Rasmussen, 1997; Bluff, 2003; Bubbico et al., 2006; Crutchfield and Roughton, 2014a; Fernández-Muñiz, 2014; Jamroz et al., 2014; Kontogiannis et al., 2016);
- **Safety Case** – a way of managing safety (Kritzinger, 2006a; Hopkins, 2012; Sutton, 2012);
- **Safety culture** – a contribution of certain human factors to safety, including the related concept of safety climate (Sorensen, 2002; Kritzinger, 2006a; Leveson 2011a; Schneider et al., 2013; Crutchfield and Roughton, 2014b);
- **Safety Management Systems** – a particular way of managing safety (EU, 1997; SASNZ, 2001; Kritzinger, 2006b; Crutchfield and Roughton, 2014c);
- **Targets** – for road safety to describe objectives, the system's purpose and monitor progress (Elvik, 1993; OECD, 1997c; OECD, 2002; SRA, 2006; OECD/ITF, 2008; FHA, 2013); and
- **Vision** – for road safety to raise awareness that road trauma is socially unacceptable (OECD, 1997c; OECD, 2002; SRA, 2006; FHA, 2013).

The Introduction to this thesis raised several issues regarding these complementary topics. Some have different versions or detail, possibly inconsistent or unnecessary. Others have differing levels of detail. Paper I demonstrated that different safety domains offered alternatives for safety models or frameworks and their content. So, in a similar way, other domains may inform the topics identified here or provide better versions as Benner (1975 and 1985) suggested. It is possible that the alternatives are continuing to mature and may not yet be consistent or stable. It may be asked if these topics are to be applied, is there an underlying theory that provides a rationale and proven basis which OECD (1997b and 1997c) described the value of? In other words, are the topics suitable and valuable for their intended purpose (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000)? Finally, has the practical use of these topics and specific versions been demonstrated to have value? That is, they contribute to an improvement in road safety, and not merely reflect conjecture or opinion (Smeed, 1949).

Information and guidance is available for the first four topics: *actors'* activities, responsibilities and contributions; *relationships* between actors, components and policy tools; *principles* that can guide road safety strategies, and *processes* for strategy management, as described in more detail below. These requirements are then incorporated in principle into the framework developed, as described in the conclusions.

All the different parts of the framework will need to be rigorously applied to realise their value. For example, Salmon et al. (2017) describe the application of systems approaches to investigate the emerging problem of driving under the influence of drugs, either illicit or prescription. Their example illustrates several system characteristics including application of multiple policy tools, complex feed-forward and feedback relationships, societal factors and more sophisticated analytical processes. The framework can contribute to such assessments by guiding the researcher regarding actors, policy tools and components that are involved in the particular parts of the system that are being investigated.

7.4.1 Actors

As the Introduction to this thesis described, road safety strategies are complex, multifaceted and may be difficult to develop. Therefore, good guidance is likely to be valuable for any actor involved. Guidelines and manuals are available including *Towards Zero: Ambitious Road Safety Targets and the Safe System Approach* (OECD/ITF, 2008), *Strategic Highway Safety Plans: A champion's guidebook to saving lives* (FHA 2013), *Road Safety Manual: A guide for Practitioners* (PIARC, 2015), *Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System* (OECD/ITF, 2016a) and standards (ISO, 2012). At this stage the framework is at least generally consistent with this guidance material. However, this thesis challenges whether such documents incorporate adequate breadth and detail or not. Moreover, these documents provide little guidance regarding consistency, relationships between actions and application of frameworks by actors within road safety management.

The term 'actor' covers any individual entity whose actions can affect road safety, including government, agency, association, company or individual person (Rasmussen, 1997; Leveson, 2009). Actors may not recognise the effect of their actions on road safety, and may act wilfully or intentionally in ways that positively or negatively affect road safety outcomes (Salmon et al., 2015). Generally, actors that can improve road safety are described and are a focus of interest for policy and research (e.g. driver behaviour).

A hierarchy of actors (individuals and organisations) based on a complementary control system approach and more general systems theory (Rasmussen, 1997) has been proposed for industrial safety (Leveson, 2004, 2011b; Hollnagel, 2008) as summarised in Table 7.3. While there are clear differences between the descriptions, there are also significant similarities, despite the different safety domains. The descriptions have also become more detailed or mature over time. Considering and responding to how these actors behave could provide a valuable perspective to the proposed framework as a complementary approach. Further research and practice could investigate the relationships between individual actors with the policy tools and subcomponents in the framework. Doing so would be consistent with system theory and may increase the efficiency and effectiveness of road safety strategies.

Leveson (2011a) described a hierarchy of control in industrial situations to assist in identifying where and how to identify actions and therefore affect them to improve safety. Salmon et al. (2016) subsequently adapted this to describe actors affecting road safety in more detail. While these control hierarchies extend to individual staff in companies, they do not clearly extend to the level of users who are amongst the most important actors in road safety. Based on these earlier descriptions, a hierarchy of actors who can affect road safety can be implied and described, as shown in Table 7.4. This summary does not unduly lose the detail of the description, but extends previous descriptions for road safety to include users of the road transport system, as described in the components above.

Table 7.3. Alternative descriptions of actors affecting safety

Context and Source	Summary													
<p>Industrial Safety The socio-technical system Rasmussen (1997)</p>	<p>Government Regulators, Associations Company Management Staff</p>													
<p>Industrial Safety Hollnagel (2004)</p>	<p>Society (<i>morals, social norms</i>) Government Regulator Company Management Local workplace Individual</p>													
<p>Road Safety The key organisations influencing policy development Peden et al. (2004)</p>	<p>Government and legislative bodies (<i>e.g. transport, public health, education, justice, finance</i>) Users/citizens Industry Police NGO's, Special interest groups Professionals Media</p>													
<p>Safety Management A hierarchical safety control structure Leveson (2011b)</p>	<p>Congress and legislatures Government regulatory agencies, industry associations, user associations, unions, insurance companies, courts Company management</p> <table border="1" data-bbox="608 1323 1401 1574"> <thead> <tr> <th data-bbox="608 1323 1002 1368"><u>System Operations:</u></th> <th data-bbox="1002 1323 1401 1368"><u>System Development:</u></th> </tr> </thead> <tbody> <tr> <td data-bbox="608 1368 1002 1413">Operations management</td> <td data-bbox="1002 1368 1401 1413">Project management</td> </tr> <tr> <td data-bbox="608 1413 1002 1458">Operating process</td> <td data-bbox="1002 1413 1401 1458">Design, documentation</td> </tr> <tr> <td data-bbox="608 1458 1002 1503">Maintenance and evolution</td> <td data-bbox="1002 1458 1401 1503">Implementation and assurance</td> </tr> <tr> <td data-bbox="608 1503 1002 1547">Manufacturing management</td> <td></td> </tr> <tr> <td data-bbox="608 1547 1002 1574">Maintenance and evolution</td> <td></td> </tr> </tbody> </table>		<u>System Operations:</u>	<u>System Development:</u>	Operations management	Project management	Operating process	Design, documentation	Maintenance and evolution	Implementation and assurance	Manufacturing management		Maintenance and evolution	
<u>System Operations:</u>	<u>System Development:</u>													
Operations management	Project management													
Operating process	Design, documentation													
Maintenance and evolution	Implementation and assurance													
Manufacturing management														
Maintenance and evolution														

Table 7.4. Hierarchy of actors in road safety

Level of Actor	Actor Group	Examples of individual actors
Parliament & Legislatures ↑ ↓	National, State/Regional, Local Ministers and elected representatives Ministerial Councils Inquiries	
Government agencies (may be several levels of government) ↑ ↓	Strategy, policy and planning departments	Transport, Police, road safety, treasury, highways, infrastructure, health, etc.
	Co-operatives	Joint agencies, OECD, EU, International Transport Forum, National Transport Commission, Austroads, etc.
	Regulators	Police, road safety, workplace safety, auditors, ombudsmen, etc.
	Courts	
	Education	Professional, trade, universities
	Research	Universities, Cooperative Research Centres, CSIRO, industry, etc.
Industry and other groups ↑ ↓	Unions	
	Standards and certification organisations	ISO, Standards Australia, Transport Certification Australia, etc.
	Industry and professional associations	Australasian College of Road Safety, Engineers Australia, Roads Australia, FIA, Local government associations, etc.
	Community groups	
Operations and Delivery ↑ ↓	Government departments	Construction, operations, maintenance, enforcement, health, etc.
	Individual companies	Transport, property, business, engineering, vehicles, insurance, medical, suppliers, information and software, service providers, specialist consultants, etc.
	Information media	Electronic, print, social media, etc.
	Project managers and teams	Planning, design, procurement, construction, maintenance, operations, emergency and incident response, etc.
Individuals and Users	Employees	Managers, planners, designers, operators, etc. All professional and technical disciplines All work capabilities
	Transport system users	<i>see note</i>
	Beneficiaries of transport	Freight forwarders, 'downstream' services (e.g. tourism, business, industry, retail, commerce, etc.)
Note: There is a multitude of differentiation or dimensions of individuals and users. Mode segregation is obvious and commonly applied (driver, passenger, cyclist, etc.) as in the components above. However, numerous other segregations are possible, such as by location (city, suburb, rural, remote), by trip purpose (business, recreation, education, journey to work), freight or people movement, etc.		

7.4.2 Relationships

One of the fundamental concepts of system theory is the relationships between components (Ackoff, 1971; Leveson, 2004, 2011a). This thesis has described the previously recognised sequence of interaction over time, as context, crash and consequence. In systems terms, this is called feed forward. However, as Leveson (2004) describes:

"Accident models that consider the entire socio-technical system must treat the system as a whole, taking into account all facets relating the social to the technical aspects, and not just the parts taken separately. They must consider the relationships between the parts of systems: how they interact and fit together."
(Leveson, 2004, p249).

In addition, feedback interaction has been identified as affecting the system outcomes (Leveson, 2011a) and over a longer period of time. In economics terms the immediate sequence is called the 'short run'. The system response to the short run effects over an extended period is called the 'long run', during which time the system adapts to the changes (or 'stimulus'). Leveson (2011a) emphasised identification and understanding all the causal factors, both direct and indirect, contributing to an industrial accident, and the relationship between them, in order to explain why such accidents occur, so that future losses may be prevented.

The focus of this thesis is to extend the application of system theory to road safety, primarily in the areas of policy tools and components. Relationships exist within and between policy tools, components and actors. Positive relationships (interdependent and complementary) are fundamental to a system achieving its purpose. Negative relationships (independent or conflicting) may exist, but are inconsistent with a system achieving its purpose. Relationships are recognised as an essential element of the road safety system, but are too complex to investigate in any detail in this thesis. System theory recognises the positive relationships, but may not always recognise negative relationships.

Safety domains commonly recognise the short run, linear sequence of events that Leveson (2004) recognises can work well in some circumstances, such as simple systems with physical component failures. However, this simple approach can limit safety investigations in complex and dynamic circumstances that have become more common. In practice, interactions can be very complex, thereby introducing compounding effects. Apart from the linear sequential process, there may be interactions between several components at the same time and the outcomes dependent on the strength or sequence of each of these. As this thesis described, in addition to the planned or observed sequence of events, there can be feedback mechanisms affecting earlier parts of the process. These interactions can be positive or negative in respect of achieving outcomes. This complexity has been researched via complex analytics, such as System Dynamics (TRKC, 2004; Leveson, 2011a) although rarely in transport or safety (Goh et al., 2010; McClure et al., 2015). In a true system, the effect of these relationships with respect to the components is complementary, where two components together achieve greater outcomes than each in isolation.

Components may not always operate as a system to achieve the intended objectives (Racioppi et al., 2004; Stigson et al., 2008), a situation rarely described in the literature. Alternatively, there may be no relationship at all with the components operating totally independently. Components may be in conflict, where the operation of, or change in, one component negatively affects another component, even if the outcome as a whole improves. Such negative interactions are inconsistent with the components then comprising a system.

The same can occur between actors or policy tools. Microeconomic theory is based on individuals operating to maximise their own personal utility, or value. System theory is based on cooperation between components and actors. However, in real situations, there are 'winners' and 'losers', when policy tools are applied that result in situations like 'the tragedy of the commons' and 'gaming' between actors. Sometimes these conflicts, which can be characterised as inequity, are mitigated or managed by governments that have the highest level of control.

As an example, consider the case of reducing vehicle speed in order to reduce crash frequency and severity. To achieve this most efficiently and effectively may require the application of complementary policy tools; speed signs, road modifications, driver information, and enforcement. The application of these may need actions by actors that are responsible, capable and in control, including Police, road authorities, traffic or transport agencies. Others may complement these activities, such as motoring organisations, or nearby land uses, such as schools or shopping centres.

Given the number of policy tools, components (and sub-components) and actors, the number of potential relationships is very large. Therefore, there appears to be a potentially large and difficult task to research this part of the road safety system. There may or may not be value in doing so in terms of applying any results to achieve road safety outcomes.

7.4.3 Processes

Processes are a series of complementary activities to achieve an outcome. Since time occurs in one direction, processes often occur linearly and sequentially. However, different activities in processes can occur simultaneously. Processes occur in many situations including management, research, policy deployment and implementation, as the examples below describe. As described in the framework, Safety Management is an essential component required to achieve road safety outcomes.

Management has been described as activities that occur in a process, or according to a hierarchy. Several similar hierarchies have been suggested for road safety management (LTSA, 2000; ETSC, 2001; Koornstra et al., 2002; OECD/ITF, 2008), such as the ones illustrated in Figure 7.3 (Holló et al., 2010) and Figure 7.4 (Zimolong and Elke, 2006).

Figure 7.3. A typical road safety system hierarchy

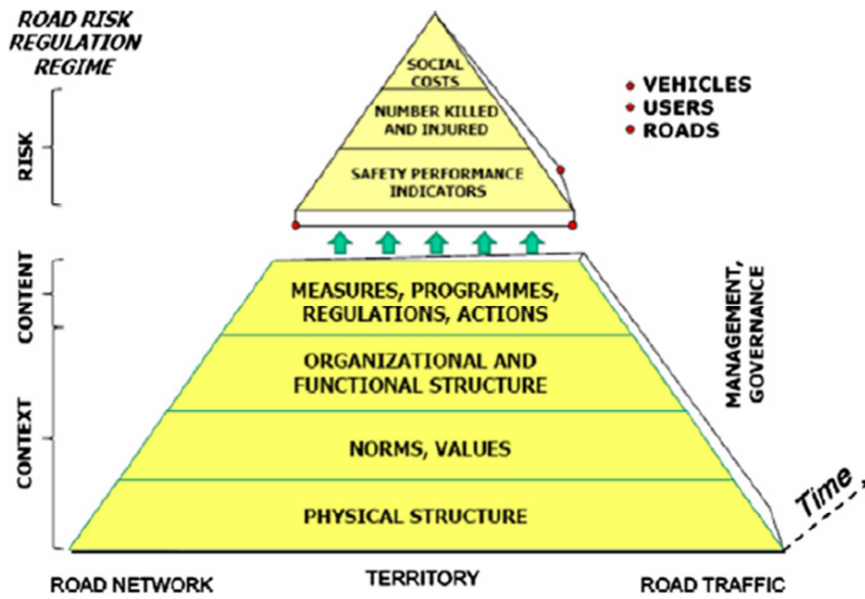
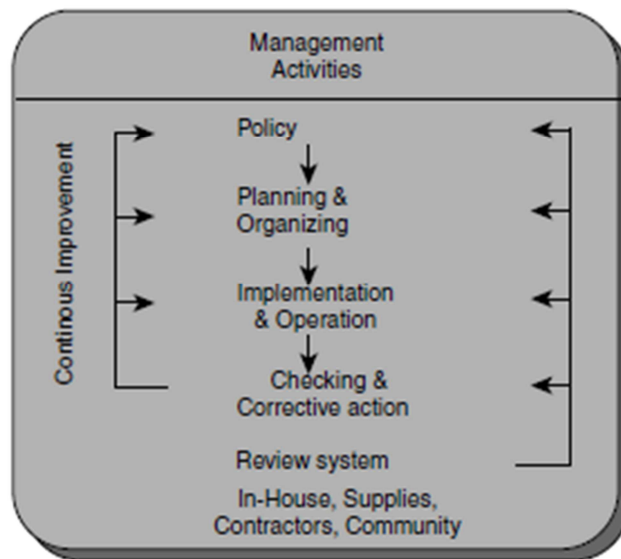


Figure 7.4. A management control cycle system



Activities that are sometimes described as a process for safety management are diverse, such as those from other safety domains summarised in Table 7.5. Road safety management occurs at several levels, so it can be argued that clear management processes must be practised, in order for the actors to be focussed on the components to efficiently and effectively develop and implement policy tools to improve road safety outcomes. Different approaches to road safety management are summarised in Table 7.6.

Table 7.5. Alternative safety management approaches and processes

Context and Source	Summary of Safety Management	
<p>Risk Management Glendon and Waring (1997)</p>	<p>Pure risk topic and Speculative risk topic Hazards/threats – objects of risk management Contexts Risk Management Objectives Risk management methods</p>	
	<p><u>Management System Model</u> Policy, strategy, objectives Organising, planning, resourcing Implementation Monitoring and measuring performance Audits, Reviews</p>	<p><u>Risk Management Process</u> Hazard/threat identification Risk analysis and assessment Risk strategies</p>
<p>Occupational safety Kjellén (2000)</p>	<p>Leadership and commitment Policy and strategic objectives Organisation, resources and documentation Evaluation and risk management Planning for activities, changes and emergencies Implementation and monitoring Auditing and review</p>	
<p>Industrial safety Risk assessment Hollnagel (2004)</p>	<p>Characterise the context Identify risks (accident types) Analyse risks (accident potential) Decide on countermeasures</p>	
<p>Industrial safety System safety process components Leveson (2011a)</p>	<p>Leadership → Culture → Behaviour Policy Safety Management Plan Safety Information System Safety Control Structure - responsibility, accountability, authority, controls - feedback channels Continual Improvement</p>	
<p>Aeronautics risk analysis NASA Independent Technical Authority (ITA) Leveson (2011a)</p>	<p>Preliminary Hazard Analysis</p>	<p>System hazards Safety constraints System requirements</p>
	<p>Model Control Structure</p>	<p>Roles and responsibilities Feedback mechanisms</p>
	<p>Map Requirements to Responsibilities</p>	<p>Gap analysis</p>
	<p>Hazard Analysis</p>	<p>Basic risks Coordination risks</p>
	<p>Categorise Risks</p>	<p>Intermediate and longer term</p>
	<p>Causal Analysis</p>	<p>Potential causes of risks</p>
	<p>Findings and Recommendations</p>	<p>Policy Structural Risk mitigation strategies</p>

Table 7.6. Alternative road safety management approaches and processes

Context and Source	Summary of Safety Management	
<p>Road safety OECD (1997)</p>	<p>Road/traffic safety ↓</p>	<ul style="list-style-type: none"> • Vision • Targets
	<p>Problem identification/ characterisation ↓</p>	<ul style="list-style-type: none"> • Identify road safety problem areas/issues <ul style="list-style-type: none"> - Vehicle factors - Human factors - Roadway factors
	<p>Targeted road safety programme development ↓</p>	<ul style="list-style-type: none"> • Road safety indicators • Organise institutional roles • Integrate safety/other transport policies
	<p>Road safety countermeasure options analysis ↓</p>	<ul style="list-style-type: none"> • Determine set of countermeasures • Delegate responsibility and countermeasures • Link budgets to costs and benefits • Study countermeasures cost/effect
	<p>Targeted road safety programme implementation ↓</p>	<ul style="list-style-type: none"> • Assemble key data • Analyse implementation problems • Marketing countermeasures • Compliance/enforcement
	<p>Evaluation and monitoring</p>	<ul style="list-style-type: none"> • Independent follow up
<p>Road safety Information transfer and learning process OECD (1990)</p>	<p>Local policy and decision-making Assessment of traffic safety targets Goal setting Design of an integrated programme Operation and implementation Evaluation</p>	
<p>Road safety OECD (2002)</p>	<p>Formulation of vision or philosophy Problem analysis Target setting Developing countermeasures Socio-economic appraisals Safety programmes Evaluation and monitoring</p>	
<p>Road safety OECD/ITF (2008)</p>	<p>Strategic results focus to: - Develop management capacity - Provide a comprehensive strategy with targets - Deliver interventions - Review performance Coordination of key agencies to develop and deliver policy and strategy Effective legislation Adequate funding, resource allocation and institutional management Promotion of road safety Monitoring and evaluation to measure progress Proactive research and development and knowledge transfer</p>	

While processes have been applied to road safety strategies and management generally, their value, efficiency and effectiveness have not been well described. While these processes, their use and their utility is clearly accepted, they have not been well researched in terms of underlying theories and practice in road safety. It may be, as Benner (1985) found for investigations, that there are too many different models, and some are less effective and only a few are required, perhaps for different purposes or contexts. Therefore, further research may assist in improving road safety management processes.

7.4.4 Principles for road safety

Principles for safety management are a broad way of behaving that are expected to be followed, that reflect, or are reflected in, values, beliefs, norms, and other actions in an organisation (Hine et al., 1999). Principles are regarded as being important to guide decision making and actions. Saleh et al. (2014) developed broadly applicable system safety principles to be independent of the context and technology. The four examples of safety principles in Table 7.7 illustrate that they can be diverse. The reasons for differences are not clear, partly because they have not necessarily been grounded in theory and proven in practice, or they may relate to specific contexts. Further research and development of principles may be required to ensure their efficiency and effectiveness.

Principles to guide road safety management have been clarified and incorporated into many road safety strategies over recent years, primarily based on *Vision Zero* (SRA, 2006; Belin et al., 2011) and the Tylösand declaration (Vägverket, 2008). These principles describe the basis of other strategic approaches to road safety (Peden et al., 2004; Racioppi et al., 2004; SRA, 2006; OECD/ITF, 2016a), including contemporary and leading road safety strategies (Wegman and Aarts, 2006; MOT, 2010; ATC, 2011). Since the framework developed is consistent with previous approaches to improving road safety, it is likely that it is consistent with contemporary road safety principles. However, this has not been explicitly investigated considered or tested.

Table 7.7. Alternative principles to improve safety

Context and Source	Summary of Principles
<p>Organisational safety Hine et al. (1999)</p>	<ol style="list-style-type: none"> 1. All injuries are preventable 2. Employee involvement is essential 3. Management is responsible for safety 4. Working safely is a condition of employment 5. All operating exposures can be safe-guarded 6. Training is essential 7. Safety is good business
<p>Road safety Peden et al. (2004)</p>	<ol style="list-style-type: none"> 1. Road crash injury is largely preventable and predictable; it is a human-made problem amenable to rational analysis and countermeasure 2. Road safety is a multisectoral issue and a public health issue – all sectors, including health, need to be fully engaged in responsibility, activity and advocacy for road crash injury prevention 3. Common driving errors and common pedestrian behaviour should not lead to death and serious injury – the traffic system should help users to cope with increasingly demanding conditions 4. The vulnerability of the human body should be a limiting design parameter for the traffic system and speed management is central 5. Road crash injury is a social equity issue – equal protection to all road users should be aimed for since non-motor vehicle users bear a disproportionate share of road injury and risk 6. Technology transfer from high-income to low-income countries needs to fit local conditions and should address research-based local needs 7. Local knowledge needs to inform the implementation of local solutions
<p>Industrial safety Saleh et al. (2014)</p>	<ol style="list-style-type: none"> 1. Background information: accident sequence and hazard level 2. The fail-safe safety principle 3. The safety margins (or safety reserves) principle 4. The un-graduated response principle: rules of engagements with hazards 5. The defence-in-depth principle 6. The observability-in-depth principle
<p>Total safety management Kontogiannis et al. (2016)</p>	<ol style="list-style-type: none"> 1. Risk management (RM) should create and protect business values 2. RM should be central to the organisation's processes 3. All decision making within the organisation involves the explicit consideration of risks and the application of risk management to some appropriate degree 4. RM should be based on best available information 5. Continual communication with external and internal stakeholders, including comprehensive reporting of safety performance 6. RM should be comprehensive and clear about accountability for risks, controls, and risk treatment processes 7. It should be systematic, structured, and applied to critical activities in a timely manner 8. It should take into account human and cultural factors 9. It must be dynamic, iterative, and responsive to change 10. It must facilitate continual improvement of the organisation

OECD/ITF (2016a) describes these principles underpinning a Safe System as:

- *"People make mistakes that can lead to road crashes.*
- *The human body has a limited physical ability to tolerate crash forces before harm occurs.*
- *A shared responsibility exists amongst those who design, build, manage and use roads and vehicles and provide post-crash care to prevent crashes resulting in serious injury or death.*
- *All parts of the system must be strengthened to multiply their effects; and if one part fails, road users are still protected."* (OECD/ITF, 2016a, p26).

However, Paper III described that principles in road safety strategies are diverse. Leading road safety strategies include principles similar to those described in OECD/ITF (2016a). While most were similar there were also some differences. A theoretical basis for principles is not evident and their utility has not been established. It is not clear what the objectives of principles are, how they can be best used, or their value. Nevertheless, road safety literature describes them as being useful in providing guidance for the development of strategies and policy tools, so they are recognised here.

7.4.5 Discussion on additional potential approaches, techniques and concepts

While many road safety actions are planned, many others occur by different means, or at different times, or to different extents than are planned. Good system management is flexible and adaptable to exploit opportunities, or otherwise respond to threats to success whenever and however these may arise, even though they are not planned. For instance, Bugeja et al. (2011) suggest that problem recognition, development of injury prevention policy and political will are the three conditions that are required to create the 'windows of opportunity' for public policy success. There have been many changes to road safety that apparently have occurred due to several motivations (perhaps necessity, altruism or profit) and by various paths (perhaps by adaptation from other domains, by design, by opportunity or by novel creativity). The framework presented provides an opportunity to stimulate either planned or opportunistic innovation, by providing

the policy maker, planner or researcher with a clearer and more complete description of the system as a whole that can therefore be considered to investigate new, different and strategic changes that might be possible under any prevailing circumstances, as opposed to simple, incremental and operational improvements.

In the course of this thesis 10 approaches, techniques or concepts emerged as being potentially useful to road safety management, particularly from other safety domains. Introductory information is provided for four topics: actors, relationships, processes and principles. However, questions remain regarding the validity and utility of these topics.

The research in this thesis is based on theory, research, objective analysis and evidence in practical application. This approach raises several questions regarding the additional topics introduced above that would be valuable to answer, including whether the topics are:

- uniform, stable, and mature?
- consistent across domains?
- relevant or transferable from one domain to another?
- proven to be useful and therefore valid in practice?
- based on sound and relevant theory?

For some of the topics these questions have clearly been addressed. For instance, the topic of performance targets has been subject to research and debate regarding data accuracy and future performance, alternative performance measures and practical application (ETSC, 2001; Hakkert et al., 2007; Holló et al., 2010; Hughes and Hopkins, 2011; Hughes et al., 2011; Papadimitriou and Yannis, 2013). However, other topics, such as principles appear to lack robust foundations, are diverse and vague, and have not had value demonstrated in practice. Therefore, further research is required on each of these to confirm their applicability and utility on road safety.

7.5 Road safety strategies for future transport systems and contexts

The nature of road safety strategies has been retrospective and reactive, as earlier authors have identified, and this thesis has described in more detail. The process by which road safety strategies are developed is based on analysis of past crash history at both the macro and micro levels (Wegman, 2017). Road safety strategies are developed by analysing the past and attempting to improve it, and since they incorporate little economic, transport, land use or social contextual information or analysis, they have little ability to foresee a different future, except one extrapolated from the past (Hollnagel, 2008; Lundberg et al., 2009). However, it is clear that the current contexts and systems are already different to those in the past, and the future will be even more different. Therefore, in future there is a need to make the most of opportunities that occur as these contexts change, in order to improve road safety, and also protect against new adverse consequences that have not occurred in the past.

Recent commentators have described that the future will be much more dynamic; volatile, uncertain, complex, and ambiguous (or VUCA) (Bennett and Lemoine, 2014; Solomon and Ertel, 2014). This environment pervades society, technology, business and transport, and will continue to escalate. Convergence and interconnection between these sectors is likely to drive new arrangements that are structurally different and disruptive to those in the past. De Greene (1993) summarised how the current and future context has changed before arguing for a new paradigm in policymaking incorporating a systems approach:

"In short: theories, models, philosophies, and methods stemming from an earlier era of scientific thought and developed for simpler, mostly physical systems are largely inapplicable for a mind, a society, an economy, or an ecosystem."

(De Greene, 1993, p7).

Since the commencement of this thesis, two new changes have clearly emerged that will dramatically impact road safety in the future; systemic contextual disruption and new services. This chapter introduces these issues, the relevance to

this thesis, and future research that may be important taking these issues into account. Consideration and analysis of these changes from a policy and practice perspectives are well beyond the scope of any thesis. However, they should be recognised for future consideration.

Rasmussen (1997) similarly identified changing circumstances for industrial safety:

"Compared to the stable conditions of the past, the present dynamic society brings with it some dramatic changes in the conditions of industrial risk management". (Rasmussen, 1997, p186).

In describing the context for industrial safety management, Rasmussen and Svedung (2000) describe four key factors generating the dynamic conditions:

- the pace of change of technology in all forms of transport is very fast;
- the steadily increasing scale of industrial installations;
- increasing integration and interconnection of complex and sophisticated systems; and
- the business environment becoming more aggressive and competitive.

Leveson (2011a) expanded on these by adding:

- reduced ability to learn from experience;
- changing nature of accidents;
- new types of hazards;
- decreasing tolerance for single accidents;
- difficulty in selecting priorities and making tradeoffs; and
- changing regulatory and public views of safety;

Rasmussen (1997) suggested these changes need to be accounted for in modelling for safety, and the same would appear to be true for safety management in general. Observation suggests that the context and circumstances described above are evident in the changing nature of transport systems as described below. Therefore, transport management, and road safety in particular, must be prepared to respond to these changes, engage in the dynamic environment and take the opportunities that these changes bring to improve road safety.

There are many facets to future changes, such as when they may occur, the complexity of transitions with competing or incompatible technologies, who 'wins' and 'loses', the role and responsibility of governments, what sectors will be changed, and so on. Safety may not be the only outcome affected, as there may be many economic and social effects (such as privacy, security, insurance, etc.). The multitude of effects may bring moral dilemmas, such as choosing between competing outcomes, even within the same type of outcome (e.g. safety, economic or environmental). Therefore, a good understanding of relevant systems, including safety, can help guide choices to achieve good outcomes.

7.5.1 New futures impacting road safety

Our whole context, let alone for a single issue like road safety, is constantly changing (Rasmussen and Svedung, 2000; Leveson, 2011a; Hakkert and Gitelman, 2014). The first major changes are systemic and include a range of ubiquitous technology, business and operational changes to transport, society and the economy, that are often called disruptions. So, according to De Greene (1993), road safety needs to be able to respond with appropriate theories, models, and practices that can continue to result in improvements to road safety.

Social, economic and technology contexts are subject to continual change with new and different users' preferences for travel, including less car travel and more by public transport, at least compared to recent decades in the newer USA, Canadian and Australian cities (Arup 2014; Atkins, 2015; USDOT, 2016; McKenzie, 2016). Demographics, urban structures and users' behaviour are far more diverse than the relatively homogenous communities of the 20th century, whether they be old style cities, such as in Europe, or new world cities in USA, Canada, South Africa, New Zealand, Australia or elsewhere. New technologies, such as renewable energy, cheap communications, and automation will drive a range of applications in business, industry and transport (Manyika et al., 2013; Anderson et al., 2016). Therefore, responses, such as transport planning, are likely to be very different according to these diverse changes. General approaches and principles, such as

frameworks and processes, may be transferable, but specific responses may not easily be (Clayton Utz, 2016; NHTSA, 2016; USDOT, 2016).

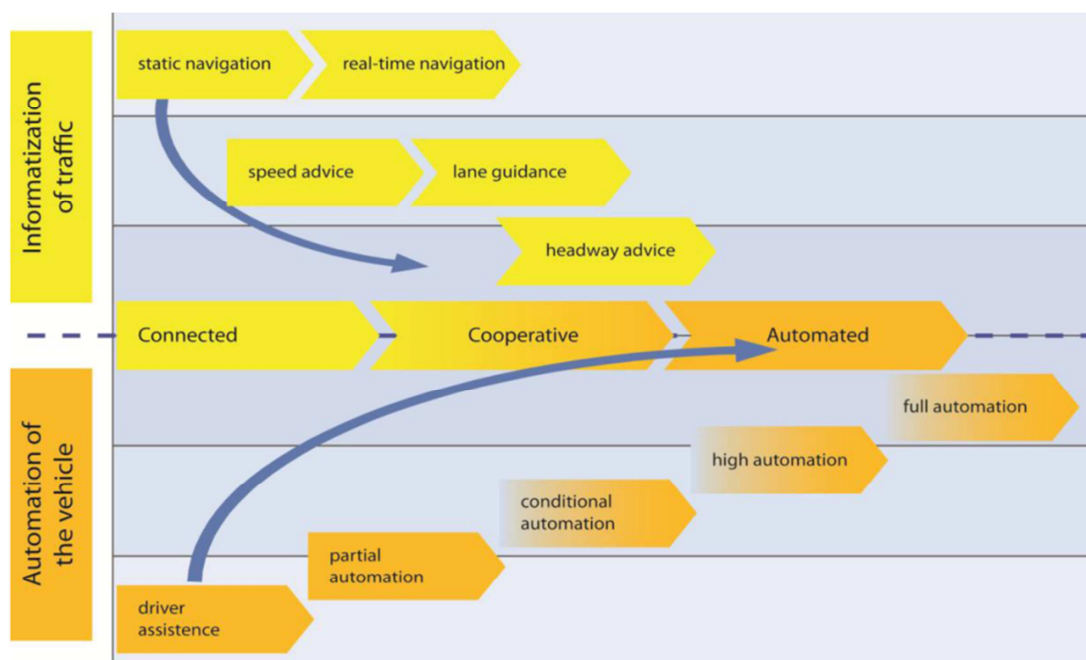
The second change is the specific effects and opportunities these disruptions will bring to transport in the forms of autonomous⁷ vehicles and mobility-as-a-service (MaaS) (Fishman, 2012; Deloitte, 2015; Holmberg et al., 2015; TSC, 2016; USDOT, 2016). These changes to services are occurring so quickly that they cannot be accommodated by considering the future as a natural extension of the past. They also change transport so fundamentally that existing transport management is likely to be inadequate to deal with them efficiently and effectively. Transport has changed rather slowly and incrementally over the past 100 years. The basic components of drivers, vehicles and roads remain the same, although the latter two are now much better engineered. However, the future promises to be very different in terms of information systems, vehicles and infrastructure, communications, and vehicle autonomy. Several technologies and applications have been developing very quickly and it appears they will continue to do so. These new technologies have developed independently, but are complementary for transport systems, and are therefore converging to their natural integrated use (Fishman, 2012), as shown in Figure 7.5 (EU, 2016) and described as connected, cooperative and automated car driving developments coming together to benefit society.

These changes will drive new business models for cheap, shared fleets, on-demand transport and individualised services, such as Mobility-as-a-Service (or MaaS⁸) and autonomous (and eventually driverless) vehicles that meets the mobility requirements of a customer.

⁷ The terms for new vehicles with increasing automation are not yet clear. There is a continuum of levels of automation, which at the basic level might include applications such as automatic transmissions, cruise control and automated functions, such as hands-free parking. At the furthest level is self-driving vehicles, sometimes called driverless, autonomous or connected vehicles.

⁸ Mobility-as-a-Service (MaaS) may be defined as using a digital interface (such as a smart phone) to source and manage an individual's transport related service requirement(s) (TSC, 2016). However, this is a new idea which should not be narrowly and precisely defined as it will change in future (Holmberg et al., 2015).

Figure 7.5. Convergence of technologies affecting future car driving



New ICTE⁹ technologies have been introduced to vehicles and roads since their infancy early last century. One view is that the convergence of several technologies in coming years will fundamentally change transport in ways that are at least difficult to comprehend. Another view is that these changes, even if they represent acceleration in deployment, are part of the long term changes that have constantly been occurring (Litman 2014). Intelligent Vehicle Highway Systems (IVHS as it was then known) and electronic technologies in cars were introduced in the 1970's and 1980's. From the 1990's these became known as transport telematics and Intelligent Transport System (ITS) (IRF, 2012). The new road transport technologies are expected to (eventually) eliminate driver error, traffic signs and signals, on-road enforcement and speeding, but perhaps some hazards and failures are not easily eliminated by vehicle automation alone, such as straying wild animals, avalanches, or falling trees? Maybe new failures will continue to occur, such as vehicle tampering and technology failures? Given that the age of the vehicle fleet in many

⁹ The term 'technology' is commonly viewed as Information Communication Technology (ICT). However, much of the advances in ITS, telematics, vehicle automation and MaaS are equally due to electronic technologies, particularly regarding transducers (sensors, actuators, etc.) which interface between the ICT and the physical and human worlds (Anderson et al., 2016). Examples include touch screens, virtual reality displays, brake actuators and throttle controllers. Therefore ICTE has been used here to include electronic technology.

jurisdictions is around 10 years, there will certainly be a long transition period before even the majority of vehicles have significant levels of automation. There will also be challenges caused by incremental introduction of partial automation, prior to fully autonomous vehicles and the mixing of vehicles with automation and those without (Litman, 2014).

7.5.2 Considerations for future application

These perspectives of the future appear to have not yet been commonly taken up in the academic road safety literature. It seems unlikely that the road safety approaches and strategies of the past can relate to such system components or changes that do not exist in current frameworks. The framework presented in Paper VI implicitly includes aspects of this new future, including transport context (transport alternatives, company operations, accessibility and transport integration), legal (regulation), social context (social norms, traditions), human (driving process, capability), vehicles (active safety and other technology), road infrastructure (active signs and signals, safety devices), crash response (reporting and incident management) and safety management (information, technology capacity, communication). So, the framework for road safety developed in this thesis offers the opportunity for future road safety strategies to accommodate the new technologies and contexts, as well as the policy tools by which they can be managed.

The rational technical management approaches of the past are unlikely to be capable of dealing with this new future (APSC 2007, Head and Alford, 2013). The changes may well surpass the capability of governments to manage because they are beyond the traditional capabilities, policy tools or power of governments. Because these new systems do not operate as they did in the past, they are not a good fit with traditional government control, which must recognise the new expansive nature and disruptive character to respond with new policy tools. Preferably, governments should instead respond by embracing, engaging and influencing these new developments.

While the impact of specific social, economic and technology changes are beyond the scope of this thesis, they are not omitted or excluded from the framework in principle. Whereas these changes are also beyond existing road safety strategies, the framework developed in this thesis implicitly covers these perspectives by including the social, economic, and transport system contexts. However, the changes already evident, and others emerging, should be recognised for future consideration in road safety strategy development, research, policy, and practice.

7.6 Conclusions

Paper VI developed a framework for road safety strategies based on a typology developed from previous road safety and policy theory, research and practice, as summarised in Figure 7.1. The framework positively responds to several specific challenges and criticisms previously raised. The framework described nine mutually interacting components (with 75 subcomponents) that contribute to crashes and 10 generic policy tools that can be applied to reduce the outcomes of these crashes. Compared to previous road safety handbooks, guidelines, standards, research and strategy, this framework is more comprehensive, in terms of both breadth and number of components and policy tools, than any other previous description applied to improve road safety.

A systematic research methodology was adopted to take a broad approach to develop the framework (Hancock and Bezold, 1994; Voros, 2003). The methodology overcame narrow thinking previously evident in road safety strategies (Hollnagel, 2008; Hovden et al., 2010). In doing so, the pitfalls of *What-You-Look-For-Is-What-You-Find*, and *What-You-Find-Is-What-You-Fix* (Hollnagel, 2008; Lundberg et al., 2009) were avoided. The research successfully searched for policy tools and components not commonly identified.

The framework with its detailed content is consistent with previous approaches that have been demonstrated to be effective in appropriate circumstances, thereby demonstrating its legitimacy. The fundamental sequence of interactions described

in the framework; context → crash → consequence, is consistent with the earlier precrash, crash and postcrash phases (Haddon, 1980a).

The categories of policy tools – incentives, disincentives and influence – are consistent with previous rationales, such as those presented by Vedung (2003), Elvik et al., (2009) and Bliss and Breen (2012), and contemporary road safety strategies four E's (FHA 2013) and Safe Systems descriptions (Wegman et al., n.d.; Koornstra et al., 2002; MOT, 2010; Paper II, Hughes et al., 2015a). The individual applications of the policy tools may overlap since the distinction between them is not always clear, and an action may have multiple effects. For instance, changing the behaviour of young drivers may be achieved by changing their social norms, perhaps with better parent skills in talking to their children. Doing so covers aspects of both the human and the social context components, as well as the behaviour change and capabilities policy tools.

The categorisation of components in the framework into transport and land use, economic, social, natural environment, safety management, road infrastructure, vehicles, human, and response system is consistent with the previous approaches (Haddon, 1980a), including Safe Systems descriptions (Wegman et al., n.d.; Koornstra et al., 2002; MOT, 2010; Paper II, Hughes et al., 2015a). However, the framework importantly extends previous categories, particularly in the context phase. Another extension recognises the effects of the natural environment on both the context and crash phases that had not previously been described in frameworks. Similarly, safety management is clearly identified and recognised as affecting all three context, crash and consequence phases.

With its detailed descriptions, the framework covers the complexity of road safety with its multifaceted and interconnected factors, influences, interrelationships, components and countermeasures. In doing so, it recognises and addresses the full range of factors and influences that affect outcomes (Smeed, 1949; Peden et al., 2004). It also offers a new perspective and comprehensive approach with the

potential for improving road safety strategies (Benner, 1975, 1985; May et al., 2008; Lundberg et al., 2009; Hovden et al., 2010; May et al., 2011).

The framework can be assessed for its utility, and the outcomes of applying the framework can be measured. Paper V described appropriate measurement of the outcomes of the strategy, if applied and that data are available for measuring outcomes. Therefore, the framework can be tested (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013). The framework responds very positively to the weaknesses Benner (1985) found, by being highly consistent compared with the desirable evaluation criteria for road safety models, as illustrated in Table 7.8.

The framework presented conforms to Kjellén and Larsson's (1981) criteria for occupational accident models. Since it is derived from previous perspectives that have been successful, it is likely to be suitable for the purpose of improving road safety. It is designed to be easy to understand, since it can be described in simple forms. It is intended to be relevant to address the continuing challenges that governments face to improve road safety. With its detailed descriptions, it completely covers all the relevant policy tools, and components. It is therefore likely to be suitable for prevention of future crashes (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000).

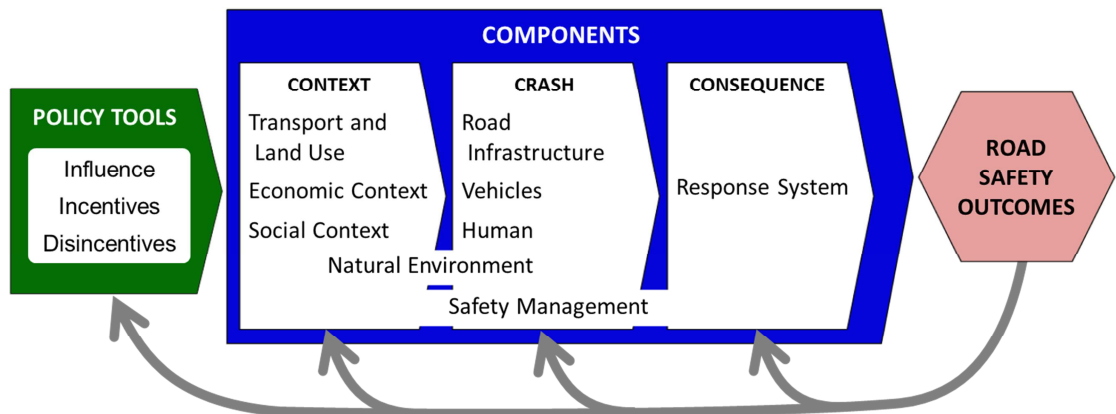
Table 7.8. Comparison between the comprehensive framework developed and model assessment criteria

Criteria	Requirements
Realistic	The framework represents reality, and the observed nature of the crashes The framework represents both sequential and concurrent events and their interactions over time The framework represents the context in which accidents occur
Definitive	The framework identifies the information required to describe crashes that should drive investigations, analysis, countermeasures and strategy The framework uses definitive, descriptive building blocks
Satisfying	Application of the framework has the potential to contribute to demonstrable achievement of government objectives
Comprehensive	The framework encompasses the development and consequences of crashes The framework defines the beginning and end of crashes with a complete description of context, components and policies that can be applied Use of the framework has the potential to help avoid ambiguity, equivocation, or gaps in understanding
Disciplining	The framework is a technically sound framework incorporating building blocks for all stakeholders to contribute to
Consistent	The framework is consistent with current theory and provides consistency with government safety objectives and programs The framework can provide guidance for consistent high quality road safety strategies
Direct	The framework provides for identification of context and components that contribute to safety problems in ways that provide options for countermeasures
Functional	The framework provides functional links to countermeasures, and makes it possible to link crash descriptions to aid identification of countermeasures that result in improved road safety performance
Noncausal	The framework provides a full description of crashes, showing interactions among all components The framework is technically supported and does not oversimplify or apportion blame
Visible	The framework enables policy developers and others to see the relevance of the model to all crashes easily and credibly The framework describes readily visible interactions, is easy to comprehend and is credible to the public and victims as well as policy developers

The framework developed is highly consistent with systems theory. Figure 7.6 illustrates the concepts incorporated in the framework based on systems theory and approaches (von Bertalanffy, 1968; Ackoff, 1971; Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009, 2011a) that Michaels (1963) and Kjellén and Larsson

(1981) sought, but were not well applied in road safety (Salmon and Lenné, 2015). Specifically, the framework incorporates a defined outcome, all contributing components, all policy tools that can be applied, sequence of actions and interrelationships between components and policy tools (including feedback mechanisms). Paper III described how road safety outcomes become part of economic context that is also true for the transport, land use and social contexts and other components. As road safety changes, these components adjust to suit. In the same way, policy tools are refined and adjusted as the effects of their deployment are understood. These feedback mechanisms have been observed as the evolution of road safety strategies over many decades.

Figure 7.6. System relationships in the road safety framework



The framework developed in this thesis has the potential to contribute to holistic thinking, innovation, and comprehensive strategies involving coordinated and interrelated actions required to improve road safety. Therefore, the research conducted in this thesis addresses many of the weaknesses and criticisms of previous approaches to road safety, and in doing so potentially meets the challenge to adopt new thinking in road safety research and practice "to aid the design and operation of safer road transport systems and to facilitate new reductions in road trauma." (Salmon and Lenné, 2015, p247).

Chapter 8. Study Limitations

During this research several relevant concepts emerged, such as risk management, safety culture and the practical application of systems approaches that are recognised as being potentially significant and valuable in contributing to road safety. The framework incorporates systems approaches and safety culture as part of both the social context and a potential policy tool to influence road users and other actors involved in road safety. However, further examination of these concepts, with the potential for their inclusion in the framework or incorporation otherwise into road safety strategies, are beyond the scope of this thesis. Further, more detailed and specific research into the application and potential value of systems approaches, risk management and safety culture, is recommended.

While the framework is comprehensive and detailed, further work is required to put it into practice, and assessment to demonstrate its utility. Since the framework is reasonably generic, it has the potential for use beyond government in the private sector (such as a trucking company), for individual modes or circumstances (such as a foundation for a bicycle safety strategy) or for specific industries (such as tourism). It is likely it can be easily adapted for use in other domains, such as industrial, mining or occupational safety.

Although the research process was not limited to developing countries, there was no consideration of the effect of the level of economic or social development of the location. While countries are often considered as developing in terms of economic activity, the concept also applies to all other components, including the transport, land use, society, drivers, vehicles, roads, information systems and response systems. Most literature in Paper I, and all the road safety strategies in Papers II and VI were from developed countries. Therefore, it may be possible that other components or policy tools may emerge from other locations. Furthermore, Paper VI described significant challenges for development of road safety strategies in developing countries, so further work in this area will be necessary to apply the

strategy appropriately. Some of the challenges here include availability of data, knowledge of actors and the level of skills, knowledge and experience of professionals developing the strategies, as has been identified elsewhere (Mohan et al., 2006).

Section 7.4 identified several additional approaches, techniques and concepts that could complement the strategic framework development. Two of these are regularly used in road safety (targets and vision), and three (processes and management, actors and principles) can be readily incorporated as described. However, four others are not commonly used in road safety, despite being successfully applied in other safety domains and could be included in the safety management component of the framework. Doing so would require further research, practical application and testing.

The thesis achieved a measure of integration between theory, observation and practice. As noted in the introduction there are no clear answers as to which of these should come first. In this case, each has informed the others in an interactive, rather than linear process. However, the reality of research was that some papers naturally preceded others in time, before later papers could inform them. It is therefore acknowledged that the papers written earlier in time would be more robust and may be improved if they were researched again and rewritten now that a more theoretical basis exists, and could therefore be revisited.

Chapter 9. General Discussion, Conclusions and Recommendations

9.1 General discussion

While road safety strategies have evolved and developed over time, they have not been developed in a way that is based in theory and research. Several criticisms have been aimed at safety strategies, particularly regarding narrow scope of content, lack of a systems approach and failure to apply information from other safety domains. The framework in Paper VI was developed to address the following criticisms and opportunities identified in the introduction:

- Road safety has been recognised as a complex field with multifaceted and interconnected factors, influences, interrelationships, components and countermeasures (Smeed, 1949; Peden et al., 2004; Racioppi et al., 2004). Yet, as described above, this complexity is not reflected in road safety strategies over a long period of time.
- Road safety strategies need to address the full range of factors and influences that affect outcomes. New and comprehensive approaches offer the potential for improving road safety strategies (Benner, 1975, 1985; May et al., 2008; Lundberg et al., 2009; Hovden et al., 2010; May et al., 2011).
- Systems approaches in particular have been successfully applied in other safety domains (Michaels, 1963; Kjellén and Larsson, 1981; Chapanis, 1996), but not commonly or thoroughly in road safety (Salmon and Lenné, 2015).
- Models for safety should be, but are rarely, assessed for suitability for their purpose (Kjellén and Larsson, 1981; Benner, 1985; Kjellén, 2000).
- The ultimate test of road safety strategies should be performance measures, which are difficult to assess (Gitelman et al., 2010; Holló et al., 2010; Papadimitriou and Yannis, 2013), so new performance assessment techniques are required to take account of the systems nature of road safety.
- To overcome narrow thinking previously evident (Hollnagel, 2008; Hovden et al., 2010) requires a broad perspective and systematic research methodology (Hancock and Bezold, 1994; Voros, 2003).

9.2 Summary of conclusions

Based on many years' literature, road safety strategies, models and investigations should be based on robust theory, tested for efficiency and effectiveness and demonstrated in practice. Alternatives should be analysed, compared and tested to determine those that are most valuable. Specific situations, such as location, or context should be accounted for.

The systems approach has been applied in developing the framework by applying main constructs of systems theory – *actors* that employ *processes* to apply *controls* to *components*, while recognising *interrelationships* to achieve an intended *purpose*. Additionally, the use of *principles* may also assist in guiding this approach in practice.

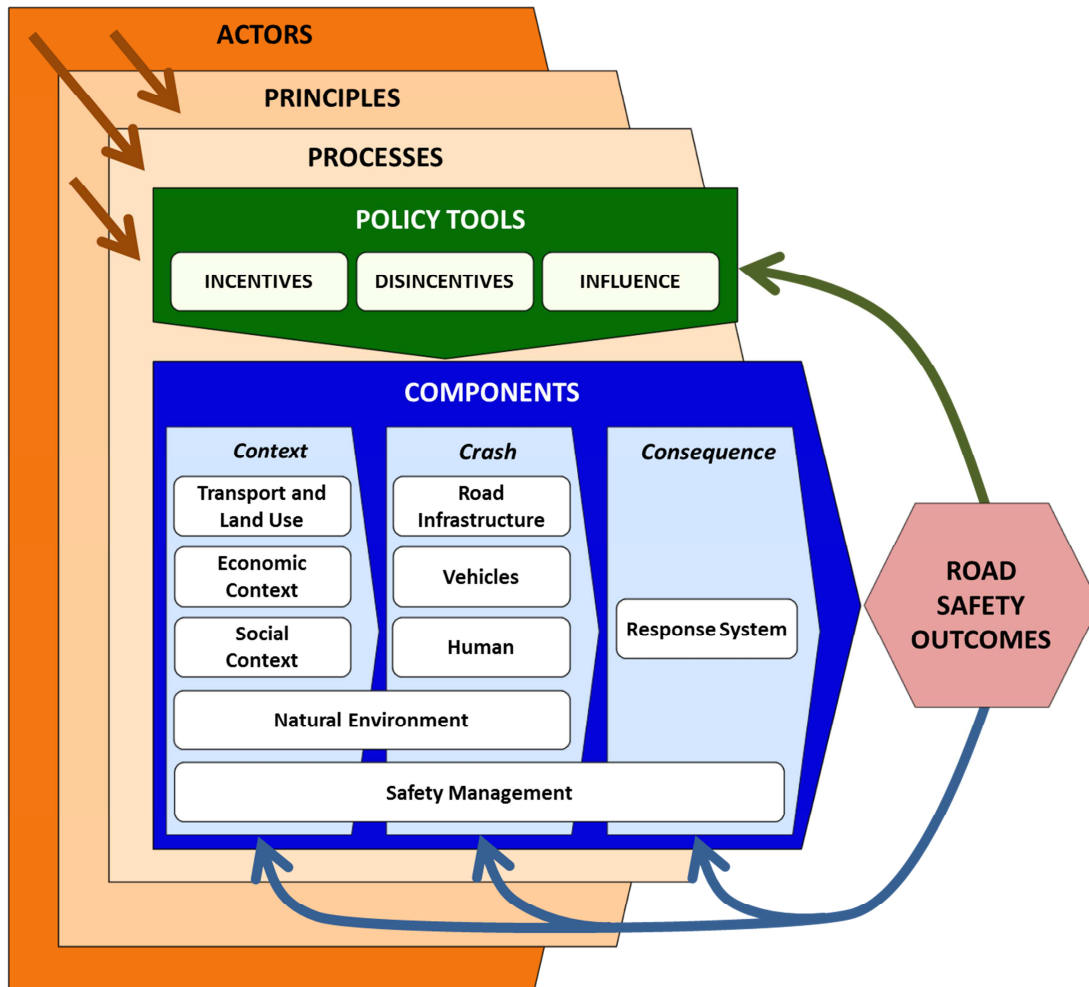
The comprehensive framework developed in Paper VI to meet these requirements, based on a thorough underlying rationale, consistent with comprehensive system theory, is illustrated in Figure 9.1. In this arrangement, *actors* apply *principles* through *processes* to employ *policy tools* to affect *components* contributing to road safety, in order to achieve *outcomes* (improvements to road safety). The arrows represent *relationships* or influences of change between different parts of the framework.

The framework is apparently robust, thorough and legitimate because it:

- incorporates elements of several different types of model, including component models, sequence (or event chain) models, or process models;
- summarises and comprehensively describes all components that contribute to road safety outcomes;
- summarises and comprehensively describes all policy tools that are applied to components to improve road safety, incorporating aspects of intervention models, and risk and safety management systems;

- properly incorporates the important aspects of systems theory components, relationships, joint purpose and interdependency (including feedback interaction); and
- recognises interrelationships between actors, components and policy tools.

Figure 9.1. The framework of policy tools applied to components in a system to achieve outcomes



The process for development of the framework presented addresses criticisms by Lundberg et al. (2009) and Benner (1975, 1985), by applying Hancock and Bezold's (1994) narrowing focus approach commencing with a wide perspective regarding road safety, whether it be research, investigation analysis, countermeasures or strategies. This method has provided the widest description of contributors to road safety outcomes. Doing so provides a great opportunity to learn from and apply any

available knowledge particularly from other safety domains and relevant similar processes.

Road safety strategies have been developed incrementally, with a continuing focus on drivers, vehicles and the roads over a long period of time. Several authors have called for a greater appreciation of complexity in road safety analysis and management (Smeed, 1949; Peden et al., 2004; Racioppi et al., 2004; Stigson et al., 2008). While Haddon's (1980a) matrix covers human, vehicle and equipment, physical environment and socio-economic environment, this diversity is not common in road safety management. So, even the most modern road safety strategies have limited perspectives. The framework presented in this thesis is not limited in scope, but completely describes the full range of components that contribute to road safety outcomes.

In the same way, the complete range of policy tools needs to be considered for application in order for road safety strategies to be efficient and effective. The comprehensive identification and description of all policy tools and components is a contribution to new and thorough approaches that offer the potential for improving road safety strategies (Benner, 1975, 1985; May et al., 2008; Lundberg et al., 2009; Hovden et al., 2010; May et al., 2011).

The framework presented overcomes Benner's (1975) criticism by not narrowly delineating the beginning and end of crashes, and presenting information clearly and concisely. Yet further detail in the framework is comprehensive and incorporates concepts from diverse perspectives including systems theory and more traditional component and process approaches. Doing so, therefore has the potential to reduce unnecessary barriers to understanding crashes, enable transfer knowledge and dispel popular misconceptions about the nature of crash phenomena. As a result, the framework provides potential for improving the efficiency of development of safety countermeasures.

The framework responds to the weaknesses Benner (1985) found by harmonising diverse crash models into a simple, cohesive and comprehensive framework. Doing so is highly consistent with meeting the evaluation criteria Benner (1985) developed.

Lundberg et al. (2009) described that accident investigation models, including those used in road safety, were weak and could be improved if they were less focussed on individual parts and more focussed on the whole, as is the framework developed here. Going further, this framework is also consistent with systems theory, and comprehensive that Lundberg et al. (2009) suggested is also required.

The framework is also consistent with the directions that Peden et al. (2004) and Salmon and Lenné (2015) proposed to improve road safety because:

- it incorporates systems thinking models that afford the opportunity to take a far more holistic approach to road safety;
- existing systems thinking models and methods have been considered and incorporated in this road safety research and practice application; and
- it incorporates suites of countermeasures that target different aspects of the road transport system together (both policy tools and components) that are more effective than interventions focussed on one component alone.

This model does not simply fit into one category of accident model. Its robustness can be demonstrated by its incorporation of features from system theory, component models and sequence models. On one level it is a simple representation of contributing factors and influences. However, it also provides a detailed level with comprehensive content.

9.3 Recommendations for further research, development, testing and evaluation

While the research in this thesis is both broad and detailed, it cannot cover everything, so further work is suggested as being beneficial. Based on the scope of this thesis, and its limitations, the following research is suggested as being potentially worthwhile:

- test the framework in the development of policy tools and components for road safety, including trial in the development of a road safety strategy;
- investigate interactions between actors, components and policy tools, whether they be positive or negative, to suggest where improvements may be made for the efficiency and effectiveness of achieving road safety outcomes;
- investigate complementary aspects of road safety including principles, decision making systems, processes (including implementation) that are in use in road safety. It is not evident that these have a clear foundation in theory, or are consistently applied. Their use could be examined to determine the level to which they contribute to safety outcomes being achieved;
- investigate the activities, responsibilities and contributions of actors, with appropriate processes for efficient and effective strategy management and incorporation of principles that can guide strategies. Integration of these with the components, policy tools and systems concepts in the framework may improve the efficiency and effectiveness of achieving road safety outcomes;
- investigate performance assessment measures that better reflect the systems nature of road safety, and different analytical techniques, such as system dynamics to more usefully inform the management of road safety systems;
- investigate the theoretical basis, application and utility of systems approaches, risk management and safety culture to road safety;
- investigate the potential value of incorporating and applying of systems approaches, risk management and safety culture; and
- investigate the relevance and application of the framework for developing countries, and develop modifications as required.

9.4 Closing comments

The limited array of components (factors and influences) targeted in road safety strategies to date suggests they may often be limited in regard to the nature of contributors to, and causes of, crash outcomes, which is a trap Hollnagel (2008) and Lundberg et al. (2009) described as *What-You-Look-For-Is-What-You-Find*. The natural consequence is that the effectiveness of strategies may be limited because, if Hollnagel (2008) is right, *What-You-Find-Is-What-You-Fix*. Furthermore, this thesis shows that the limited range of policy tools generally used in the past to counter these causal factors and influences, suggests that, in Hollnagel's language, *What-You-Have-Is-What-You-Use*. Given the incremental nature of road safety evolution, and the dramatic changes that are occurring to road transport as a whole that are expected to accelerate in future, these limitations suggest, like Goldsmith (2007) suggested, that *What-Got-Us-Here-Won't-Get-Us-There*. Therefore, a more structural and substantial change to road safety strategies, as outlined in this thesis, is likely to be required in order for the significant reductions in road trauma to continue to be achieved in future, as Benner (1975, 1985), Peden et al. (2004) Lundberg et al. (2009), Hovden et al. (2010), Salmon and Lenné (2015) and others have suggested. This thesis hopefully provides an opportunity to overcome both the limitations previously suggested in the literature, and provide a broader range of solutions that are likely to be necessary to meet the policy and transport system challenges to road safety in the future.

Since the framework is largely consistent with, and based on, previous descriptions of phases, policy tools and components, it may be on the one hand considered to be only an incremental improvement. On the other hand, the extension of the breadth of the components and policy tools and their detailed descriptions represent substantial development of them. In addition, the thorough incorporation of systems concepts, including descriptions of interactions, are new inclusions for road safety strategies. Consequently, the framework is substantially different to previous road safety strategic approaches.

This thesis responds to the lack of integrated or 'systems' approaches that Michaels (1963) sought, that are reflected in observations by Larsson et al. (2010, p1170) of the "*few references to systems theory and road safety found when a literature research is carried out*". This thesis attempts to meet the needs identified in OECD (1997, p90) "*If future policies and actions are to be fully successful, a comprehensive theoretical basis for road safety is needed.*" Finally, in doing so, it aims to contribute to the difficult and complex problem of road safety (Smeed, 1949) with complementary and synergistic countermeasures, by a structured and comprehensive approach to road safety strategies.

It is expected that application of this framework can contribute to the improvement of road safety strategies to be more applicable, efficient, effective and responsive to different contexts and futures, with the result that the burden of road safety on the community and industry, both socially and economically, can be reduced.

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Appendix 1

Declaration of Authorship

To Whom It May Concern

I, Brett Peter Hughes, contributed:

- 85% of the design and analysis of the study and authoring of the paper entitled "*A review of models relevant to road safety.*" C.C. Shu assisted with sourcing the papers for the literature search. Prof. Falkmer, Assoc. Prof. Anund and Assoc. Prof. Newstead supervised the study and reviewed the paper.
- 85% of the design and analysis of the study and authoring of the paper entitled "*System theory and safety models in Swedish, UK, Dutch and Australian road safety strategies.*" Prof. Falkmer, Assoc. Prof. Anund supervised the study and reviewed the paper.
- as sole author, 100% of the design and analysis of the study and authoring of the paper entitled "*Government policy: the accidental effect on road safety.*"
- 95% of the design and analysis of the study and authoring of the paper entitled "*Outcomes-based national road safety performance measures.*" Prof. Hopkins supervised the study and reviewed the paper.
- 80% of the design and analysis of the study and authoring of the paper entitled "*Data foundations for relationships between economic and transport factors with road safety outcomes.*" Sahar Shafei assisted with the data analysis and authoring the paper. Assoc. Prof. Newstead and Prof Hopkins supervised the study and reviewed the paper.
- 85% of the design and analysis of the study and authoring of the paper entitled "*A comprehensive conceptual framework for road safety strategies.*" Prof. Falkmer, Assoc. Prof. Anund supervised the study and reviewed the paper.

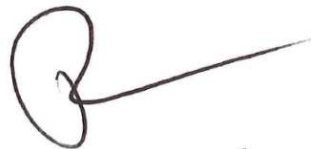
Brett Hughes



Date: 15/6/2017

I, endorse that this level of contribution by the candidate indicated above is appropriate.

Professor Torbjorn Falkmer
Supervisor and co-author



Date: 15/6 /2017

Assoc. Professor Anna Anund
Co-supervisor and co-author



Date: 22/5-2017

Assoc. Professor Stuart Newstead
Co-supervisor and co-author



Date: 23rd may 2017

Appendix 2

Other publications by the author

Babb, C., Smith, B., Hughes, B., Falconer, F. (2016). *Travel Demand Management Options for Perth*. In Biermann, S., Olaru, D., Paül, V., (Eds), *Planning Boomtown and Beyond*. Perth, Australia: UWA Publishing.

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Appendix 3

A review of models relevant to road safety

Paper I



A review of models relevant to road safety



B.P. Hughes^{a,*}, S. Newstead^b, A. Anund^c, C.C. Shu^d, T. Falkmer^{a,e}

^a School of Occupational Therapy & Social Work, Curtin Health Innovation Research Institute, Curtin University, Perth, WA, Australia

^b Monash University Accident Research Centre, Monash Injury Research Institute, Monash University, Melbourne, Australia

^c Swedish Road and Transport Research Institute, 581 95 Linköping, Sweden

^d Neurodegenerative Disorders Research Pty Ltd., Perth, Australia

^e Rehabilitation Medicine, Department of Medicine and Health Sciences (IMH), Faculty of Health Sciences, Linköping University & Pain and Rehabilitation Centre, UHL, County Council, Linköping, Sweden

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ABSTRACT

It is estimated that more than 1.2 million people die worldwide as a result of road traffic crashes and some 50 million are injured per annum. At present some Western countries' road safety strategies and countermeasures claim to have developed into 'Safe Systems' models to address the effects of road related crashes. Well-constructed models encourage effective strategies to improve road safety. This review aimed to identify and summarise concise descriptions, or 'models' of safety. The review covers information from a wide variety of fields and contexts including transport, occupational safety, food industry, education, construction and health. The information from 2620 candidate references were selected and summarised in 121 examples of different types of model and contents.

The language of safety models and systems was found to be inconsistent. Each model provided additional information regarding style, purpose, complexity and diversity. In total, seven types of models were identified. The categorisation of models was done on a high level with a variation of details in each group and without a complete, simple and rational description. The models identified in this review are likely to be adaptable to road safety and some of them have previously been used. None of systems theory, safety management systems, the risk management approach, or safety culture was commonly or thoroughly applied to road safety. It is concluded that these approaches have the potential to reduce road trauma.

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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). Road safety strategies are developed to choose, guide and describe actions to reduce this burden of injury. Road safety strategies focus on road users, vehicles, roads, and socio economic factors (Haddon, 1980). Recently, road safety strategies have been described as being a safe systems approach (Wegman et al., 1995; OECD, 2008).

Strategies to understand and reduce accidents and injuries have been developed in many domains, for example in occupational health (Rasmussen, 1980), hazardous industries (Johnson, 1980) and other modes of transport (Gibson, 1961; Helmreich and Merritt,

1998), thus being applied to different contexts. Types of safety models from these and other fields may be applicable to road safety but do not meet the description of a system (Wilson, 2014a; Perrow, 1984; Leveson, 2004). The full range of safety model types which may be applied to road safety strategies, such as the safety management system (Standards Australia and Standards New Zealand, 2001a,b) are not evident in road safety. Therefore, other types of model may potentially be applied to improve road safety strategies. In order to determine whether that is the case or not, the different types of safety models need to be categorised according their characteristics and compared. If however, the range is known, then the most appropriate model type may be used to develop more comprehensive and effective road safety strategies.

1.1. Models

A 'model' is a simplified description or representation of something to assist understanding. Models assist in creating a mental picture, facilitate questioning and information, establishing rules, checking, evaluation, analysis, identifying and assessing

* Corresponding author at: 5/296 Mill Point Road, South Perth 6151, Australia. Tel.: +61 8 6551 6140; fax: +61 8 6551 6948; mobile: +61 477 346 814.

E-mail addresses: brett.hughes@transport.wa.gov.au, banddhughes@bigpond.com (B.P. Hughes).

countermeasures and communication (Kjellén, 2000). Physical, visual, mathematical and descriptive models have been constructed for a variety of purposes. In this review, models are defined as concise descriptions of a whole entity, variously called models, frameworks, concepts or other terms. In this case, the purpose of applying the models was to explore possible ways to improve safety. At the highest level, these models are generally descriptive, often with a visual aspect (diagrammatic), rather than the more detailed mathematical and quantitative models used for particular analytical purposes. The utility of models is dependent on the context and application, and therefore it is important to recognise the distinction between descriptions (the models) and how they are applied (a process) (Underwood and Waterson, 2013a). Models are not perfect, neither in description, nor in application, which leads to criticism and conflicting preferences between proponents or practitioners (Underwood and Waterson, 2013a). Weaknesses in high level models are often overcome by the application of more specific analytical techniques (Underwood and Waterson, 2013a). The present review considers models of safety at a high and holistic level. However, the term model is ambiguous and may be applied in other ways, such as those used for quantitative analysis or simulation, or qualitative descriptions of principles or concepts, as described below.

Taxonomy of types of models is rare in the literature. System theory, energy models, process models, information-psychology theories and other approaches have been applied (Kjellén and Larsson, 1981) but not categorised. There is reference to types of research where data sources were broadly classified as accident analysis, field studies, questionnaires of safety participants, expert opinion, theory or literature, and simulator studies (Hale and Hovden, 1998). Studies have also classified by purpose (e.g., model, audit, analysis tool, training, etc.) and in finer detail by topics included in the study (e.g., structural, human resources, political or symbolic) (Hale and Hovden, 1998), originally being devised for categorising organisational purpose (Bolman and Deal, 1984). Experimental, ethnomethodological and survey research types have been proposed for ergonomics research (Dekker and Nyce, 2010). However, such approaches are neither holistic nor systematic classifications of all possible models of road safety at the strategic level, and thus excluded from the current review.

1.2. Systems concepts

Systems concepts are highly influential in safety, although the term 'system' is widely, but inconsistently used (Waterson, 2009). Furthermore, studies suggest that applying systems concepts techniques provide a deeper understanding of how dynamic, complex system behaviour contributes to accidents, resulting in better safety outcomes (Underwood and Waterson, 2013b). The term 'system' and its related concepts may be defined variously and used differently depending on its situation, users, foundational theories and application (Underwood and Waterson, 2013a). While not unambiguously defined, the literature describes:

- i. system (an operating entity),
- ii. systems theory (an underlying rationale for definition of systems characteristics),
- iii. systems approaches (a process to analyse and understand a system), and
- iv. systematic processes (a manner of application).

There is a general agreement that systems involve the processes of transforming input to output for a purpose, but a deep and broad conceptualization of systems theory and its application is lacking (Waterson, 2009; Wilson, 2014b). A system may exist and be investigated in non-systematic ways or not according to systems

theory. A systems approach to analysis (or process) would be consistent with systems theory and should be systematic, but other approaches to analysis may also be consistent with systems theory, without necessarily following the thorough systems approaches described in the literature. However, a thorough description of these differences and the variations in different literature is beyond the scope of the present review, but summarised below.

Systems theory is a scientific exploration of wholeness, covering various constituent elements and their relationships (Von Bertalanffy, 1968). Systems theory challenges reductionist views and analysis, which attempts to draw information and conclusions of certain sections in isolation from other parts of the system. Systems theory describes that systems exist when there are interdependent, but related components achieving a valued pre-set objective, purpose or function (Wilson, 2014a; Leveson, 2004; Perrow, 1984). According to system theory, the fundamental constructs of a system are components, relationships, joint purpose and interdependency, which may be complemented by other descriptive principles or dimensions, such as time. These characteristics are used to describe a system, proving a system model. However, other models may also exhibit characteristics of systems.

A systems approach to safety is a process which views accidents as the result of unexpected, uncontrolled relationships between different parts of the system, instead of being limited to traditional cause-effect accident models (Underwood and Waterson, 2013b). Importantly, in this approach, systems are analysed as whole entities, rather than considering their parts in isolation (Underwood and Waterson, 2013a; Waterson, 2009). Systems approaches may be described by principles, characteristics, processes or constituent parts. The systems approach offers the benefits of understanding and consideration of the whole subject, providing a deeper knowledge on how dynamic, complex system behaviour contributes to accidents (Underwood and Waterson, 2013b). As a method, it is comprehensive, rigorous, founded in theory and proven in practice. Other approaches may be more reductionist and overly simplistic in assessing individual aspects in isolation, ignore complementary effects and interdependence or not yet be demonstrated to be valuable. Systems theory and techniques have successfully been applied to improve safety in the most 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). Any investigation or analysis may be conducted systematically without recognising any system characteristics. Systematic investigations are logical, thorough and robust. Some of the clearest systematic approaches are systematic literature reviews (Cochrane Reviews, 2011), which may not relate to a system as understood in system theory or safety as a particular outcome.

Applying systems theory and systems approaches have been accepted as being meaningful despite the lack of widely accepted explanations of exactly what this means in relation to theory, principle and practice (Waterson, 2009; Wilson, 2014a). Some safety procedures have been codified based on accepted principles or practical expertise and judgement from experienced practitioners, but have little or no scientific basis (Hale and Hovden, 1998). The limitations of traditional cause-effect accident models have been acknowledged, but the use of system models is not always considered appropriate (Underwood and Waterson, 2013b) depending on the application, organisational culture, an individual's previous experience and training or availability of data. Therefore systems theory and systems approaches should be applied more thoroughly.

1.3. Models relevant to road safety

Several types of models have been used to understand and improve road safety. However, the justification for the choice of

Table 1
The stepwise search process for articles and books.

Step	Article search	Book search ^a
1.	Definition of the review question, selection of search terms and development of criteria for searches	
2.	Preliminary scan of search results	Identification of potential suitable books from search results and articles
3.	Initial search selection of search and download of summary information	Request suitable books from external sources
4.	Refine search to reduce size	Identify library book sections for shelf scan
5.	Elimination of duplicates in two stages	
6.	Initial information selection based on relevance, quality and potential value, sequentially by title then abstract and papers in English	
7.	Collect and review potentially relevant papers	Scan books to identify relevant information
8.	Discard papers without useful information	Retain books with useful information
9.	Identify and summarise useful models	

^a Including government reports.

type of model and the relative utility of different types of models have not been described. System models are one of the full range of available types investigated in the present review to find out if they are relevant and applicable to improve road safety strategies.

While systems theory and systems approaches have been applied to several transport safety domains including aviation and rail (Waterson, 2009) and for specific situations in road safety (Read et al., 2013), a comprehensive understanding about systems theory is not evident in road safety at the strategic level. Systems approaches to road safety at the strategic level are rare despite the limitations of traditional, reductionistic approaches which a systems approach could overcome (Larsson et al., 2010). The few references to thorough applications of systems theory and systems approaches to road safety mainly relate to individual incidents or analysis (Read et al., 2013; Salmon et al., 2012; Goh and Love, 2012).

The systems approach to safety is based on systems theory applicable to analysing various performance and operating aspects, such as efficiency and safety, which have been evaluated in practice. In contrast, the 'safe system' approach applied to road safety strategy is based on philosophical positions, such as ethical arguments, and evidence from practical experience with road safety countermeasures, such as limitations of the human body to tolerate transfers of kinetic energy, rather than on a theoretical basis.

2. Methods

The current review searched models from a wide variety of fields and contexts that are potentially applicable to road safety. A stepwise review of the safety strategies described in peer and non-peer reviewed scientific literature was carried out based on a variety of similar procedures (NHMRC, 2000; Cochrane Reviews, 2011; Petticrew, 2001), as summarised in Table 1.

Eight databases were used; The Cochrane database, EBSCO HOST, Embase, Informat, Medline, ProQuest, Web of knowledge and Safety Science and Risk Abstract.

The databases were searched for relevant literature with no limitations to the year of publication or contexts such as industry, health transport or recreation. The following search terms were used:

- i. safety or accident (being the antonym of safety) and
- ii. system, framework, strategy, policy or model.

Using pairs of these two types of terms yielded 10 pairs for 8 databases, with a total of 110 initial searches. The search pairs safety + model, safety + system, accident + model, and accident + system with these terms in the article title were examined,

which yielded the 11,334 results, summarised in Table 2, for which the endnote summary information was downloaded. Duplicates were eliminated, which resulted in a total of 2620 unique records.

A set of criteria was used to filter out articles retrieved from the databases, deemed to be of little value or relevance. This included:

- literature that was too specific to provide information at the system (macro) level,
- generalised models used in non-safety contexts (such as strategic or operational business planning, total quality management or other processes),
- specialised assessments, tools, techniques or models for detailed and specific analytical purposes,
- literature that was too vague to be considered as a coherent model description,
- literature originating from ambiguity of terms (such as a document on insurance policies instead of other policy),
- book reviews, letters to journals, and editorials offering no new information, or
- formal industry standards or legislation described within legal frameworks or regulatory models.

Following the process described in Table 1, the summary information from the remaining 2620 documents was scanned. Of these, 557 full text documents were sourced and reviewed, and 121 models describing different content were summarised (Appendix A). Finally, the models were categorised based on the characteristics which described them. A widely applicable taxonomy of model types, not previously evident in the literature, was developed to categorise as many of the models as possible. Models which used for road safety purposes were specifically identified. Most models were characterised by one of seven types, but some contained additional descriptive information which did not fit into these types.

3. Results

3.1. Safety models

Models of safety are widely applied to industrial, transport, government and personal situations to describe a level of likelihood and adverse consequence of expected or unexpected events (Reason, 1990), but were found to be poorly defined. Terms such as safety, risk, hazard, and accident were often used interchangeably, with or without clear definition. The diversity of types and content of models developed to describe and investigate safety issues and develop responses are summarised in Table 3.

Table 2
Initial searches from which information was downloaded in August 2011 (papers numbered in brackets with * were not downloaded).

Databases (see below) search terms	1	2	3	4	5	6	7	8
Safety + model	32	(315*)	(635*)	264	(519*)	(379*)	(3148*)	519
Safety + system	119	(131*)	(974*)	315	(776*)	(926*)	(8509*)	528
Safety + strategy	35	252	366	386	271	201	734	179
Safety + policy	9	523	267	334	245	280	697	943
Safety + framework	0	65	94	77	72	65	286	98
Safety + model + system		28	18		12	29	298	
Safety + model + strategy		1	7		6	4	17	
Safety + model + policy		7	1		1	4	7	
Safety + model + framework		2	7		7	0	13	
Safety + system + strategy		7	12		9	7	40	
Safety + system + policy		16	6		3	5	30	
Safety + system + framework		5	2		2	0	44	
Accident + model	2	109	162	204	135	71	(856*)	226
Accident + system	4	85	134	131	126	78	(878*)	79
Accident + strategy	2	16	28	24	26	17	157	26
Accident + policy	2	105	34	56	31	39	150	17
Accident + framework	0	9	4	5	10	2	45	5
Accident + model + system							47	
Accident + model + strategy							3	
Accident + model + policy							1	
Accident + model + framework							2	
Accident + system + strategy							7	
Accident + system + policy							3	
Accident + system + framework							2	
Total	205	1230	1142	1796	956	802	2583	2620
Database	Sub-database included and notes							
1. Cochrane	Reviews							
2. EBSCO HOST	Business Source Complete, EconLit, ScoINDEX							
3. Embase	1988–July 2011							
4. Informit	APA-FT, APAIS-Health, AMI, ATRI, Health Collection, Health and Society, Humanities and Social Sciences Collection, RURAL							
5. Medline	1948–2011							
6. ProQuest	Central – journals, reports, books, dissertations and working papers							
7. Web of knowledge								
8. Safety science and risk abstract	Conference papers, books and peer-reviewed journals							

3.2. Model types

Seven different types of safety models were identified, arising from different domains, purposes, uses, characteristics or perspectives. Some models described the component parts, such as the human–machine–environment model. A second group summarised the how the sequences of events and activities which existed or contributed to adverse events may have been changed. A third group of models was described by individual interventions used to improve safety, such as engineering, education, enforcement and encouragement. This group was closely aligned with, and often occurred with analytical or quantitative models for assessing the interventions. Another group of models represented the sequence of events by which the adverse outcome occurs. Some models described comprehensive safety management systems or risk assessment processes by which safety may be analysed and managed, although the descriptions were not directly related to the theoretical descriptions of systems as described earlier. A final group was described as a systems approach, although again, not all of these were related to theoretical descriptions of systems. These groups covered the majority of models identified although some models fell outside the categories.

The models had evolved and changed over time. Early models tended to focus on the components contributing to activities or safety. Later emphasis was on interventions, quantitative analysis, work processes and failure sequences. The most recent models adopted systems terminology, particularly for management of safety. Some of the models identified were seminal, and had become the foundations for safety concepts and risk management, referred to or used as a basis many times.

Models were identified from a great variety of fields including all major modes of transport, general industry, hazardous industries,

health and recreation. Some models were at a high level of a whole country, while others were for specific locations such as for recreation centres. Component models, sequence models, intervention models and mathematical models have been applied to road safety. System models safety management models from other domains have not yet been applied to road safety. Each of the seven model types potentially offers advantages and disadvantages by describing the safety situation in quite different ways, which is further addressed below.

3.3. Additional supporting information

In addition to structured simplified models constructed to improve understanding, further useful information was found. It included the theory and rationale underlying safety models (Von Bertalanffy, 1968; Wilson, 2014a), reasons for models (Waterson, 2009; Leveson, 2004, 2011), approaches to structure or type (Attwood et al., 2006), principles (Johnson, 1980), assessment or evaluation (Benner, 1985), and applicability or relevance to contexts or situations. There were fundamental differences in the underlying basis of the models, such as whether human failure is something to be accepted as inevitable, or if it can be managed and improved. Any of the models could include additional valuable information about definitions, principles, objectives, targets, or other content, but was not necessarily specific to a particular domain, model type or context.

3.4. Two important terms

In addition to the model and system, safety culture also emerged from the review as an important concept. The review particularly highlighted issues with respect to these latter two terms.

Table 3
Examples of different types of safety models.

Model type	Characteristics of model type	Examples of the model type
1. Component models	Identifies all the individual contributing parts or units.	Gordon (1949), Gibson (1961), Haddon (1968 ^a , 1972 ^a , 1980 ^a), Fell (1976) ^a , Rasmussen (1980), Rasmussen (1982), Rasmussen (1997), Heinrich et al. (1980), Johnson (1980), Booth (1980) ^a , Poole (1986), Grey et al. (1987), Embrey (1992), McGraw et al. (2008), Burns and Machado (2009)
2. Sequence models	Based on a specific series of events resulting in incident(s) (e.g., event chain, energy transfer and fault tree analysis).	Haddon (1968 ^a , 1972 ^a , 1980 ^a), Heinrich et al. (1980), Johnson (1980), Cameron (1992) ^a
3. Intervention models or	Identifies activities or countermeasures which improve safety (e.g., engineering, enforcement).	Johnson (1980), Rasmussen (1982), Loader and Hobbs (1999), Standards Australia and Standards New Zealand (2001a,b), Pun and Hui (2002), Hirasawa et al. (2005) ^a , Newnam and Watson (2011) <i>(Note these models have characteristics of both Intervention and Mathematical models)</i>
4. Mathematical models	Based on quantitative analysis of data and relationships.	
5. Process models	Identifies sequences of, and relationships between work and/or activities.	Blake (1963), Heinrich et al. (1980), Rasmussen (1982), Reason (1990), Sauter et al. (1990), Childers and Rohrer (1992), Stang (1996)
6. Safety management models	Identifies management components, system, relationships and outcomes. Describes the manner and process by which safety is managed (e.g., safety management system or risk management system).	Gibson (1961), Blake (1963), Glass et al. (1979), Heinrich et al. (1980), Johnson (1980), Rasmussen (1982), Childers and Rohrer (1992), Wegman et al. (1995) ^a , Weinstein (1996), Glendon and Waring (1997), Redinger and Levine (1998), GAO (2006), Standards Australia (2006a,b), Bellamy et al. (2008), McGraw et al. (2008), Makin and Winder (2008), Burns and Machado (2009), Whitefield (2009), Holló et al. (2010) ^a , Hsu et al. (2010), Ball (2011), Black et al. (2011)
7. System models	Describes purposes, components, relationships and interdependency.	Johnson (1980), Stang (1996), Porter and Wettig (1999), Standards Australia and Standards New Zealand (2001a,b), Leveson (2004), Australian Transport Council (2004) ^a , Burns and Machado (2009), Whitefield (2009), Larsson et al. (2010) ^a , Salmon et al. (2012) ^a , Goh and Love (2012) ^a , Read et al. (2013) ^a
Additional supporting information Definitions, principles, objectives and targets		Gordon (1949), Glass et al. (1979), Haddon (1980) ^a , Heinrich et al. (1980), Rasmussen (1982), Perrow (1984), Poole (1986), Donegan et al. (1989), Reason (1990), Glendon and Waring (1997), Redinger and Levine (1998), Standards Australia and Standards New Zealand (2001a,b), GAO (2006)
Other framework concepts and information		McGraw et al. (2008), Whitefield (2009), Burns and Machado (2009), Wallis and Dovey (2011), Miller et al. (2011), Ball (2011) ^a

^a Examples of model type applied to road safety.

3.4.1. Systems properties

Only a few models defined terms thoroughly. The term system, described by Perrow (1984), Leveson (2004), Underwood and Waterson (2013b) and Waterson (2009) was particularly problematic, being widely and differently used without clear definition. As mentioned, systems theory describes four key attributes; the components of the system, interrelationships between components, the system's purpose and interdependency between components. Additionally, these attributes may be based on an underlying theory and supported by principles. While regularly used in the literature, the term system was generally not used consistent with a theoretical approach or in another well-defined or justified way.

3.4.2. Safety culture

The term 'safety culture' emerged as a strongly supported concept used to describe the underlying nature of an organisation's approach to safety. Safety culture was described as a characteristic, property or component of systems, rather than a model in itself (Hale and Hovden, 1998; Helmreich and Merritt, 1998; Morley and Harris, 2006). A healthy safety culture is multi-dimensional with well-developed norms and rules to promote safety, an informed and healthy attitude towards risk, and possessing mechanisms to provide feedback concerning safety performance (Morley and Harris, 2006). However, the term safety culture was poorly defined,

described inconsistently and used in different ways across the literature. Nevertheless, safety culture has apparent potential to contribute to understanding to improve safety in a system.

3.5. Comparison of types of model

The seven different types of strategic safety model were compared according to purpose, use, characteristics, strengths, weakness and relevance to road safety, as shown in Table 4. The strengths and weaknesses were substantially assessed against systems characteristics (holistic, relational descriptions, components and purpose). Purposes particularly considered four organisational aspects: structural, human resource, political and symbolic (Hale and Hovden, 1998; Bolman and Deal, 1984).

While the form of the frameworks may be categorised as above, the content within each description could vary widely. For instance, the Component Model of host, agent and environment used for epidemiological assessment (Gordon, 1949) was quite different to Haddon's matrix (Haddon, 1980) used for road safety, which included human, vehicles and equipment, physical environment, and socio-economic environment components. Therefore, the types of model categorised in Table 3 covered a wide range of specific models.

Comparing the attributes of models based on systems theory with the models classified in Table 3 (and described in Appendix A)

Table 4
Comparison of different types of safety models.

Model type and purpose	Model use	Strengths	Weaknesses	Relevance to road safety application
1. Component models For development and assessment of strategies, policies and programmes for countermeasures	Used in safety strategy development Provides a structure for general safety information Provides general descriptions	Holistic, enabling identification of specific unit weakness and general countermeasures Describes contributions to purpose Categorisations of components may vary (e.g., physical, organisational or activities) Can describe human resources and structural aspects	May not describe relationships between elements Unlikely to cover political or symbolic aspects Difficult to assess risk or causes of failure Difficult to analyse activities or processes May not be sufficiently specific or detailed Difficult to identify specific hazards Difficult to describe all outcomes May be difficult to move between domains	Road safety components often described as four E's: engineering, enforcement, education, encouragement Safe systems approach of vehicles, roads, drivers has been applied
2. Sequence models For determination of cause and countermeasure development	Used for individual incident/accident analysis	Describes contribution to failure rather than contribution to purpose Focus on proximate causes, interfaces and time Good examination at micro level Detailed descriptions of relationships between directly contributing components, including human factors	Difficult to apply to large, non-linear and complex systems with many components and interactions, at strategic level Unlikely to cover political or symbolic aspects Often subjective with evidence base restricted to event Does not take account of context or holistic effects Difficult to apply to a series of small contributing failures Often limited by a start and end time or part of sequence Difficult to include whole-of-system factors (e.g., organisational safety culture or factors outside the organisation or span of control) Often restricted to identifying cause, blame or prosecution	Used to analyse specific types of crashes or interventions Not used at strategic level
3. Intervention models For development and assessment of strategies, policies and programmes for countermeasures	Used to analyse specific policy or strategy	Relates directly to agency roles, contribution and responsibilities Based on generalised causes Can be used to describe outcomes Can recognise human resources and structural aspects Strong understanding of outcomes	May not describe relationships between activities or recognise all contributing components May be too specific and insufficiently holistic May be difficult to assess specific risks or causes of failure Unlikely to cover political or symbolic aspects	Used as impact analysis or cost-benefit analysis of specific interventions Could be applied in assessment of the whole system
4. Mathematical models For investigation of systems, events, risks and countermeasures	Used for quantitative analysis of effects of specific policy or strategy	Provides strong evidence basis Powerful evidenced based tool for influencing and making decisions Suits detailed micro analysis Strong understanding of relationships and outcomes	Generally focuses on only one very specific element or issue Likely to be too specific, insufficiently holistic and not recognise all components Needs to be conducted with consideration of the whole context Unlikely to cover political or symbolic aspects Can be difficult to apply if data is not available or analysis becomes impossible Risk of being too narrow resulting in justifying preconceptions, or what-you-see-is-what-you-find	Many different types including typical statistical analysis, epidemiological, economic, risk or time series analysis Generally chosen to suit the specific road safety research question Not used at strategic level
5. Process models To understand activities and operations	Used to develop and prioritise countermeasures: identify and assess potential risks and causes to develop and assess countermeasures	Allows understanding of sequences of and relationships between activities Facilitates identification of specific hazards and countermeasures Likely to be holistic, focus on purpose and consider relationships and components Likely to cover human resources and structural aspects	Implicitly describes components Difficult to apply to situations with many components since the process becomes too complex to analyse May not describe all outcomes May not cover political or symbolic aspects	Can be used for very specific driving tasks Otherwise difficult to apply due to the complexity of the driving tasks and the complexity of wider transport system as a whole Not used at strategic level

Table 4 (Continued)

Model type and purpose	Model use	Strengths	Weaknesses	Relevance to road safety application
6. Safety management models For management of causes and risks, and development of countermeasures	Used for management assessments: organisation, procedures, resourcing, reporting	Frequently includes or is based on safety culture Non-specific, generally applicable to many situations or contexts Strong holistic focus on purpose and components Likely to cover human resources aspects Strong structural and human resource focus Can describe political and symbolic aspects	May not identify all causes, particularly outside the core system, or due to interactions Unlikely to consider all relationships Can be difficult to identify all opportunities for countermeasures May require management commitment or legal basis (as in OHS) Relies on subsequent specific issues and countermeasures to be identified and assessed Provides little guidance to individual activities, processes, situations, contexts	Not evidently used Potentially applicable
7. System models To understand and develop system operation	Used to analyse systems including effects of countermeasures, influences and consequences	Facilitates an understanding of the whole and contribution of components to purpose Focuses on holistic outcomes and changes Can encompass structural, human resources, political and symbolic topics Recognises interdependencies for consideration of all possible effects of any changes either in isolation, on other elements or together as complements May be supported by principles and/or a theoretical basis Should recognise structural, human resource, political and symbolic aspects as necessary	Can easily be too complex to be useful due to a multitude of relationships and components Difficult to apply to situations with many components since the process becomes too complex to analyse May not describe all outcomes Difficult to analyse and provide a strongly quantitative evidence basis	Descriptive models occasionally developed Detailed analytical models typically include statistical analysis, epidemiological, economic, or time series analysis can be used Currently used models are simple, not yet thoroughly based in theory and practice

identified that different models are not exclusive and exhibit characteristics evident in other model types. This is especially true for system models, which particularly include characteristics of component and sequence models. Different types of models may be more or less valuable depending on the circumstances to which they are applied. Safety management systems and the associated standards give good guidance for management, although they gave little assistance in describing and understanding the system under consideration itself. The most comprehensive descriptions relevant to understanding safety models were the management oversight and risk tree (MORT) descriptions, which were more of a toolbox of various concepts to be selected and used, depending on the needs and therefore incorporated several different model types.

4. Discussion

4.1. Relevance of alternative models to road safety

There were a variety of model types which have the potential to improve road safety, but are not yet applied. Probably all of the models identified in this review have the potential to be adapted to road safety and indeed, several have been used. Transport is characterised by thousands of components, operating relatively independently, but in close relationship over a period of time. Therefore, a variety of models may be applicable to road safety depending on the specific purpose to which it is used, and its context.

None of systems theory, safety management systems, the risk management approach, or safety culture was commonly or thoroughly applied to road safety, so application of these approaches may improve road safety strategies. The systems approach has the advantage of potentially including all relevant factors, components, contributors and outcomes, if thoroughly applied. Systems theory

and systems approaches provide the opportunity to contribute to further improvements to efficiency and effectiveness of safety strategies.

Other safety domains, covering other modes of transport, took a wider perspective than road safety, recognising more contributing elements to safety, such as organisational culture, emergency responses, the health system and economic factors and influences (McInerney, 2005; Standards Australia, 2006a,b). Economic and social factors have long been recognised as being important considerations for the road safety context (Gordon, 1949; Haddon, 1973), but are often omitted. While supporting the current models of road safety policy, a broadening in thinking to a holistic view has been argued, by challenging social paradigms that were typically taken for granted in road safety policy (e.g., May et al., 2010). Other models described principles such as accidents being viewed as an ecologic problem (Gordon, 1949) or accidents being avoidable events and a result of human error (Heinrich et al., 1980). Many models took a narrow view of the accident causation based on the specific situation or task such as the human-machine-environment model (Wang et al., 2010). Mathematical models focussed on very specific or singular details, ignoring the wider context and interactions with other parts of the system. Therefore these alternative and sometimes complementary approaches may also have application to road safety.

Systems approaches and models have been successfully applied to several other safety domains, including transport, and to specific situations in road safety (Larsson et al., 2010; Salmon et al., 2012; Goh and Love, 2012; Read et al., 2013). While a systems approach has been claimed to be applied to road safety strategy (Wegman et al., 1995; Australian Transport Council, 2004; OECD, 2008), it has not been found in this study to have been applied thoroughly according to its theoretical foundation and practice elsewhere. The term 'system' was commonly, but casually, used in

the road safety literature, without clear basis or definition. Models based on systems theory were characterised by individual units and their interrelationships, such as energy, information, etc. Relevant aspects of systems theory included definitions, specification, the nature of interrelationship and hierarchy. While ‘system’ is a fundamental concept in other safety domains, it has not been found in this study to have been soundly based or rigorously applied to road safety strategy and its use therefore offers potential to reduce road trauma.

Road safety strategies are often written with a government road safety perspective in mind. However, there are many other contexts and situations for which road safety and models are valid, including government non-transport agencies (e.g., treasury or education), private companies (particularly transport companies and those undertaking significant travel), the general public, NGOs and interest groups and service organisations. Application of these models is appropriate beyond government, despite it being held primarily responsible, which in itself is a contradiction of systems theory.

4.2. Categorisation of models

4.2.1. Systems theory and safety models

The term ‘system’ was commonly and often casually used in the literature without clear basis or definition. The literature highlights the need for distinction between terms including system, systems theory, systems approaches and system models. System models are primarily based on components, interrelationships, purpose, and interdependency, which other types of model may also describe in some way, although without the same theoretical basis or clarity. However, the generic term system is often used without definition and the specific system under consideration, and more specifically the boundaries of the system, is also often not clearly defined. Systems approaches (as described by principles, characteristics and processes) represent a way of thinking to analyse and improve systems.

4.2.2. Types of model

Seven different types of safety models were identified covering most of those described in the literature. Several models included human aspects (operator or user), infrastructure (or equipment), process (flow of work), the contextual environment (of widely varying types) and management. Models were based on a variety of perspectives, such as causes of accidents, or errors, leading to different elements being used in the descriptions to suit. Within model types there was diversity as to their content, with similar models found to include different details or applied in different contexts. Despite the hundreds of references and considerable variety, some models were more commonly used, with many referring to seminal work by Haddon (1968), Rasmussen (1980), Heinrich et al. (1980), Johnson (1980) and Reason (1990), further presented in Appendix A.

As mentioned, the language of strategy, modelling and safety was either poorly defined or poorly used. Terms such as safety, risk, hazard, and accident were often used interchangeably, whether or not they had specific definitions. Strategy could refer to a whole group of activities to achieve a widely based outcome (Wegman et al., 1995), or to a single activity (Rasmussen, 1980), a single situation (Wallis and Dovey, 2011), a single mechanism (Carayon et al., 2006) or a single outcome (Classen et al., 2007). The term strategy commonly related to a general direction of activity, whereas tactic or countermeasure tended to relate more often to specific interventions. Although the terminology is not universal, the terms model and system commonly appeared in our review, and can be applied to other activities besides strategy, including policy, planning, design, evaluation or other activities conducted to improve

safety. However, the vague and diverse nature of the language used for models made analysis and understanding difficult.

4.2.3. Model diversity

The literature revealed models displaying diversity of size, complexity, maturity and sophistication, which were useful descriptors of systems, but one does not imply any of the others to any degree. For instance, a small system may be complex and an immature system may be sophisticated. A typical challenge for modelling is over-simplification which can improve ease of understanding, but result in loss of information or confusion. More extensive models are more thorough, but more difficult to understand. Even within one model type, there were many details which were not consistently described amongst all models of the type, so that a complete, simple and rational description was often not evident.

The evolution in refinement of models over time is evident. At the same time, contexts and systems also change requiring new models. For instance, Pun and Hui (2002) observed a move towards self-regulation reflected in UK, European, Australian and ISO standards. As the frequency of aircraft crashes increased as airline travel grew (Du and Liu, 2009), safety management systems, models and analysis were improved. Over time, models continue to develop and be devised to meet new challenges or represent alternative useful perspectives.

4.3. Purpose and value of different models and approaches

4.3.1. Purposes of models

Well-constructed models are best used to contribute to the ultimate purpose, in this case to improve safety efficiently and effectively. Ideally, models should be useful (informs and efficiently assists the reader practically); be adequate (complete and sufficient); be rational (logical, structured, coherent and reasonable), and be understandable (as simple as possible) (Kjellén and Larsson, 1981; Hayden, 2006). Models inherently have inaccuracies due to over-simplification and often depend on specific language.

It is important that any model is relevant and useful (Hayden, 2006). This review was limited to strategy and policy at the macro level defined as “...consistencies, in the form and content of lower order systems (micro-, meso-, and exo-) that exist, or could exist, at the level of the subculture or the culture as a whole along with any belief system or ideology underlying such consistencies” (Bronfenbrenner, 1979, p. 26). Therefore the models reviewed were at a high level to understand:

- alternatives and facilitate choices;
- all outcomes (other beneficial outcomes) and conflicts (undesired adverse outcomes); and
- synergies (complementary outcomes when activities occur at the same time).

Since most, or all, of the models presented have some acceptance in practice, it is likely that each of them may be useful depending on the context and the needs of the user. Many models may be reasonable, but were not clearly based in theory or practice. It is also not evident that any type of model is necessarily more valuable than others. Models appear to be originally developed based on an individual’s perspective, although many have apparently been tested and developed satisfactorily in practice over time, such as those of Haddon (1968), Heinrich et al. (1980), and Reason (1990). Unfortunately, the comparative value of different types of model, or applicability to specific situations has not been tested in the present study or the literature, and offers the opportunity for further consideration to improve the application of models.

4.3.2. Advantages of different safety models

There are few examples of where different types of models are compared. It was not clear that any one particular type of model was most appropriate or more valuable, except perhaps for the narrow purpose for which it was employed. System models are most likely to be comprehensive covering the most important information and topics, but also importantly describing interrelationships and interdependencies. Mathematical models offer the most robust evidence base for quantitative analysis of consequences. However, while mathematical models provide a strong evidence base for very specific or singular issues of detail they tend to ignore the wider context and interactions with other parts of the system.

Models were described independently of other models and did not refer to other types in terms of value, comparative benefits or weakness. It was not evident that models of a specific type were generally suitable for a variety of other purposes for which they may be employed. Different models exist for different purposes, to suit different contexts or based on different theories. For this reason, a single comprehensive universally applicable model for all situations was probably unlikely to be devised. Alternative models covered different types of components, systems or processes, or provided additional information, which may potentially be applied in road safety. Despite the potential benefit of using a model from one field to another, some models from other fields have not been applied road safety.

Strategies are developed to make improvements to situations, by addressing a perceived problem. Road safety strategies focus on road users, vehicles, roads, and socio economic factors (Haddon, 1980; Leveson, 2004) to reduce crashes. However, safety strategies exist in many other fields as well, such as in occupational health (Rasmussen, 1980) and in hazardous industries (Johnson, 1980). Strategies also exist in other modes of transport (Gibson, 1961; Helmreich and Merritt, 1998) to improve safety. The information from these alternative perspectives has the potential to be transferred to further improve safety in different domains.

Activities and systems do not occur or exist in isolation, so strategies and models must consider the wider environment. The transport environment is diverse and includes community, technology, funding limitations, different levels of government, and other aspects (Hughes, 2010). A model for analytical purposes may be quite different to a model for strategy used to illustrate, summarise or 'sell' policy activities. For instance, strategies need to be targeted, since not all issues can be addressed at any point in time. So, it is entirely appropriate that strategies omit some, or many, issues. At the same time, unless the development of strategies is open to all the issues and opportunities there is a risk that the policies included will be sub-optimal.

5. Conclusions for road safety

Application of safety models from other domains should be investigated for use in road safety strategy. The investigation should be framed in terms of applicability to the situation and utility in achieving the intended outcomes. In particular, application of systems theory, safety management systems, the risk management approach, and safety culture models should be investigated to determine their utility in improving road safety.

System models and systems approaches have been successfully applied in other safety domains, including transport, providing the most thorough and comprehensive understanding of safety. Systems theory and systems approaches should be thoroughly applied in road safety research and practice at all levels, but particularly at the whole of system or strategic level. This result is consistent with Read et al. (2013, p. 773) who concluded for specific cases: "*The existing research has not applied a systems approach, and thus has not identified, described or explained emergent phenomena, variability in system functioning, dynamic aspects of the system and how influences at different system levels interact.*"

Techniques based on systems theory and the systems approach provide a more holistic and comprehensive understanding of a wider range of components and their interaction to influence the desired outcome. Previous conclusions regarding the use of terms according to systems theory and systems approaches were found to occur in road safety, "*the term 'systems' is being used rhetorically and one might conjecture, inappropriately*" (Waterson, 2009, p. 1192). Again, consistent with Read et al. (2013) systems theory and practices should be thoroughly applied to develop measures to improve road safety as a whole, which are more efficient and effective, especially in association with other complementary measures, rather than in isolation. As indicated, applying systems concepts techniques which provide a deeper understanding of how dynamic, complex system behaviour contributes to crashes (Underwood and Waterson, 2013b) would be expected to result in better road safety outcomes.

Models from other domains which include a wider context and greater breadth of factors affecting safety should be applied to improve road safety. Additional factors should be investigated, such as the effect of organisational culture, emergency responses, the health system and economic influences on road safety. In the context of road safety strategy development, analysis of road crashes at all levels should be broadened from a narrow view of causation based on the specific situation, task or crashes and direct contributing factors to take the wider contextual factors into account. There are theories, information and practices which can yet be applied with the potential to improve road safety at the strategic level.

Appendix A.

Origin	Type	Key elements and description
Gordon (1949)	Epidemiological	<i>Principles:</i> causative factors are in the host, agent and environment. The mechanism of accident production is the process by which the three components interact to produce a result, the accident; it is not the cause of the accident <i>Host:</i> age, sex, race, genetic inherent susceptibility <i>Agent:</i> physical, chemical, biological (not the mechanism) <i>Environment:</i> physical, biological, socioeconomic
Gibson (1961)	Accidents as an ecologic and psychological problem	<i>Environments:</i> terrestrial, geographic, natural and artificial <i>Classification of dangers:</i> mechanical energy (active impact, passive impact, interference with breathing, tool and machine forces, machine failures, animal forces, weapon produced forces), thermal energy (heat and cold), radiant energy (heat, ultraviolet, atomic), chemical (poisons), electrical energy (natural or man transmitted) <i>Margins of safety:</i> temporal and physical (barriers, gaps, and other protections) <i>Reasons:</i> misperception of danger, inappropriate reaction, motivation <i>Accident factors:</i> contributors to industrial risks
Blake (1963)	Causes of accidents	<i>Agency:</i> machines, moving equipment, boilers and pressure vessels, vehicles, animals, power transmission equipment, electrical equipment, hand tools, chemicals, inflammables and hot substances, dusts, radiations, working surfaces <i>Agency part:</i> specific individual parts of agencies <i>Unsafe condition:</i> inadequate guard, defect, hazardous arrangement or procedure, poor lighting or ventilation, unsafe dress or apparel, etc. <i>Accident type:</i> physical striking, being caught, fall, slip, exposure, inhalation, absorption, ingestion, electrical contact, etc. <i>Unsafe act:</i> operation without authority, improper operation, disabling safety devices, unsafe position, distraction/teasing/abusing/startling, failure to use protection, etc. <i>Unsafe personal factor:</i> improper attitude, lack of knowledge or skill, physical defect or weakness, etc.
Nader (1965) Haddon (1968, 1972)	Components Components and phases	<i>Components:</i> engineering, enforcement, education <i>Components:</i> drivers, passengers, pedestrians, bicyclists, motor-cyclists, vehicles, highways, police, and 'many more specific issues'. <i>Factors:</i> human, vehicle & equipment, cargo, environment <i>Phases:</i> precrash, crash, postcrash
Fell (1976)	Driver/vehicle/environment information flow	Ambience, highway, vehicle, speed and directory, other road users Ambient information restrictions Vehicle information restrictions Aids to observations Driver: perception, comprehension, decision, action Guidance, vehicle controls, auxiliary Communication to others
Glass et al. (1979)	Safe system of work	Legal interpretation of definition used in legislation. The ordinary or usual method of carrying out the operation in which an employee is engaged. Specific systems vary but generally include process arrangement, operational steps, co-ordination of the operation, methods of use of equipment and process, supply of equipment and manpower, proper instructions, warnings and notices.
Haddon (1980)	Factors, phases and results	<i>Factors:</i> human, vehicles & equipment, physical environment, socio-economic environment <i>Phases:</i> pre-crash, crash, post-crash <i>Results:</i> damage to people, damage to vehicles & equipment, damage to physical environment, damage to society
Rasmussen (1980)	Human in a control system	<i>Process plant:</i> physical processes, mechanical, electrical, chemical <i>Control system:</i> symbolic processes <i>Operator:</i> information processes, goals & intentions, models & strategies, performance criteria
Heinrich et al. (1980)	Steps of accident prevention	<i>Relationships:</i> instructions, information, actions Basic philosophy of accident occurrence and prevention: attitude ability, knowledge, the desire to serve (humanity, industry, country)
Heinrich et al. (1980)	Sequence of factors (domino model)	<i>Organisation, fact finding, analysis, selection of remedy, application of remedy</i> <i>Social environment/ancestry, fault of person, unsafe act (mechanical or physical/hazard, accident, injury)</i>
Heinrich et al. (1980)	Accident sequence after Bird	<i>Lack of control/management, basic causes/origins, immediate cause/symptom, accident/contact, injury-damage/loss</i>
Heinrich et al. (1980)	Accidents causation after Adams	<i>Management structure:</i> (objectives, organisation, operations), operational errors (manager behaviour, supervisor behaviour) <i>Tactical errors:</i> (employee behaviour, work conditions) <i>Accident incident:</i> injury producing, the near-miss no injury incident, the property damage incident, injury or damage (to persons, to property)
Johnson (1980)	Management oversight and risk tree (MORT)	<i>Risk management:</i> system definition, risk identification, risk evaluation, risk reduction <i>Levels of relationship:</i> generic events (problems), basic events (causes), criteria (judgement rationale for adequacy) <i>Functions to complete a process</i> <i>Steps to fulfil a function</i> <i>Judgement criteria to judge adequacy</i>

Appendix A (Continued)

Origin	Type	Key elements and description
Johnson (1980)	Management oversight and risk tree (MORT)	<i>Management policy and implementation</i> <i>Hazard analysis process with risk evaluation</i> <i>Operations readiness: preparation, test and qualification of physical elements, procedures and managerial controls and personnel</i> <i>Operations & supervision</i> <i>Human performance</i>
Johnson (1980)	System definition in project risk analysis model	<i>System components: plant and equipment, materials, energies, controls, human factors, operations/processes/procedures and environment</i> With: performance and risk criteria, delineation of probable and potential changes, establishment of life cycle plan and numbers And: regulations, standards & recommendations
Johnson (1980)	Dynamics of home accidents	<i>Background factors: persons (training experience, judgement), home (dwelling, yard, etc.), accident susceptibility, accident potential</i> <i>Initiating factors: change in pattern, agent of accident</i> <i>Intermediate factors: physiological & mental factors, no recognition of danger, environmental factors, "makeshifts"</i> <i>Immediate factors</i> <i>Measurable results: mitigating factors, personal injury, property damage, no injury or damage, "near accident"</i> <i>Intervention: another person, safety awareness, automatic cutoffs</i> <i>Return to normal procedure</i> <i>Accident sequence: patterns of operation (behaviour), person/day/activity, increase in susceptibility or potential, increase in hazard, unsafe act (trigger mechanism), agent of injury or damage</i>
Booth (1980)	Police approach to road safety	<i>Engineering</i> <i>Education</i> <i>Enforcement: information, organisation, vehicles, driver characteristics, arrests, patrols, selective enforcement, strategy</i>
Rasmussen (1982)	Human malfunction in industrial installations	<i>Performance shaping factors: subjective goals & intentions, mental load & resources, affective factors</i> <i>Situational factors: task characteristics, physical environment, work time characteristics</i> <i>Causes of human malfunction: external events, excessive task demand, operator incapacitated, intrinsic human variability</i> <i>Mechanisms of human malfunction: discrimination, input information processing, recall, inference, physical coordination</i> <i>Internal human malfunction: detection, identification, decision, action</i> <i>Personnel task: equipment design, procedure design, fabrication, installation, inspection, operation, test & calibration, maintenance & repair, logistics, administration, management</i> <i>External mode of malfunction: specific task not performed, erroneous act, extraneous act, sneak path or accidental timing of several events or faults</i>
Perrow (1984)	'Normal Accident' definitions	<i>Systems: for levels – units, parts, subsystems, system</i> <i>Incidents: cause damage to or failures of units or parts and hence failure of the whole system</i> <i>Accidents: involve damage to subsystems or the system as a whole causing the system to be stopped promptly</i> <i>Component failure accidents (units, part or subsystem): linked in anticipated sequences</i> <i>System accidents: unanticipated interaction of multiple failure</i> <i>Policy recommendations, depend on potential level of catastrophe and cost of countermeasure: abandon, restrict, tolerate & improve</i>
Poole (1986)	Framework for comparative analysis of industrial relations	<i>Environmental conditions: 1. Subjective meanings & policies – sociocultural values, political ideologies, economic policies, public and legal policies, 2. Structures – social, economic, political, technological, legal, demographic</i> <i>Organisational structures & processes: management policies, management styles</i> <i>Industrial relations systems: extent of shared decision making</i> <i>Outcomes</i>
Grey et al. (1987)	Human factors for work design	<i>People factors: people, equipment and machines, personal workspace, wider workspace, physical environment, work organisation and job design</i> <i>Environment: financial, technical, legal, social</i>
Kasperson et al. (1988)	Hazard chain	<i>Human needs, Human wants, Choice of technology, Initiating event, Release, Exposure, Consequences</i>
Donegan et al. (1989)	Fire safety model	<i>Policy – fire safety</i> <i>Objectives – life safety, property protection</i> <i>Tactics – ignition prevention, fire control, safe egress, rescue</i> <i>Components – occupants, doors, communications, internal planning, travel distance, flues/ducts</i>
Reason (1990)	Accident cause, human error	<i>Principles: humans are the source of all system problems, but not simply at the operator level. Other failures occur during any phase of the process or system including planning, design, constructions and maintenance.</i> <i>Dimensions: type of activity, focus of attention, control mode, predictability of error types, ratio of error to opportunity for error, influence of situational factors, ease of detection, relationship to change</i> <i>Errors: skill based, rule based or knowledge based</i> <i>Production system components: decision makers, line management, preconditions productive activities, defences</i> <i>Contributions to failure: fallible decisions, line management deficiencies, unsafe acts, inadequate defences</i> <i>Unsafe acts: slips, lapses, mistakes, violations (normal, exceptional)</i>

Appendix A (Continued)

Origin	Type	Key elements and description
Sauter et al. (1990)	Psychological disorder prevention strategy categories	Job design to improve working conditions, surveillance of psychological disorders and risk factors, information dissemination, education, and training; enrichment of psychological health services for workers.
Embrey (1992)	MACHINE (Model of Accident Causation using Hierarchical Influence Network)	<i>Human errors</i> : active, latent, recovery <i>Hardware failures</i> : human induced, random <i>External events</i> <i>Causal influences</i> : training, procedures, supervision, definition of responsibilities, demand/resource matching, production/safety trade-offs <i>Causal influences (policy)</i> : operational feedback, human resource management, risk management, design, communications system
Cameron (1992)	Road trauma chain	<i>Pre-crash</i> : entities exist (humans, vehicles, roads), entities eligible for road use (licensed registered roads opened), road use (distance, time), energy build up (speed, mass), exposure to crashes, crash involvement <i>Crash and post-crash</i> : crash involvement, energy dissipation, energy transfer, injury, severe injury, death <i>Risks</i> : public health, transport, injury, severe injury, fatal injury
Childers and Rohrer (1992)	Hazard Analysis and Critical Control Points (HACCP)	Identification and assessment of hazards Determine critical control points (CCPs) to control any identifiable hazards Establish critical limits to be met Establish CCPs monitoring procedures Establish corrective actions for deviations Establish effective record-keeping system Establish HACCP system verification procedures
Rothenberg (1993)	Based on Wildavsky's (1989) principles	<i>Principle of uncertainty</i> : irreducible uncertainty is universal <i>The axiom of connectedness</i> : good and bad are intertwined in the same acts and objects <i>The rule of sacrifice</i> : the safety or macro-stability of the whole is dependent upon the risk or instability of the parts
Cox and Cox (1996)	Integrated approach to safety systems	<i>Hardware</i> : technological & physical environment <i>Software</i> : management & work systems & procedures <i>People systems</i> : person, organisation, job
Rahimi (1995) Stang (1996)	Strategic safety management (SSM) System approach to investigation	<i>Culture change, long range planning, empowerment, leadership</i> <i>Human-machine system</i> : interactive and tightly coupled parts, the proper functioning of the whole depends on the proper functioning of the parts, the proper functioning of the parts depends on the functioning of the whole. Complex technology is prone to multiple failure sequences. The failure of a part may interact with other parts and lead to failure of the system as a whole. Multiple failure possibilities are an inherent and normal system characteristic. There are possible multiple failure sequences, that cannot be predicted on either design or operating levels. Some result from unplanned, unexpected interactions between parts of the system (complex interactions). The human operator is a system component that intervenes at the critical moment. Human failures are component failures, which may enter into complex interactions with other components. Human failures are part of a multiple failure sequence. There are some rare complex interaction sequences that will bring the system to a halt and eventually destroy it. High energy concentrations mean risk of system destruction and catastrophe for the system's environment.
Liu and McDermid (1996)	Relationships to describe a physical system for fault tree analysis	<i>Physical Connection relation</i> <i>Logical Connection (relation)</i> <i>Contain (relation)</i> <i>Control (relation)</i> <i>Input relation (materials or information)</i> <i>Output relation (materials or information)</i> <i>Get-Information-From (relation)</i> <i>Process relation (process materials or information)</i> <i>Other relations</i>
Weinstein (1996)	Total quality management (TQM) applied to safety	<i>Basic TQM concepts</i> : product/customer focus, leadership and commitment, company culture, effective communication, employee knowledge, employee empowerment, responsibility and excellence, management by fact, long-range view <i>TQM techniques</i> : statistical process control, structured problem solving, best techniques, continuous improvement, quality management, quality planning <i>Steps to installing TQM</i> : assessment & planning, implementation & organisation, cultural change, recognition & reward systems, leadership development, team building, hiring & promoting practices, management readiness, statistical & analysis techniques, training <i>ISO 9000 quality programme requirements</i> : management responsibility, quality system, contracts review, design control, document & data control, purchasing, customer supplied product, product identification & traceability, process control, inspection & testing, equipment inspection measurement & testing, inspection & test status, control of nonconforming product, corrective & preventative action, handling, storage packaging preservation & delivery, control of quality records, internal quality audits, training, servicing, statistical techniques

Appendix A (Continued)

Origin	Type	Key elements and description
Rasmussen (1997)	Socio-technical system	<i>Stages:</i> government, regulators & associations, company, management, staff, work <i>Environmental stressors:</i> political climate & public awareness, market conditions & financial pressure, competency & education, technology <i>Disciplines:</i> political science, law, economics, sociology, decision theory, organisational psychology, industrial engineering, management & organisation, psychology, human factors, human-machine interaction, engineering (mechanical, chemical and electrical) <i>Risk:</i> pure, speculative <i>Objects:</i> hazards, threats <i>Objectives:</i> eliminate, reduce, control, enhance utility/benefit, reduce/eliminate detriment <i>Contexts:</i> inner, outer, change <i>Methods:</i> management system, risk management
Glendon and Waring (1997)	Occupational safety management	<i>Executive leadership:</i> change culture, create high standards, democratic commitment <i>Training:</i> leadership, community, management, employees, accident investigation <i>Communications:</i> coordinate communications plan, communicate leadership commitment <i>Safety improvement processes:</i> implement safe work practices, implements practices, improve shop floor safety processes <i>Alternative work programme/return-to-work:</i> accommodate injured employees
Ansari and Modarress (1997)	Aircraft manufacturing industry safety strategy	<i>Management commitment and resources, employee participation, occupational health and safety policy, goals and objectives, performance measures, system planning and development, OHSMS manual and procedures, training system, hazard control system, preventive and corrective action system, procurement and contracting, communication system, evaluation system, continual improvement, integration, management review</i>
Redinger and Levine (1998)	Summary of occupational health safety management systems	<i>OHSMS principles</i> <i>Measurement criteria for each principle</i> <i>Suggested measures for each measurement criterion</i> <i>Data collection mechanisms</i> <i>Scoring/ranking scheme</i> <i>Methods for score/rank interpretation</i>
Redinger and Levine (1998)	OHS management system assessment components	<i>External environment:</i> stakeholders, regulating agencies/units <i>Open system elements:</i> continual improvement, integration, management review <i>Evaluation (OHS feedback):</i> communication system, evaluation system <i>Initiation (OHS inputs):</i> management commitment & resources, employee participation <i>OHS process:</i> formulation – OHS policy, goals & objectives, performance measures, system planning/development, manual & procedures <i>Implementation/operations –</i> training system, hazard control system, prevent/correct actions, procurement/contractors <i>OHS outputs:</i> OHS goals & objectives, illness & injury rates, workforce health, changes in efficiency, overall organisational performance
Redinger and Levine (1998)	OHS management system assessment instrument structure	<i>Stages:</i> root cause, immediate cause, incident, accident, consequences, impact <i>Risk reduction/prevention:</i> reduce frequency, reduce exposure, prevent accident, reduce consequences, reduce impact
Harrald et al. (1998)	Model the impact of human error in a maritime system	<i>Crew performance input factors:</i> individual aptitudes, physical condition, crew composition, regulatory environment, operating environment, professional culture, organisational culture, national culture <i>Crew and mission performance functions:</i> crew formation & management, aircraft flight control, communications, decision processes, situational awareness, operating procedures <i>Mission and crew performance outcomes:</i> safety, efficiency <i>Individual and organisational outcomes:</i> attitude, morale
Helmreich and Merritt (1998)	Aviation crew management – Crew performance model	<i>Air traffic control, workload, fatigue, complacency, maintenance</i> <i>Crew behaviour:</i> positive or negative – professional culture, national culture, training, organisational culture, safety culture, safe behaviour
Helmreich and Merritt (1998)	Aviation crew management – errors and defenses	<i>Compliance activity:</i> administrative, analytical, production formulation, packaging formulation, marketing, monitoring, information management <i>Compliance strategies:</i> production & operations, information technology, marketing, distribution, supply chain. <i>Regulatory responses:</i> stone-walling (doing as little as possible), opportunity seeking (to gain relative competitive advantage), mixed (new product development and marketing)
Loader and Hobbs (1999)	Food safety regulation response adapted from French & Neighbours (1991)	<i>Organisation and personnel, identification and evaluation of major hazards, design of new installations, operational control, including management of change, training and management of personnel, emergency planning, performance monitoring and audit.</i>
Hawksley (1999)	Major accident prevention policy (MAPP), EU directive	<i>Safety, health and environment (SHE) commitment, management and resources, communication and consultation, training, materiel hazards, acquisitions and divestments, new plant, equipment and process design, modifications and changes, SHE assurance, systems of work, emergency planning, contractors and suppliers, environmental impact assessment, resource conservation, waste management, soil and groundwater protection, product stewardship, SHE performance and reporting, auditing</i>
Hawksley (1999)	ICI Group SHE Standards	<i>Organisation and personnel, identification and evaluation of major accident hazards, operational control, management of change, planning for emergencies, monitoring performance, audit and review.</i>
Porter and Wettig (1999)	Safety management system, following EU directive	<i>Problem definition</i> <i>Problem analysis:</i> exogenous influences, traffic, accident statistics, possible measures, expert opinion <i>Risk model:</i> present risk, future risk <i>Evaluation:</i> risk limits, perception, acceptance, financial consequences, risk reduction
Van Urk and De Vries (2000)	Sea shipping safety – risk management	

Appendix A (Continued)

Origin	Type	Key elements and description
O'Hare (2000)	Taxonomy for aviation analysis based on Helmreich	<i>Hazards recognised, hazards unrecognised</i> <i>Global conditions:</i> policies, philosophy, procedures <i>Local precipitating conditions:</i> task demands, interface, resources <i>Local actions:</i> by frontline workers <i>Local level factors:</i> representation/interface (displays, controls, communication), task demands (complexity, coupling, dynamism, uncertainty/risk), operator resources (physiological, psychological, skills/knowledge, attitudes/motivation)
O'Hare (2000)	Ladder model of human information processing for aviation analysis, from Rasmussen	<i>Goal, strategy</i> <i>Diagnosis</i> <i>Procedure</i> <i>Action</i> <i>Information</i>
Bottelberghs (2000)	Risk management cycle	<i>Identification of risks</i> <i>Assessment of the identified risks</i> <i>Evaluation of risks on the basis of acceptability criteria</i> <i>Imposing risk-reducing measures</i> <i>Monitoring and maintaining the acceptable risk</i>
Standards Australia and Standards New Zealand (2001a,b)	Occupational health and safety management system	Part of the <i>overall management system</i> which includes: organisational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the OHS policy, and so managing the risks associated with the business of the organisation. <i>Continuous improvement process:</i> policy, planning, implementation, measurement and evaluation, management review.
Standards Australia and Standards New Zealand (2001a,b)	Occupational health and safety management system	Establish, implement and maintain documented procedures. For hazard identification, hazard/risk assessment and control of hazards/risks. For activities, products and services over which an organisation has control or influence. <i>Policy:</i> commitment integration & relevance, compliance, accountability, consultation, prevention
Suraji et al. (2001)	Construction accidents	<i>Distal factors:</i> constraints and responses creating conditions or situations in which accidents become more likely – physical & business environment, project conception constraints, project management constraints & responses, client responses, project design constraints & responses, construction management constraints & responses, subcontractor constraints & responses, operative constraints <i>Proximal factors:</i> inappropriate construction planning or control, inappropriate site condition, inappropriate operative action, inappropriate construction operation <i>Accident event:</i> undesired event, ultimate undesired event, undesired outcome
Herijgers et al. (2002) Pun and Hui (2002)	School safety policy and strategy Safety-focused quality management (SQM)	<i>Inspections, school rules, evacuation plan, accident registration, safety report</i> <i>Dimensions of standards:</i> Purposes, emphasis, eligibility, participants, evaluation, orientation, mechanics <i>Elements:</i> management responsibility, quality system, control review, design control, document & data control, purchasing, customer-supplied product, product identification, process control, inspection & testing, inspection & measurement, inspection & test status, control of non-conforming product, corrective/preventive action, handling, storage & delivery, control of quality records, internal quality audits, training, servicing, statistical techniques
Pun and Hui (2002)	Procedural guideline – implementation sequence	<i>Define corporate vision and mission</i> <i>Commit to change and improvement</i> <i>Develop safety-focused quality management objectives, goals and strategies</i> <i>Establish steering committee</i> <i>Identify critical processes and success factors</i> <i>Promote cultural change and team works</i> <i>Provide education and training to employees</i> <i>Incorporate with quality and safety management requirements</i> <i>Integrate the total quality management concepts and principles</i> <i>Build an integrated quality management system with safety focus</i> <i>Measure results and benchmark achievements</i> <i>Standardise improved procedures and practices</i> <i>Reinforce good safety-focused quality management practices with recognition and rewards</i> <i>Achieve performance excellence through continuous improvement</i> <i>Total environment:</i> safety future, local environment, production environment <i>Management system (FSMS):</i> policy implementation, co-ordination, functional, development, policy
Beard and Santos-Reyes (2003)	Fire safety management system (FSMS) structural organisation	<i>Organisational influences:</i> resource management, organisational climate, organisational process <i>Unsafe supervision:</i> inadequate supervision, planned inappropriate actions, failed to correct problem, supervisory violations <i>Preconditions for unsafe acts:</i> Environmental factors (physical, technological), condition of operators (adverse physiological states, adverse mental states, physical/mental limitations), Personnel factors (crew resource management, personal readiness) <i>Unsafe acts:</i> Errors (decision, skill-based, perception), violations (routine, exceptional)
Wiegmann and Shappell (2003)	Human factors analysis and classification system (HFACS)	<i>Implicit cognitive model</i> – human: knowledge, skills, rules <i>Machine state space</i> – state changes and machines states: normal, degraded, operator actions, machine induced events, flow induced events <i>Flow description</i> – flow
Vernez et al. (2003)	Petri nets theory based risk analysis and accident modelling	

Appendix A (Continued)

Origin	Type	Key elements and description
Leveson (2004)	Systems approach, classification of factors. STAMP (Systems-Theoretic Accident Modelling and Processes)	<i>Inadequate enforcement of constraints</i> – unidentified hazards; inappropriate, ineffective, or missing control actions <i>Inadequate execution of control action</i> – communication flaw, inadequate actuator operation, time lag <i>Inadequate or missing feedback</i> – not provided in system design, communication flaw, time lag, inadequate sensor operation <i>Primary characteristics</i> : 1. top-down systems thinking recognising safety as an emergent system property rather than a bottom-up, summation of reliable components and actions; 2. focus on the integrated socio-technical system as a whole and the relationships between the technical, organisational, and social aspects; 3. focus on providing ways to model, analyse, and design specific organisational safety structures
Lund and Aarø (2004)	Structure of safety systems	<i>Process factors</i> : attitudes and beliefs (person), social norms, safety culture (context) <i>Risk factors</i> : behaviour (person), physical and organisational environment (context) <i>Prevention measures</i> : behaviour modification, attitude modification (person), structural modification (context)
Australian Transport Council (2004)	The safe system framework	<i>Safer speeds, safer vehicles, safer roads and roadsides</i> Admittance to the system, understanding crashes and risk, education information supporting road users, enforcement of road rules Including alert and compliant road users and human tolerance to physical force
Ng and Chow (2005)	Airport terminal fire safety strategy	<i>Passive building construction, fire services installation, fire safety management, control of risk factors</i>
Mitropoulos et al. (2005)	Hazard-exposure-incident	<i>Exposures</i> : hazardous situations, efficient work behaviours affected by activity & context characteristics, unpredictability of task and conditions, efforts to control situations, production pressures, efforts to control behaviours <i>Incidents</i> : exposures, errors & changes in conditions affected by error inducing factors, error management Incident and consequences (from exposures and incidents) affected by protective measures
Loo et al. (2005)	Organisational activities for road safety strategies	<i>Vision, objectives, targets, action plan, evaluation and monitoring, research and development, quantitative modelling, institutional framework, funding</i>
Nadzam et al. (2005)	Patient safety strategy framework	<i>A culture of safety, reporting of adverse events and error-prone processes, communication about safety issues, analysis of reported adverse events, process redesign, application of technology, new safety enhancement activities</i>
Teo et al. (2005)	Framework for managing construction safety	<i>Policy</i> : understanding and implementation of SMS, understanding and participation in OHSMS, understanding and implementation of permit-to-work system <i>Process</i> : quality of subcontractors, understanding and implementation of safety procedures, carrying out work in a safe manner, carrying out work in a professional manner, type and method of construction <i>Personnel</i> : managements attitude towards safety, supervisors and workers attitudes towards safety, contextual characteristics of workers <i>Incentive</i> : monetary incentives, nonmonetary incentives, disciplinary action <i>General</i> : scope of project, interaction between new and existent facilities, etc. <i>Road structure</i> : road classification, design speed and structure of cross-section, etc. <i>Intersection</i> : number and types of intersections, visibility, layout, traffic flow, etc. <i>Road surface</i> : coefficient of sliding friction, pavement defects, surface condition, etc. <i>Delineation facilities</i> : pavement markings, delineators, lighting, road signs, etc. <i>Physical objects</i> : median strips, safety barriers/fences/shields, recovery zones, etc. <i>Natural environment</i> : weather: short- & long-term, wild animals, etc. <i>Road users</i> : automobile, pedestrian, bicycle traffic; etc. <i>Access & adjacent</i> : Development: access roads, development plans along the route, etc. <i>Winter conditions</i> : road weather information, road maintenance operation, etc. <i>Work system or structure</i> : person, organisation, technology & tools, tasks, environment <i>Process</i> : core processes, other processes <i>Outcomes</i> : employee & organisational, outcomes, patient outcomes
Hirasawa et al. (2005)	Road safety evaluation	<i>Layers of influences</i> : society, government (legislature/judiciary), regulator, senior management, middle management, line workers <ENUN>Categories <ENUN-P> concerns, influences, actions, failures
Carayon et al. (2006)	SEIPS – systems engineering initiative for patient safety	<i>Type of accident, industry where accident occurred, activity being carried out, components directly involved, causative factors (immediate and underlying), ecological systems affected, emergency measures taken</i>
Morley and Harris (2006)	Safety culture model	<i>Range of risks covered</i> : operational, process, fire, explosion dispersion, toxicity, environmental, internal domino, external domino <i>Do the results support</i> : investment decisions, siting decisions, zoning and planning, planning decisions of emergency response services, actual disaster abatement, by real time calculations <i>Risk decision steps</i> : scope are and hazard type, rank installations, identify and prioritise risks, estimate risks, propose actions, prioritise work, simulate risk identification, quantitative risk assessment, prioritise further action
Nivolianitou et al. (2006)	Major accident reporting system (MARS), EU directive response	<i>Causation</i> : genetic factors and environmental factors (including behaviours) affect good or ill health. Environmental factors include any biological, chemical, physical, psychological, economic or cultural factors that can affect health, <i>Natural history</i> : changes to health by subclinical changes and clinical disease result in death or recovery <i>Interventions</i> : Treatment, medical care, health promotion, preventative measures, public health services
Reniers et al. (2006)	Summary of risk assessment tools	
Bonita et al. (2006)	Epidemiological	

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Origin	Type	Key elements and description
Capon (2006)	Framework for sustainability and population health	<i>Ecological footprint</i> : Economy & work, transport & urban form, housing & building construction, nature & landscape, media & communication, culture & spirituality <i>Human health and wellbeing</i> : air, water, noise, infection, chemical exposures & climate, food, activity, safety, family relationships, social capital
GAO (2006)	US Occupational Safety and Health Administration (OSHA) safety programme components	<i>Management commitment</i> : establish goals, communicate to staff, information systems, establish programme responsibilities of managers and employees, accountability <i>Employee involvement</i> : reporting job-related incidents and damage, reporting hazards, access to accidents and hazards system, involvement in safety committee, employee input on safety-related training curricula, walkthroughs of worksites to identify hazardous conditions, accident investigation teams. <i>Education and training</i> : general awareness training, specified group training, monitor training <i>Identification of hazards</i> : required inspections, informal walkthroughs of worksites. <i>Following up and correcting hazards</i> : develop controls for workplace hazards, follow up on inspections, automated workplace hazard monitoring. <i>Medical management</i> : employees seen within specified time frame, automated accident data monitoring, restricted or light duty return-to-work programme, automated return-to-work status of employees monitoring.
Dandona (2006)	Road safety strategy	<i>Category</i> : magnitude of crashes, causes of crashes, prevention of crashes, legislation related to road safety <i>Measures relate to</i> : drivers, vehicles, road, traffic law enforcement, emergency care, publicity, others
Attwood et al. (2006)	Accident model for oil and gas industry	<i>External elements</i> : value of life, price of oil, shareholder pressure, royalty regime <i>Corporate elements</i> : corporate safety culture, corporate training programme, safety procedures <i>Direct factors</i> : behaviour (attitude, motivation), physical capability (co-ordination, fitness, lack of fatigue), mental capability (knowledge, intelligence) <i>Weather</i> <i>Safety design</i> <i>Personal protective equipment</i>
Reniers et al. (2006)	Risk assessment decision framework, based on Dept. of Defense	<i>Severity of consequences</i> : catastrophe, critical, marginal, negligible <i>Hazard probability</i> : frequent, probable, occasional, remote, improbable, impossible <i>Risk code/actions</i> : unacceptable, undesirable, acceptable with controls, acceptable
Standards Australia (2006a,b)	Railway safety management, general requirements	<i>General safety management principles</i> : establishing effective risk management, ensuring that emergencies and other occurrences can be properly managed, ensuring that interfaces between different organisations and organisational elements, protection of passengers, rail safety workers and maintaining public health, safety and security, and protection of property from damage <i>Implementation</i> : operational aspects, infrastructure aspects, rolling stock aspects, interfaces with other transport modes, Interfaces with other rail networks, human factors management. <i>Safety management system (components)</i> : safety management policy; allocation of responsibility and accountabilities; risk management system (risk identification, evaluation, analysis and control, maintaining a risk register; risk mitigation through an action plan that includes resources); policy and procedures for safety documentation, information and data control; procedures for personnel management; procedures for goods and services procurement; procedures for all life cycle stages of asset management (design, construction, operation, maintenance, modification and eventual removal); procedures for interface management; change management methods and procedures; procedures for disseminating information within the organisation and between organisations; emergency management; occurrence notification, investigation, analysis, developing safety actions and reporting in a 'just culture' environment; key safety performance indicators and performance monitoring; management review and auditing; security management; safety culture development and maintenance.
Gunduz and Simsek (2007)	Balanced scorecard	<i>Framework (goals & measures)</i> : customer perspectives, internal business, innovation & learning, financial <i>Perspectives</i> : financial & cultural, employee, process, learning
Classen et al. (2007)	Health promotion perspective	<i>Administrative & policy</i> : health education, policy, regulation, organisation <i>Educational and ecological assessment</i> : predisposing factors, reinforcing factors, enabling factors <i>Behavioural & environmental</i> <i>Epidemiological: health</i> <i>Social: quality of life</i>
Liou et al. (2008)	Factors of an aviation safety management system	<i>Communication, documentation, equipments, incident investigation and analysis, safety policy, rules and regulations, safety committee, safety culture, safety risk management, training and competency, work practice.</i>
Runyan and Yonas (2008)	Haddon model integrated with the social-ecologic framework (matrix)	<i>Phases</i> : precrash, crash, postcrash <i>Host factors and vehicle factors</i> <i>Relationship factors</i> : peers, parents <i>Physical and social environments factors</i> : institutions and organisations, sociocultural practices and norms
May et al. (2010)	Wellbeing paradigm	<i>Urban ecological impact</i> : economy & work, transport & urban form, housing & buildings, nature & landscape, media & communication <i>Human health and wellbeing</i> : air, water, noise, infection, chemical exposures, local climate, food access, physical activity, safety, family relationships, social capital
Zhou et al. (2008)	Safety climate factors	<i>Safety management systems and procedures, management commitments, safety attitudes, workmate's influences, employee's involvement</i>

Appendix A (Continued)

Origin	Type	Key elements and description
Bellamy et al. (2008)	Integrated functional model	<p><i>World of human factors, safety management, organisation</i></p> <p><i>Basic taxonomy</i></p> <ol style="list-style-type: none"> 1. Major hazards, onshore, chemical 2. Potential for accidents: hazards, triggers 3. Technical aspects: activities, technical measures 4. Organisation: complexity of design & process, external climate, organisational performance shaping factors (PSF's) 5. Safety management system: regulation specific (policy, organising, planning & implementing, measuring, audit & review) 6. Key risk control systems: design, operations, modifications, emergencies 7. Human factors: human factors PSF's, demands/stressors, capacities PSF's, psychological capabilities, anatomical capabilities, human behaviour outcomes <p>Accident outcomes: fire toxic release, explosion</p> <p><i>Warning themes:</i> safety management system, risk control, organisation, human factors</p> <p><i>Task competencies:</i> delivery system, major accident prevention measures, selection & training, competence</p>
Einarsson and Brynjarsson (2008)	Contributors	<p><i>Company:</i> organisational units, groups individuals</p> <p><i>Institutions/Governmental bodies:</i> external actors, contractors, fire authority,</p> <p><i>External:</i> workers environment authority, external environment authority</p> <p><i>Risks:</i> physical, process, emotional, communications, group</p>
Devine et al. (2008)	Framework for health promotion action – mining site	<i>Disease prevention, communication strategies, health education and empowerment</i>
McGraw et al. (2008)	Factors influencing clinical practice from Association of Litigation and Risk Management, based on Vincent et al. (1998)	<p><i>Institutional context:</i> economic and regulatory context, NHS executive, clinical negligence scheme for trusts, links with external organisations</p> <p><i>Organisational and management factors:</i> financial resources and constraints, organisational structure, policy standards and goals, safety culture and priorities</p> <p><i>Work environmental factors:</i> administration, building and design, environment, equipment/supplies, staffing, training, workload/hours of work, time factors</p> <p><i>Team factors:</i> verbal and written communication, supervision and seeking help, congruence and consistency, leadership and responsibility, staff response to incidents</p> <p><i>Individual (staff) factors:</i> knowledge and skills, competence, physical and mental health,</p> <p><i>Task factors:</i> task design, availability and use of protocols, availability and accuracy of test results, decision-making aids</p> <p><i>Patient factors:</i> condition, personal, treatment, history, staff–patient relationship</p>
Makin and Winder (2008)	Occupational safety management	<i>External environment, physical workplace, people, management</i>
Makin and Winder (2008)	Occupational safety 'safe system'	<i>Safe place, safe person, safe system</i>
May et al. (2010)	Social ecological model of road safety	<p><i>OHS policy, goal setting, accountability, due diligence review/gap analysis, resource allocation/administration, procurement, supply, competent supervision, safe working procedures, communication, consultation, legislative updates, procedural updates, record keeping/archives, customer service, self assessment tool, audits and system review</i></p> <p><i>Road safety:</i> Community, well-being, slow movement, sustainable transport, access to local shops, schools, services, localism</p> <p><i>Road crashes:</i> Individualism, consumerism, culture of speed, car/road dominance, closure of local shops schools & services, globalisation</p> <p><i>Road safety enhancers:</i> Peak oil, climate change, foresight</p> <p><i>Road safety inhibitors:</i> Cheap oil, road lobby, status quo</p> <p><i>Actions taken to reduce risk influenced by and informing:</i></p>
Sherman et al. (2009)	International classification for patient safety	<p><i>Contributing factors/hazards</i></p> <p><i>Incident type: patient characteristics, incident characteristics</i></p> <p><i>Detection</i></p> <p><i>Mitigating factors</i></p> <p><i>Patient and organisational outcomes</i></p> <p><i>Ameliorating actions</i></p>
Burns and Machado (2009)	Actor-system dynamics (ASD)	<p><i>Social structures:</i> political, economic, and cultural rule regimes – administrative systems, markets, democratic forms, medical systems, universities</p> <p><i>Socio-technical systems</i></p> <p><i>Physical & ecosystem structures:</i> time/space conditions, natural resources, opportunities, physical constraints, material payoffs</p> <p><i>Agency:</i> social actors, interactions</p> <p><i>Processes and outcomes generated:</i> production, distribution & exchange, innovation, deviance, power & control activities, socialisation & educational processes, conflict/competition, strategic structuring, modelling of physical & social systems, structural maintenance & reproduction</p> <p><i>Influences:</i> structural reproduction/elaboration/transformation, social structuring & selection, natural structuring & selection, impacts</p>
Whitefield (2009)	Safety management improvement	<p><i>Drivers (inputs):</i> 1. Knowledge of hazards, implementation of controls. 2. Identification of required management system elements, management systems model (AS/NZS4804), policies, procedures, instructions, forms, records. 3. Safety thinking mindset, leadership skills (leading safe behaviours, coaching safety thinking, rewarding positive behaviours).</p> <p><i>Safety management:</i> 1. Safety control (reactive, direct costs, quick improvement). 2. Safety management (proactive, direct and indirect costs, step change improvement). 3. Safety leadership (empowering, indirect costs, continuous improvement).</p> <p><i>Measurement activities (outputs):</i> 1. Workplace inspections. 2. Management systems audit. 3. Behavioural observation, safety attitude survey.</p>
Du and Liu (2009)	Air freight transport	<p><i>Human–machine–environment (H–M–E)</i></p> <p><i>Employees, management, equipments and dangerous goods</i></p>

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Origin	Type	Key elements and description
Lundberg et al. (2009)	Various models	<i>Social</i> : organisational values, relationships, trust, individual background <i>Technological organisational</i> : control hierarchy, internal regulation, incident reporting, safety audit, maintenance <i>Human</i> : consequences, compliance <i>Safety culture information</i> : availability, communication, safety relevance <i>Economy vs. production</i>
Katsakiori et al. (2009)	Types of model for accident investigation	<i>Causation models</i> : systemic (e.g., management oversight and risk tree), human information processing (e.g., work accidents investigation technique), sequential (e.g., occupational accident research unit) <i>Stand-alone techniques</i> : tree techniques (e.g., fault tree analysis)
Finch et al. (2009)	Group safety themes in recreational facilities	<i>Users</i> : casual, members, special needs <i>Staff</i> : management, programme, administration <i>Other</i> : Owners/council, insurers, professional bodies
Cassano-Piche et al. (2009)	Structural hierarchy and Accimap	<i>Government</i> <i>Regulatory bodies</i> <i>Local government</i> <i>Technical & operational management</i> <i>Physical processes & actor activities</i> <i>Equipment & surroundings</i>
Wegman et al. (1995), OECD (2008), Holló et al. (2010)	Road safety management system	<i>Results</i> : social factors, final outcomes, intermediate outcomes, outputs <i>Interventions</i> : planning, design and operation of the road environment, entry and exit of vehicles and people to the road environment, recovery and rehabilitation of crash victims in the road environment <i>Institutional management functions</i> : results focus, coordination, legislation, funding and resource allocation, promotion, monitoring and evaluation, research and development and knowledge transfer
Runciman et al. (2010)	Operational ontology of patient safety	<i>Contributing factors and hazards</i> : environmental factors, organisational factors, human factors, subject of incident factors, drugs equipment & documentation <i>Failure or penetration of defences</i> <i>Incident</i> : could have or did lead to loss or harm, near miss or adverse event, incident details <i>Factors minimising or aggravating outcomes or consequences</i> <i>Outcomes and consequences</i> : healthcare outcome for patient, consequences for the organisation <i>Action taken</i> : immediate, subsequent, planned, resource impact <i>Overall outcome (actual or potential) and resources impact and risk taking</i>
Hsu et al. (2010)	Dimensions and components of safety management system based on five international aviation standards	<i>Organisation</i> : safety policy, safety objective and goals, organisational structure, responsibilities & accountabilities, management commitment, performance measurement/baseline <i>Documentation</i> : identification and maintenance of applicable regulations, documentation describing system component, records management, information management <i>Risk management</i> : investigation capability, hazard identification, safety analysis capability, risk assessment, recommending actions based on safety metrics <i>Quality assurance</i> : safety performance monitoring, audits, change management <i>Safety promotion</i> : training, safety culture, safety lessons learned, communication, proactive process <i>Emergency response</i> : emergency response plan, risk management capability, emergency proactive action
ACT Government (2010)	Strategic plan for road safety	<i>Strategic goals</i> : Road trauma rates continue to be reduced despite increases in population and travel. The community shares the responsibility for road safety. Road safety co-ordination and support are improved. <i>Strategic objectives</i> : Safer speeds. Safer roads and roadsides. Safer vehicles. Safer road users. Improved coordination and consultation processes. <i>Countermeasures</i> : education, encouragement, engineering, enforcement, support.
Wang et al. (2010)	Quantified risk assessment (QRA)	<i>Factors</i> : human, machine or environment related <i>Events</i> : desired/undesired faults errors, anomalies <i>System behaviour</i> : safe/unsafe behaviour, accidents, incidents <i>Overall commitment to quality</i>
Wallis and Dovey (2011)	Modified Manchester patient safety framework	<i>Priority given to patient safety</i> <i>Perceptions of the causes of patient safety incidents and their identification</i> <i>Investigating patient safety incidents</i> <i>Team learning following a patient safety incident</i> <i>Communication about safety issues</i> <i>Staff management and safety issues</i> <i>Staff education and training about safety issues</i> <i>Team working around safety issues</i>
Miller et al. (2011)	Patient safety	<i>Raise awareness and improve working knowledge</i> : educate, network, create a safety culture, expand focus <i>Act and advocate to minimise harm</i> : Error reporting, leadership, enhance family-centred care <i>Apply best practice</i> : Adhere to best practice, target drug safety, redesign clinical systems, support research
Newnam and Watson (2011)	Light vehicle fleet safety	Pre-crash, At scene, Post-crash <i>Strategies</i> : management culture, journey, road/site environment, people, vehicle, society/community, brand <i>Intervention level</i> : organisation, work group, individual <i>Intervention focus</i> : senior level management, workgroup supervisor/fleet manager, individual driver <i>Intervention target group</i> : e.g., Director/CEO, pooled vehicle drivers, salary sacrificed drivers <i>Intervention strategies</i> : risk management (e.g., policies, procedures, database, recruitment, induction), leadership training, discussion groups/feedback/goal setting

Appendix A (Continued)

Origin	Type	Key elements and description
Roelen et al. (2011)	Causal modelling of air transportation system (CATS)	<i>Event sequence diagrams</i> (ESD): initiating event, pivotal event, end event <i>Fault tree</i> (FT): base event, intermediate event, human error, top event <i>Bayesian belief network</i> (BBN): managerial influences, human error probability
Ball (2011)	Process system management	<i>Leadership involvement & responsibility, identification & compliance with legislation & industry standards, employee selection, placement & competency assurance, workforce involvement, communication with stakeholders, hazard identification & risk assessment, documentation, records & process knowledge management, operating manuals & procedures, process monitoring & operational status handover, management of operational interfaces, standards & practices, management of change & project management, operational readiness & process start-up, emergency preparedness, inspection & maintenance, management of safety critical devices, work control, permit to work & task risk management, contractor selection & management, incident reporting & investigation, audit, assurance and management review & intervention</i>
Black et al. (2011)	Safety case	<i>Process:</i> 1. Safety plan: roles and responsibilities of stakeholders 2. Safety properties requirements: based on standards and culture 3. Preliminary hazard analysis Risk estimation is then completed on the hazards <i>Requirements, Safety Management, Safety, Control Measures, Hazard Intent:</i> 1. Programme management – management view 2. System purpose – customer view 3. System design principles – system engineering view 4. System architecture – interface between systems and component engineers 5. Design representation – component designer view 6. Physical representation – component implementer view System operations – operations view Part – whole: Environment, operator, system, verification & validation <i>Working environment:</i> workplace, work premises or general environment <i>Working process:</i> main type of work, task (general activity) being performed <i>Specific physical activity:</i> activity being performed just before the accident <i>Material agent of the specific physical activity:</i> the main agent associated or linked to the specific physical activity just before the accident. <i>Deviation:</i> the last event deviating from normality and leading to the accident, the event that triggers the accident. <i>The material agent of the deviation:</i> the material agent associated with the deviation – the tool, object, or instrument involved in the abnormal event. <i>Contact mode of injury:</i> the contact that injured the victim describes how the person was hurt (physical or mental trauma). <i>Material agent of the contact:</i> the main material agent associated or linked to the injuring contact
Jacinto et al. (2011)	Occupational accident reporting framework – ESAW (European statistics of accidents at work)	<i>Time, location, ship's properties, ship/ship's activity, cargo, environmental conditions, cause, other, exposure, marine event, consequence</i>
Mullai and Paulsson (2011)	Contributing factors to marine accidents	<i>Facilities in the practice, patient safety management, communication and collaboration, generic conditions for patient safety, education on patient safety</i>
Gaal et al. (2011)	Primary care health safety management	<i>Product life stages: raw materials, research design & development, production, commercialisation consumer use, disposal or recycling</i>
NSTC (2010)	Environmental health and safety research strategy	<i>Environmental pathways: air, water, soil, wastewater, landfills</i> <i>Transport and transformation: environmental conditions, biological conditions, primary & secondary contaminants</i> <i>Exposure (biota): aquatic, terrestrial</i> <i>Exposure (human): inhalation, ingestion, dermal absorption</i> Effects: ecosystems, humans
Department of Transport, Office of Rail Safety (DOT, 2011)	Comparison of rail safety management system content	<i>Safety policy; safety culture; governance & internal control arrangements; management, responsibilities, accountabilities and authorities; regulatory compliance; document control arrangements and information management; review of the safety management system; safety performance measures; safety audit arrangements; corrective action; management of change; consultation; internal communication; human factors; procurement and contract management; general engineering & operational systems safety requirements; process control; asset management; safety interface coordination; management of notifiable occurrences; rail safety worker competence; security management; emergency management; fatigue; drugs and alcohol; health and fitness; resource availability; independent investigations; codes of practice & guidelines (standards)</i>

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Appendix 4

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

Paper II



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



B.P. Hughes^{a,*}, A. Anund^b, T. Falkmer^{a,c,d}

^a School of Occupational Therapy and Social Work, Curtin Health Innovation Research Institute, Curtin University, Perth, WA, Australia

^b Swedish Road and Transport Research Institute, 581 95 Linköping, Sweden

^c Rehabilitation Medicine, Department of Medicine and Health Sciences (IMH), Faculty of Health Sciences, Linköping University and Pain and Rehabilitation Centre, UHL, County Council, Linköping, Sweden

^d School of Occupational Therapy, La Trobe University, Melbourne, VIC., Australia

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System

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.

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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.

* Corresponding author. Tel.: +61 8 6551 6140/+61 477 346 814; fax: +61 8 6551 6948.

E-mail addresses: brett.hughes@transport.wa.gov.au, banddhughes@bigpond.com (B.P. Hughes).

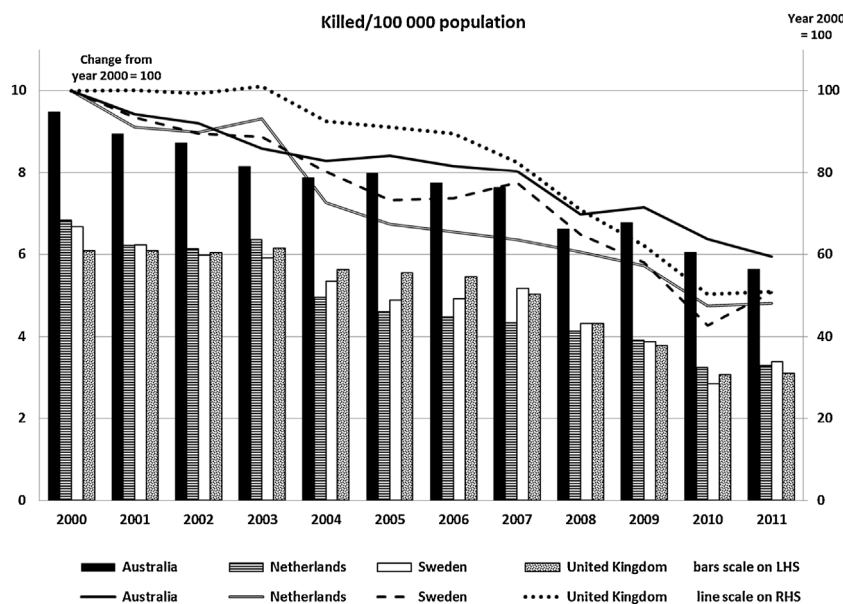


Fig. 1. Recent history of road safety outcomes in four countries. LHS = left hand scale, RHS = right hand scale. The x-axis represents the years 2000 to 2011. The curves represent normative data across the four countries.

'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: <i>Vision Zero</i> (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)	<p>Vision Zero is the philosophy and long-term guideline and traffic safety structure</p> <ol style="list-style-type: none"> 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 <p>Ten main themes, each clearly elaborated in a strategy, a set of specific actions or points of attention, and a timetable for their implementation</p> <ol style="list-style-type: none"> 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 <p>Note: This strategy was superseded by the Strategic Road Safety Framework in 2011, which was less clear in describing actions under categories</p>
United Kingdom: <i>Tomorrow's roads: safer for everyone</i> (Department for Transport, 2000)	<p>The strategy is based five principles:</p> <ol style="list-style-type: none"> 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 and 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 <p>Risk factors:</p> <ol style="list-style-type: none"> 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 <p>Key cornerstones:</p> <ol style="list-style-type: none"> 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 <p>Guiding principles:</p> <ol style="list-style-type: none"> 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 <p>Intervention priorities (a series of management functions focused on achieving results):</p> <ol style="list-style-type: none"> 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.
Netherlands: <i>Sustainable Safety</i> (Wegman and Aarts, 2006, Wegman et al., 2008)	
Australia: <i>National Road Safety Strategy: 2011–2020</i> (Australian Transport Council, 2011)	

Table 1 (Continued)

Strategy	Key components
Australia: <i>The National Road Safety Strategy 2001–2010</i> (Australian Transport Council, 2000)	<p>Strategic objectives:</p> <ol style="list-style-type: none"> 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 <p>Principles:</p> <ol style="list-style-type: none"> 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: <ul style="list-style-type: none"> – 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: <i>Vision Zero</i>	Eight guiding principles Fifteen headings Ten main themes	No	Yes	No, but implied	Yes	Not described
United Kingdom: <i>Tomorrow's roads: safer for everyone</i>		No	Yes	No, but implied	No	Observation and analysis, research
Netherlands: <i>Sustainable Safety</i>	Five principles Three high level risk factors	No	Yes	No, but implied	Yes	Road safety theory, observation and analysis, research
Australia: <i>National Road Safety Strategy: 2011–2020</i>	Four guiding principles Four 'cornerstone areas'	No	Yes	No, but implied	Yes	Observation and analysis, research
Australia: <i>The National Road Safety Strategy 2001–2010</i>	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: <i>Vision Zero</i>	Eight guiding principles	– ²	12 primary interventions	–	Based on crash record	–	–
United Kingdom: <i>Tomorrow's roads: safer for everyone</i>	Ten main themes	–	Numerous actions	–	Based on crash record	–	–
Netherlands: <i>Sustainable Safety</i>	Five principles. Three key risk factors (six sub-factors)	–	Generally described with implementation characteristics	–	Based on crash record	–	–
Australia: <i>National Road Safety Strategy: 2011–2020</i>	Four cornerstones. Four guiding principles	–	Eight intervention priorities	–	Based on crash record	–	–
Australia: <i>The National Road Safety Strategy 2001–2010</i>	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.

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Appendix 5

Government policy: The accidental effect on road safety

Paper III

**Government Policy:
The Accidental Effect on Road Safety**

Associate Professor Brett Hughes
Curtin - Monash Accident Research Centre, Curtin University
email: brett.hughes@curtin.edu.au

Abstract

This paper reflects on road safety strategy and explores economic aspects which affect road safety. Contemporary road safety policies generally focus on four key issues through the Safe Systems approach. Unlike other transport effects, transport and road safety policy do not estimate future outcomes for road safety. Consequently, these perspectives do not necessarily recognise the broader issues which also influence road safety.

Macroeconomic policy issues which could influence road safety in the long term are discussed, particularly the emissions trading scheme, taxation review, automobile industry review and road pricing. It is argued that government economic policies have the potential to affect road safety, despite reductions which result from other Safe Systems road safety policy.

The participation of advocates in the development of one of the economic policies shows that there is opportunity for greater participation to improve road safety outcomes in such policies. The paper concludes that economic policy has the potential to contribute to improvements in road safety.

Keywords

Transport Policy, Safety, Planning, Economics

Introduction

Modern road safety strategies focus on the key elements of drivers, vehicles, the road environment and speed. Unlike other outcomes, future outcomes for safety in the transport system are unknown. Wider economic policy, outside typical Australian transport or safety policy has the potential to affect transport and hence road safety. Some examples of these are explored with respect to possible effects. An example of the role of advocacy in arguing for safety outcomes in such policies is described. It is concluded that economic policy has the potential for positive safety outcomes, which are not being realised.

Foundations of Road Safety Strategies

The most contemporary road safety strategies adopt the 'Safe System' principles and framework, which has a long history. The foundations for this approach developed over many decades which Guarnieri (1) traced to Gordon (2) who had applied the epidemiological approach which assesses components of injury cause as: host, agent and environment. Importantly, Gordon separated the environment component in three distinct subcomponents; physical, biologic and socio-economic. Subsequently, but apparently independently, a series of papers by Haddon in the 1960's and 70's, resulted in a very useful and widely acknowledged matrix by Haddon (3). One axis of the matrix described three *Phases*: precrash, crash and postcrash. The other axis described four *Factors*: human, vehicles and equipment, physical environment and, socio-economic environment. In addition, Haddon recognised that *Results* occurred to different outcomes: damage to people, vehicles and equipment, physical environment and society.

There are also different versions of this matrix, such as the earlier and often used one developed by Haddon (4) with three columns, one of which is environmental factors. This version arguably makes environmental factors more difficult to define and take account of, because it would need to include the road, other road facilities, land use, the natural environment, the micro and macroeconomic elements, the

socio-economic factors and more. It would appear, perhaps as a consequence, that economic and social factors are not routinely or thoroughly incorporated in contemporary road safety strategies.

The implementation of contemporary Safe Systems approach to road safety, such as the Australian Transport Council (5), generally focuses on four core areas: speed (or more correctly energy), roads and roadsides (or sometimes infrastructure), drivers and vehicles. These elements are valid, but for policy, planning, program delivery and especially research, they are incomplete as described below. While setting valid targets for road safety, these polices generally don't estimate future safety outcomes.

The Safe Systems approach represents a new way of describing much of what has been described before, but include some important guiding principles. Typical safe system strategies, such as Road Safety Council (6), include principles such as:

- focus on reducing deaths and injuries;
- setting challenging and specific targets;
- recognise that drivers make mistakes;
- recognise the limits of the human body to withstand energy;
- creating a forgiving road-transport system;
- safe use of the road system; and
- integration and collaboration between contributing parties and authorities.

Transport systems can be described as being comprised of the fundamental elements of vehicles, infrastructure and users, although these three elements exist within a much larger setting. The fundamental driver of transport demand is the activity on and for land use, and the economy which it facilitates. Besides the four core elements described above which are the typical focus, there are innumerable interventions which individuals, governments and companies can use to affect the transport system and therefore safety. Then there are many more complexities added with community expectations, regulation, funding, three levels of government (four counting international obligations), and so on.

Future Transport System Outcomes

The Bureau of Transport and Regional Economics (7) estimated that between 2010 and 2020 population will increase by 10%, vehicle travel will increase by 18%, road freight by 32%, network delays by 24% and congestion costs by 58% in Australian cities. These increases will occur, even while improvements to roads, public transport and other elements of the system continue. However, there appear to be no estimates of transport safety for the future; fatalities, injuries, crashes or costs.

In terms of transport and health, the Bureau of Transport and Regional Economics (8) estimated that approximately 1500 people die on Australian roads each year, about 31,200 are injured. Many more are adversely affected by the financial, time and other costs of crashes, even if there are no injuries. The Bureau of Transport and Regional Economics (9) also estimated that about 1500 people die due to transport emissions and another 4,500 suffer health effects.

If the cost of road crashes described by the Bureau of Infrastructure Transport and Regional Economics (8) for 2006 is updated by the Consumer Price Index (10), and the economic assessment was based on the willingness to reduce the risk of death (generally called 'Willingness to Pay'), the cost of road crashes in Australia would exceed \$30bn per annum. The cost of health effects would be approx \$2.3bn. However, there are no estimates of what the death and health effects from the transport might be in future. Gargett et al (11) suggested that if there are no new policies, the fatality rate (deaths per population) in Victoria will stabilise at about 4.3 deaths per billion safety weighted km. If this occurs, the number of fatalities will start to rise, due to population increases, which may be in the order of 1% per annum according to the Bureau of Transport and Regional Economics (7). Accordingly, road safety policy needs to improve the performance of the transport system by 1% every year, just to keep the number of fatalities and injuries at the same level as is occurring at present, all other things being equal.

In the most recent summary of successful workers insurance claims, Safe Work Australia (12) shows that the industry category 'Transport & Storage' is the most dangerous industry in Australia, in terms of the number of deaths, in which 68 deaths occurred, while the next largest group had only 10 fatalities.

Transport and storage also has the highest number (9945) and percentage (7.6%) of total serious claims for any occupation subcategory and the highest fatality incidence rate (15.1 compensated fatalities per 100,000 employees). Furthermore, motor vehicles were the cause of another 30 deaths in other industry sectors. Motor vehicles are recorded as the cause of more deaths than any other means during work in Australia, 42% of work fatalities (98 deaths) in 2007–08. Again, there are no estimates of the safety record expected for the future.

It is implied that limits to the effectiveness of road safety measures exist, including increasing difficulty in introducing new measures, the increasingly smaller scale of benefits of safety measures and the reduced benefits which accrue for a given level of investment. For instance, the cost of road construction and the level of difficulties in introducing new measures both continue to rise (e.g. due to land acquisition cost), while the scale of measures and the benefits which accrue for a given level of investment continue to reduce. Collectively, these influences work to continually lower the benefit cost ratio of policies and programs, making the task of reducing the road toll in quantum (the total number of deaths and injuries) ever harder. For instance, the benefits of regulating for Electronic Stability Control, as opposed to relying on natural market take up, is estimated by the Department of Infrastructure, Transport, Regional Development and Local Government (13) to be worth \$139m and a saving of 128 lives over a thirty year period. While this benefit is no doubt worthwhile, it's not a substantial reduction.

Infrastructure Australia (14) suggests policies for Australia's transport future including: "*A national rail freight network development of our rail networks so that more freight can be moved by rail.*" and "*Transforming our cities increasing public transport capacity in our cities and making better use of existing transport infrastructure.*" However, this report does not propose any policy or principle to improve safety directly. In fact, virtually all the references to safety in this report, seven in all, refer to reducing the cost of regulation, which is an economic issue.

The result of the trends and influences suggest that transport demand will increase and so will consequences to an even greater degree. Expected future transport demands and transport system performance have the potential to result in higher road trauma consequences, despite reductions which result from specific road safety interventions. However, the future of the transport system in terms of safety outcomes is unknown. While a certain amount about future transport outcomes are known (or at least estimated), a considerable amount is also unknown, particularly safety. Consequently, there is a substantial gap between the information about future transport outcomes and the consequences of policy to achieve the desired objectives.

Economic Policy, the Transport System and Road Safety

Economic policies affect pricing, funding supply and demand for transport components and their use, and other financial aspects. Policies which increase the cost of transport decrease the amount of transport. From a reading of available transport policy and strategy, it would appear that there is generally very little content which relates to external macroeconomic issues, especially in road safety.

Economic policy is not restricted to financial elements, but can include regulation, behaviour change (information, awareness and encouragement), and other actions. Transport policy can also be regarded as an element of economic policy, or vice versa, depending on whether the prime area of interest is economics or transport. Such policy can affect the cost of cars, the use of roads, safety equipment, fuel, driver competence and much more. So, both economic policy and transport policy can affect all of the elements of the transport system and therefore road safety.

Reflecting on both the early concepts and contemporary road safety strategies, questions arise about the significance of economic and social influences and factors. Often these elements have limited recognition as 'socio-economic' determinants, such as in the World Health Organisation (15) which states "*Social processes often lead to poorer health in less affluent people.*" despite such factors being much broader than people's level of wealth. At other times, the economic factor is reduced to microeconomic benefit-cost analysis as described in the Australian Transport Council guidelines (16). Such analysis is at least both limited and inaccurate as stated in the guidelines, being subject to criticism as de Blaeij et al (17) and Hendrie (18) described with regard to the valuations of life.

Another effect occurs when a change occurs to a complementary or competitive mode. In introducing the Carbon Pollution Reduction Scheme Green Paper (an emissions trading scheme), the Department for Climate Change (19) describes changes which can occur to transport supply or demand, which result in small or large effects. Financial transactions can also affect transport. For instance, a charge on levied on cars can generate funds which are allocated to public transport, changing the price of both modes.

There are many economic influences outside the transport system which have the potential to affect road safety but take little account of the transport consequences. There is also little translation of transport safety issues to economic and other objectives, principles and policies, outside transport policy. The following examples describe recent Australian economic policies and their relevance to road safety.

Emissions Trading Schemes

There has been an enormous amount of science and policy written about climate change, and probably at least as much expressed as personal opinions. The issue rests on four key positions; climate change is occurring, change is due to greenhouse gas emissions, increases in emissions are caused by human activity, and the size of the change is large enough to cause substantial detrimental effect. If these points are true then it is appropriate for policy to be developed to manage responses to the consequences to an acceptable level. The two key responses are to reduce greenhouse gas emissions (mitigation) and to change systems to work within the new climate (adaptation).

In 2008, the Australian Government's principal policy response to climate change relied heavily on an emissions trading scheme so recent Australian Government policy development with respect to climate change includes reports by the Department of Climate Change (19) and the Australian Government (20). The government was also informed by numerous reports, papers, advice, submissions, and discussions which are too extensive to report here. There is some small recognition in these reports of the effect of these policies on transport. In fact, the understated theme is that transport is critically important to climate change. While the government response virtually exempts transport, Garnaut (21) clearly identifies the need for government economic policy with respect to oil price, emissions price, population, urban planning, rail, and public transport, especially to achieve modal shift.

In general, it would appear that the Australian Government position is typical of responses by other national governments:

- the effect of climate change on transport systems has not been assessed;
- the effect of climate change policy on transport systems has been only assessed to a limited degree;
- the potential for land use and transport (especially mode change) has been poorly accounted for in climate change policy or not at all (e.g. not in the European Union scheme).

Some exceptions exist, including the analyses of impacts by the Transportation Research Board (22), but they are rare and only represent a partial response to climate change and transport effects.

If it is accepted that transport will be affected by climate change policy, then it follows that transport safety will also be affected. The principle of emission trading schemes is that a price on carbon will reduce emissions by encouraging moves to more carbon efficient usage and reductions in demand. For transport this means travelling less and using more efficient modes of transport.

It is normally accepted that transport safety consequences are related to the amount of travel (sometimes called 'exposure'), as Gargett et al (11) used, as well as many others. This is so much a part of transport safety that rates (e.g. fatalities per million vehicle kilometre travelled) are used as a fundamental measure and exposure is implicitly accepted. Therefore, if an emission trading scheme is introduced which reduces travel, then the number of crashes, fatalities and injuries will reduce, thereby reducing the safety consequences, including cost.

An emissions trading scheme can have similar, but importantly diverse effects regarding the mode of travel. If the scheme increases the price of one mode of travel (e.g. by cars), the demand for travel will move from one mode to another (e.g. to public transport), depending on the relative cost differentials. Consequently, the exposure (and hence crashes) in one mode will reduce, but exposure (and again the number of crashes) in the other mode will increase. These changes are unlikely to be equal, since neither the shift from one mode to another, nor the relative safety of the two modes, are likely to be the same.

The total system consequences of these effects can be complex. For instance, if the price of transport fuel increases:

- smaller, more fuel efficient vehicles could be used which may have different safety ratings;
- there may be more two wheeled motorised vehicle use, which is less safe than in the vehicles being vacated;
- people can travel less, by shortening trips, combining trips or a whole variety of other trip modification;
- people can change to bus transport which will reduce the road toll due to superior safety performance;
- freight and passengers can transfer to rail transport which will reduce the road toll since it is no longer road transport and total transport system safety will improve due to rail's safety advantage.

No emissions trading scheme or climate change policy has been found which assesses any of these safety effects.

Industry Policy

The Review of the Australian Automobile Industry (RAAI) (23) was announced in February 2008. A discussion paper was released in March 2008, the Final Report in August and the Government's response in November 2008. Following the Discussion Paper there were 123 submissions which were posted on the Review website, although there are 133 listed in the RAAI Final Report.

Safety was not specified as an issue for the review, although it could have been included in a general reading of the scope, such as the sector's strengths and weaknesses, and future developments. There was however, a small section covering safety in the discussion paper. In the section on safety, the RAAI Final Report noted consumer and government demand for increased safety and government policy to harmonise safety standards. Notwithstanding the omission of safety as a specific issue, several of the submissions, including some from governments, raised the issue.

Vehicle policy offers many opportunities to improve road safety. Australian vehicle safety policy relies heavily on Australian Design Rules which are a powerful regulatory mechanism but not the only policy tool available. Various incentives can be given to manufacturers such as subsidies, or tax breaks for safety components or for manufacturing safety equipment. Industry subsidies for manufacturers, a key theme of the report as a whole, could be restricted to vehicles with higher safety features or crashworthiness, as they were for 'green' cars. Imported vehicles with lower crashworthiness or fewer safety features can have higher import duties imposed.

The RAAI Final Report (23) noted that a variety of vehicle safety issues, such as vehicle inspections and safety in older vehicles. Market issues can occur if Australian standards were out of step with international standards. ANCAP crash ratings were recognised with the implication that ANCAP labelling was acceptable as long as levels of crashworthiness were not mandatory.

The RAAI Final Report (23) concluded with seven key recommendations, predominantly regarding financial issues, industry assistance, subsidies and benefits from taxation and import costs. Conclusions regarding safety were limited to adhering to Australian Design Rules, standards uniformity and consistency with international obligations, which offer no incentive or requirement for manufacturers or consumers to improve vehicle safety. The RAAI objectives, content and outcomes contrast with the UK King Review of Low Carbon Cars (24) which considered safety as an integral component throughout, although in conclusion, even the King review made only one recommendation regarding safety.

Taxation Policy

An extensive review of the Australia taxation and transfer system was completed by the Australian Treasury (25) in December 2009 and released in May 2010, together with the Government's response. The review included conferences, discussion papers, research and two rounds of public consultation which generated over 1500 submissions. Due to the extent of the review, its process, content analysis and outcomes are much too expansive to summarise here. However one issue of detail, Fringe Benefits Tax (FBT), is described to illustrate the potential of taxation policy to improve safety.

The main themes of the review with respect to transport, were system efficiency, administrative efficiency and effectiveness of transport charges particularly road pricing. The review noted that safety,

like many other social effects are managed by 'non-tax policy tools' such as regulation and standards, or alternatively by charges, such as an emissions trading scheme.

According to Australian Treasury (26), FBT refers to "*Benefits received by employees from their employer in respect of employment that are in a different form to salary and wages, such as the use of a car for private purposes.*" Based on submissions, the Consultation Paper noted the link between FBT and both transport demand and therefore consequences: "*Many submissions raise the concern that the system of transport taxes distorts consumer decisions between public and private transport, as well as between road, rail and air travel.*"

Based on the RAAI Final Report it was noted that FBT on motor vehicles reduces with the amount of use (distance travelled). This reduction occurs at three thresholds (15,000km, 25,000km and 40,000km) at which point the FBT rate reduces stepwise. As a consequence it has been argued that FBT provides an incentive to drive further, although the main objections are environmental and in support of public transport. Figure 1, adapted from the RAAI (23), illustrates that some vehicles travel excess kilometres compared with what would be expected without an FBT. The consequences of the FBT incentive include encouragement to drive further and people are encouraged to drive in private cars instead of public transport or by other safer modes of transport, both of which increase crashes.

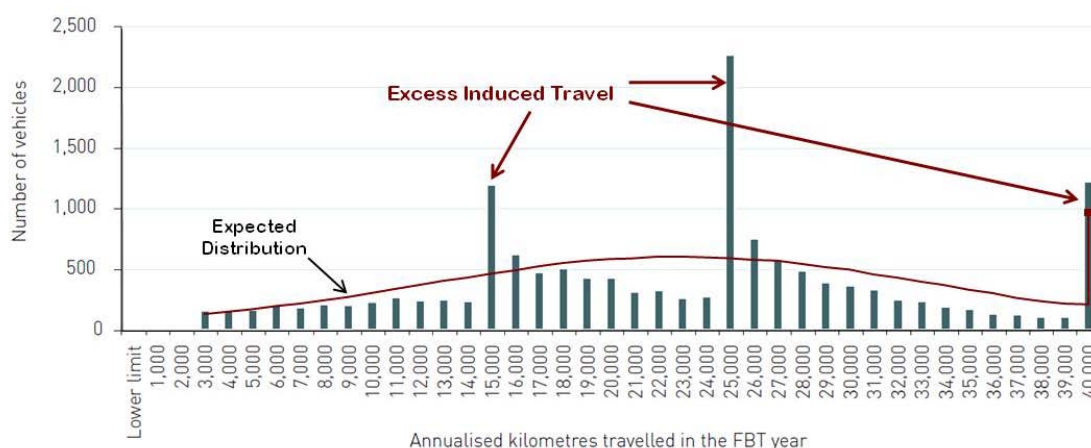


Figure 1: Vehicle Kilometres Travelled for Fringe Benefits Reporting Purposes.

In addition to FBT, there is the potential for many other taxation instruments to improve safety. As for vehicle policy discussed above, taxation policy offers many opportunities to improve road safety. These include incentives to use safer modes of travel, subsidies for safety features in vehicles, reduced costs for lower powered vehicles or those with higher crashworthiness, reduced road charges for safer travel, or tax reductions for manufacturing of safety components for manufacturers.

The taxation review by Australian Treasury (25) only recommended changes which would have reduced road transport demand and increased the amount of travel by public transport: "*The current formula for valuing car fringe benefits should be replaced with a single statutory rate of 20 per cent, regardless of the kilometres travelled.*" These changes would have reduced road trauma, however the extent that road safety would have improved is not known. The Government did not accept the recommendation.

Road Pricing and Charging Schemes

There are a wide variety of ways to charge for road use by pricing and charging mechanisms, as the Australian Transport Council (27) describes, including:

- cordon pricing (e.g. London and Singapore);
- registration charges;
- use charges (e.g. New Zealand's hub odometer system and log books for trucks);
- fuel charges (including Australia's truck charging); and
- parking charges (usage fees and charges for parking spaces).

Road user charging is a complex issue. Costs are attributable to different types of vehicles, times of day, road types, locations and externalities, amongst other things and there are many vagaries and inaccuracies. Road charges affect the cost of using roads and therefore the amount of vehicle use. If the amount of vehicle use reduces, then it would be expected that reductions in road crashes would follow.

For instance, if road charges are sufficiently high or more transparent, it could be expected that some travel would no longer occur, some car travel would transfer to buses, and some transport would transfer to trains. All these changes would be expected to lower the road toll. The last of these changes results in an increase in safety consequences in another mode, but lower transport system safety consequences as a whole due to rail's superior safety performance over road transport.

Hughes (28) describes that transfers of revenue from one source can be used to fund other outcomes, sometimes complementary. The Perth Parking Policy enables the collection of funds generated from licensing parking spaces in the Perth CBD which is applied to provide the Central Area Transit (CAT) bus service for free travel around the CBD. The users of the parking are often users of the CAT bus. Another example is the London cordon pricing scheme being used to fund public transport improvements.

New road user charging systems and other pricing mechanisms which can change travel are on several international agendas, including Australia. Therefore there are currently opportunities for safety improvements to occur as a result.

Industry Participation and Advocacy for Road Safety

Returning to the RAAI illustrates the participation of road safety advocates. Respondents to the RAAI did not demonstrate that safety was a priority, although this is mitigated to some degree by the omission of safety specifically in the terms of reference, background paper and questions to respond to. Of the 123 submissions publicly available, summarised in Table 1, only a handful mentioned safety and the largest number were from the automobile industry. None of the submissions were from road safety authorities, agencies, research institutions or entities with a predominant focus on safety. While the responses are probably as expected, there is no reason why road safety could not have been more strongly advocated.

Table 1: Summary of responses to the Review of the Australian Automobile Industry.

Submission No. and % of sector (row)	Road safety is a major issue (e.g. more than 20% of submission, full chapter or section, or at least 1 page with position and argument)	Road safety is a minor issue (e.g. full paragraph, or position and argument stated)	Road safety is peripheral (mentioned, but not discussed at all)	Road safety is not mentioned (not mentioned)	Total (including submissions not published)
Government	-	1 17%	2 33%	3 50%	7
Automobile Industry	3 8%	1 3%	16 44%	16 44%	42
Private	5 16%	3 10%	2 6%	21 68%	41
Association	4 18%	2 9%	5 23%	11 50%	22
Other	3 15%	1 5%	6 30%	10 50%	21
Total	15	8	31	61	

Notes: Respondents were not asked to respond regarding safety. 18 submissions were not published.

These submissions demonstrate that road safety is not generally regarded as an important issue by governments or industry involved in automobile manufacture in Australia. Road safety is regarded much more highly by others in the community. Advocacy groups representing general business and occupational safety did not generally participate. Unfortunately, road safety seems to be regarded as a transport problem, which is only partly true. In fact, it is a serious business problem, possibly the largest workplace safety issue based on data from Safe Work Australia (12). Sadly, the lack of participation in the RAAI by business suggests that road safety is being ignored as a workplace safety issue.

Potential for Economic Policy Contributions to Road Safety

The examples above illustrate that outcomes from economic policy have the potential to reduce travel demand, encourage one mode of transport over another, discourage particular vehicles and encourage safer vehicles. For instance, if transport policy affected transport in this way there could be potential for changes such as:

- reduced travel (trips not taken);
- travel substituted by teleworking, telecommunications, or working from home;
- trips reduced by multiuse (i.e. amalgamating purposes into a single trip);
- trips reduced by trip chaining (i.e. several trips joined into a single journey);
- car travel transferred to rail or bus public transport;
- trip lengths reduced by accessing closer facilities (e.g. shopping centres).

If each of these changes individually resulted in a 5% change in travel, the result would be a 26% reduction in road travel and therefore a 26% reduction in road trauma! At the same time, congestion in cities would be dramatically reduced, and in some cases eliminated for the medium term future. Such changes are likely to be more applicable to urban areas, although changes in rural and remote areas would also be valuable. If the average change for the transport system as a whole was 15%, approximately 225 lives would be saved and 4500 injuries would not occur, resulting in an economic saving of approximately \$4.4bn per annum. Other substantial benefits would accrue to the health sector and reduced economic costs of transport and infrastructure provision. On a pro rata basis from data published by BITRE (9), reduced transport emissions could result in the saving of 475 lives and 1125 health cases per annum, representing a saving of another \$700m per annum.

Seethaler and Rose (29) show these changes are achievable by travel behaviour modifications schemes. Economic incentives as described above, service improvements, and many other mechanisms are also valid to encouraging behaviour change by altering transport supply, prices, costs, transactions and quality.

Conclusion

Based on the principles and examples described in this paper, government policy and the future transport system's demands and performance have the potential to result in higher road trauma consequences, despite reductions which result from specific road safety interventions. However, the road safety consequences of fatalities, injuries and crashes are not described for the future or by policy outcomes.

While economic policy can affect transport safety, such considerations are generally not advocated in key recent Australian economic policy development, which do not describe transport safety consequences or potential benefits. Therefore, economic policy offers the opportunity to reduce road trauma.

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Appendix 6

Outcomes-based national road safety performance measures

Paper IV

Outcomes-Based National Road Safety Performance Measures

Hughes B.P.¹, Newstead S.² & D'Elia A.².

¹Curtin - Monash Accident Research Centre, Curtin University

²Monash University Accident Research Centre, Monash Injury Research Institute,
Monash University

Abstract

Traditionally, transport agencies tend to monitor and report on activities and outputs rather than real safety outcomes which are rarely measured apart from at the very broadest levels, for example changes in fatality counts. Recent developments in management theory, which have moved to measure performance in order to improve organisational efficiency and effectiveness, can be applied to transport safety outcomes.

This paper describes the road safety measures developed for the National Transport Commission (NTC) which sought to develop a range of outcomes-based performance measures, consistent with the most recent management concepts. The measures are formulated from a general framework for performance measurement which includes criteria for selection and content requirements.

This paper describes nine primary national and state road safety performance indicators in detail. It describes the intent and value of each measure and also relates them to rail safety performance measures for comparative purposes.

The national road safety performance measures described in this paper are comprehensive and practical for policy and operations management. The measures are important for safety focused road transport policy agencies, regulators, infrastructure owners and operators, primarily in government, but also in the private sector.

Keywords

Management, Outcomes, Measure, Performance, Indicator, Organisation

1 Introduction

Due to the diversity and levels of activity, the responsibility for outcomes from transport is shared amongst many government and private interests. National, State and Territory, and local government all have responsibilities for aspects of road and rail transport in Australia which may not be consistent. The National Transport Commission has responsibilities for some aspects of national transport performance across a range of outcomes. This paper reports the development of performance indicators for the NTC with respect to road safety.

The National Transport Commission (NTC) was formed as an independent statutory authority by agreement between the Australian, State and Territory Governments, to develop and coordinate regulatory reform for nationally consistent road and rail transport policies and laws, and for intermodal transport. NTC develops and submits reform recommendations to the Australian Transport Council (ATC) for approval and assists in co-ordinating and monitoring implementation of approved reforms. NTC proposed to develop performance indicators for its performance in five themes relevant to its objectives: transport productivity and efficiency,

safety and environmental performance, as well as regulatory efficiency and its own organisation strategies. The Council of Australian Governments (COAG 2009) challenged transport agencies to focus on outcomes of value to the community, rather than only on activities or outputs which relate to the operation of the organisation. The NTC proposed that performance measures should therefore be 'outcomes-based' as opposed to reporting 'activity' or 'outputs' and improve reporting consistency.

A review of the NTC (National Transport Commission Review Steering Committee 2009) noted: "*The next phase of transport reform will be challenging as the focus shifts from improving individual modes to lifting the performance of the national transport system as a whole. Reform development needs to holistically consider impacts on productivity, safety, pricing, network access and land-use planning and investment.*" Therefore the NTC sought to measure performance in all five of the areas identified in order to support reporting the outcomes of national transport reform.

In order to manage activities safely, problems need to be considered in the context of past and current operating conditions for improvements to be made: "*a problem can be defined as a situation that requires a revision of the currently initiated program of events. The schematic mode of control can only operate satisfactorily when the current state of the world conforms to the regularities of the past. The departures from routine demanded by these situations can range from relatively minor contingencies, swiftly dealt with by pre-established corrective practices, to entirely novel circumstances, requiring new plans and strategies to be derived from first principles.*" (Reason 1990).

The recently released Draft Australian National Road Safety Strategy (Department of Infrastructure Transport Regional Development and Local Government 2010) describes: "*The cornerstone interventions must be supported by a series of management functions focused on achieving results. These are addressed in Section 11, which outlines the priorities for: Adopting a results focus for the implementation of the strategy*" and "*Monitoring and evaluating road safety progress*". This approach relies on measurement of performance.

In response to the recent government context, the need to manage its own operations effectively and report on the national transport system as a whole NTC sought to develop modern measures of performance based on contemporary management and transport philosophies.

2 Study process

The National Transport Commission engaged the Curtin- Monash Accident Research Centre (C-MARC), with subconsultants to prepare performance measures for the five areas of its primary interest. The measures were to be based on contemporary management and relate to present government requirements, transport agency needs, transport system performance and community benefits (Hughes, Hopkins et al. 2011). This paper describes the road safety performance measure outcomes of the study and the relationship with the contextual framework, but does not describe nor substantiate the whole of the study basis and outcomes. The study premise that performance measurement is a valid management tool has not been tested, although it can be inferred from the large number of studies, the amount of management effort and organisational reporting which use the technique. Further discussion on this aspect including the management theory basis and practice is described in the report.

The study included the following stages:

- Reviews of:
 - transport and management literature to understand contemporary concepts,
 - government requirements from agencies with respect to reporting,
 - current practice in transport performance measurement to understand current practice and to relate to contemporary concepts and requirements; and
- Preparation of descriptions of:
 - selection criteria for performance measures,
 - specifications for performance measures,
 - proposed performance measures.

Each of the activities involved close collaboration between the study team itself to ensure a common basis as well as consistency of style and content. The team also collaborated closely with staff of the NTC to ensure requirements were met. The study did not require, and time limitations did not allow, any consultation with stakeholders.

3 Foundations for performance reporting

3.1 Management of safety performance

There are numerous methods and principles which can be applied to managing performance generally and safety in particular, and the reporting of results is an essential part.

A process to develop a management system to manage performance has been defined (Diamond 2005) with the following steps: defining performance measures, overcoming technical issues and ensuring the measures relate to the allocation of resources for the organisation's activities to occur.

The COAG Inter-Governmental Agreement (IGA) (COAG 2009) requires performance to be reported and notes that data quality is crucial. Therefore data should be: meaningful, understandable, timely, comparable, administratively simple and cost effective, accurate and, hierarchical. (Diamond 2005) proposes 5 desirable (or SMART) characteristics for performance targets: specific, measurable, achievable, relevant; and timed.

The Commonwealth Government of Australia accrual-based outcomes and outputs budgeting and reporting framework (Chan, Nizette et al. 2002) seeks to focus public-sector decision-making and accountability on three core issues: outcomes (the intended influence of the government on the community), outputs and administered items (the achievement of the government of the influence); and performance indicators (the means by which the government and the community describe the achievement of the influence in an efficient and effective way) (Chan, Nizette et al. 2002). The GOSPA model facilitates the definition of a specific evaluation structure via the following structural descriptions: Goal, Objectives, Strategies, Plans/Programs and Actions (Newstead and Diamantopoulou 2010).

In transport the PIARC framework for reporting performance in road agencies (PIARC 2004) describes four categories of reporting: road planning or operational indicators (both outputs form activities and social outcomes), indicators for physical structures (assets), functional indicators, and community indicators (relating to community impacts).

Agencies and other organisations measure performance, but doing so is only beneficial if it informs decisions to produce better results (outcomes), represent value to the beneficiaries, is useful in practice and relates to the management of the organisations activities. In other words the performance measures must be relevant and valid, and represent value, both for the community and governments, and operationally for transport agencies.

A question remains as to the value of performance reporting. There is no doubt that it is accepted in many fields of endeavour, including general industry, government, transport and road safety. However an assessment or evidence of the value of performance reporting, in itself in improving outcomes was not required in this study.

3.2 Transport safety performance measures

There are several important issues and details which should be applied when measuring safety performance generally (Reason 1990) which apply equally to road safety:

- there is a recognised problem (although it may be presumed rather than explicit) which may range from minor to catastrophic;
- there is a current situation, controls and a program of events;
- existing controls are relevant to previous practice and circumstances;
- fundamental change may be required to deal with the problems.

The components of a robust safety culture includes having good data through a safety information system (Reason 1997). Measuring safety performance is as fundamental to managing the transport system as a whole, as it is to the agencies, organisations and individuals which are an integral part of it. Making useful and effective improvements is difficult and unlikely without understanding of the existing situation and problems. This requires understanding of the system conceptually and analytically, including measures of performance.

There are many possible measures for road safety used in the academic literature, by government agencies and by others. These commonly focus on the number of people killed and injured, and rates compared with travel and population as well as quantifiable social costs of crashes expressed in financial terms. However, these high level indicators are generally too broad for use in policy development and strategic planning, so more disaggregated measures are often sought and used. This results in a multitude of inconsistent measures notwithstanding the possible rationale for their validity individually. Indeed one measure may be very appropriate for one circumstance and irrelevant for another.

In the case of the NTC, one criteria considered valuable was consistent measures to compare road and rail transport, since the NTC has responsibilities for both and because the modes compete for demand and government intervention. It is also highly desirable to have measures which can be aggregated and disaggregated by State, for different types of use, or by types of vehicle. This is partly because it reflects how the data is often originally collected and how it can be used for practical purposes.

The survey of agencies reported in this study demonstrated that agencies can and do measure activities, (which translate inputs into outputs), outputs (the means produced by agencies which achieve outcomes) and outcomes (results which have value to others). In transport, intermediate consequences exist, such as the amount of travel, asset value, mode share or

financial values of consequences (benefits and costs). However, there is a predominance of activity, output and intermediate measurement compared with outcomes.

The purpose of rail safety reporting (ATSB 2010) could equally be applied to road safety: *"to assist rail safety professionals and researchers in understanding and mitigating risk. In addition, it can be used for international comparative research, while informing the public about emerging issues in rail safety."* Indeed in this study, road and rail safety were considered together.

The crucial initial question regarding safety surrounds the definition of what it is, so that it can be measured for a variety of purposes. BITRE (Bureau of Infrastructure Transport and Regional Economics 2009) concludes: *"The definition of a road crash is essential to costing the economic impact of road crashes and comparing changes over time. Not all accidents on a road are considered by authorities to be road crashes, and not all crashes occur on public roads."* and *"Equally important is that this definition of road crash excludes suicides and homicides; events indirectly related to a road crash; off-road crashes...and collisions involving only non-road vehicles."*

The European situation is similar to Australia where the following issues in reporting road safety between countries are critically important (SafetyNet 2004):

- the only comparable measure of reporting is fatalities;
- for non-fatal crashes there are widely different definitions of severity; and
- there is significant underreporting of non-fatal crashes.

The reasons for measuring safety performance have been summarised (European Transport Safety Council (ETSC) 2001) as:

- reporting on (real) underlying performance when short-term fluctuations occur;
- to report accurately;
- to understand what leads to crashes;
- to inform the development of effective countermeasures;
- to highlight problems as they develop before substantial consequences occur;
- to demonstrate the effectiveness of countermeasures and programs; and
- to monitor progress and improve performance.

Targets for road safety are an essential part of vision-based contemporary road safety strategies. Therefore, being able to measure the outcomes is essential if targets are to have any meaning in reality and utility for management to make improvements (Wegman, Lynam et al. undated). For the Swedish 'Vision Zero' Road safety strategy initially only six key indicators were chosen; speed, seat belt, car safety, rural roads, urban roads, drink-driving and bicycle helmets (Berg, Strandroth et al. 2009). Subsequently these were expanded to 13 indicators: speed (state roads), speed (municipal roads), drink-driving, seat belt, bicycle helmets, car safety, safe heavy vehicles, rural roads, urban roads (crossings for pedestrians and cyclists), urban roads (crossings for cars), urban roads (sum), rapid and qualitative emergency care, non-fatigue, valuing of road safety. Other parameters were described for each of these including exact measurement, objective, starting point and effect on fatalities.

National road safety indicators typically include road accident fatalities, fatalities per 100,000 population, fatalities per 100,000 motor vehicles (Elvik 2008), (IRTAD 2009). Less

commonly reported are the number of people seriously injured or injured, crashes, and the total cost of road crashes.

There are many difficulties in reporting these figures. Countries and Australian States use different definitions, even for death, depending for instance on the elapsed time or other circumstances (e.g. suicide). Data can be difficult to collect accurately, particularly for non-motorised vehicles and pedestrians. Countries have different criteria as to whether crashes are reported (Elvik, Høy et al. 2009), which is also true for Australian States.

The primary target outcomes may be the total social cost of road crashes (OECD 2009) or the numbers of people impacted. The social cost is a poor measure for comparison between countries, since the value of human life and quantifiable financial costs are much lower in developing countries than developed countries. It is important to not have too many indicators. Focus on a few key indicators which have a major effect on road safety is more effective (Elvik 2008).

Recently there has been more recognition of 'exposure' as an important parameter for relative comparison since it is a most objective measure of exposure to risk, so fatality rate (fatalities per billion vehicle kilometres travelled) has often been reported (IRTAD 2009). Population has been used as another comparator for normalising the outcomes, which relates to public health measures.

The consequences of road 'unsafety' are twofold:

- direct personal effects (death, injury, pain and suffering, lost quality of life, etc.); and
- financial effects (including property damage to vehicles, infrastructure and product, lost production, etc.).

Measures of these two primary effects could be used for reporting performance. However, many of these consequences can be measured diversely. Absolute numbers, years of life lost and, dollar costs are but a few and all of the alternatives, all of which can be normalised with relative rates, as noted above. Despite many measures being possible, suggested or used, clearly the highest level indicator is the number of people killed and injured (or seriously injured).

A survey of Australian road and transport government agencies and industry annual reports, corporate plans and performance reports identified nearly 30 individual measures of performance in addition to activities and outputs. Twelve documents reported measurable safety indicators, but six documents had no measurable safety performance indicators. Public transport safety performance reporting may include road and/or rail transport, so the road safety performance may combined and not be clearly distinguished.

A useful property of performance measurement data is scalability to vehicle types, regions, types of roads. Such disaggregation is necessary to identify specific issues worthy of being addressed specifically. However, stratified data results in too many indicators and too much detail for strategic purposes and detailed data is not always available.

3.3 Performance measure selection and specification

As a result of the review of management literature, Australian government requirements and transport agency practice, the following criteria were set to choose the relevant measures to report transport performance:

- policy relevance;
- accessibility;
- representativeness and validity;
- reliability;
- simplicity; and
- outcomes-focussed.

Based on the selection criteria, each of the proposed measures need to be described in order to be used. The descriptions included the following components:

- title - name of the indicator;
- purpose - why it is being measured;
- object - what is being measured;
- metric and direction - definition of the indicator (e.g. dimensions) and in which direction is progress measured;
- data requirements - what the input data is;
- data collection methods - how the data is collected;
- timing - whether a short or long-term indicator, any delay in reporting and any timing issues;
- ownership - the source of the data and the agency which reports it;
- reliability - consistent across states, modes, internationally, etc.;
- relationships - links between the performance indicators and other proposed indicators;
- future developments - such as improving accuracy, reduced cost, improving consistency, etc.; and
- other information - any other issues, comments, problems, opportunities, other information, etc.

4 Proposed national road safety performance measures

The proposed performance measures are detailed in Tables 1a, 1b and 1c. Two other specifications included are not shown here; ownership and other information. Ownership describes the agency responsible for collecting and maintaining the data. Other information includes some additional specific detail with respect to the measure which should be noted.

The performance measures proposed are largely consistent with other jurisdictions (Breen 2004), (IRTAD 2009), with a few particular differences. Performance measures can also be interpreted from strategy target measures. However, there will be some differences between reporting, despite intentions to standardise.

There are numerous other measures which could be devised although in practice this normally occurs with stratification into sub-categories. Road user grouping is perhaps one area of reporting which is perhaps more useful for further measures. In particular, vulnerable road users (especially indigenous users, young users, older users, pedestrians, cyclists and motor cyclists) are overrepresented in safety statistics and are sensitive for the community.

It is desirable for the performance measures to relate to agency philosophies and operations. In the Safe Systems approach to road safety, vehicles, roads and speeds are physical elements which are relatively easy to measure, assess and monitor. The pillar which is most subjective and variable is the road user who responds biologically, emotionally and intellectually in ways which are not only difficult to determine, but also difficult to measure and manage.

Therefore performance indicators for road users are possible but are often difficult to measure, are subject to variability and may only apply to certain sub-groups rather than the population as a whole.

A great range of additional or alternative performance measures may be justifiable or even preferable. Some indicators, such as "The traffic weighted percentage of State road length which meets AusRAP standards" may not be as robust as other measures, due to difficulties in measurement. The safe speed measure assumes that speed zones are set consistent with Safe Systems principles. This is unlikely to be the case given the relatively recent development of Safe Systems, its gradual introduction in practice, and the extended length of time for speed zones to be reviewed. An alternative indicator may be the proportion of roads with speed zones which comply with safe systems principles.

Table 1a. Road Safety Performance Indicators (1-3)

Component	Details	Details	Details
Indicator Title	1. Fatalities and Serious Injuries 1.1 Road	2. Safe Vehicles	3. Safe Roads
Purpose	To measure human impacts on individuals in society	To indicate the improvements in passenger vehicle safety which are occurring	To indicate the improvements to road infrastructure to improve safety which are occurring
Object	The number of people killed and seriously injured	The level of vehicle safety quality of new passenger cars	The level of safety quality of roads
Metric and Direction	The number of people killed according to current definitions (<i>lower is better</i>) The number of people seriously injured according to a definition yet to be agreed (<i>lower is better</i>)	The percentage of new passenger car sales which are 5 star ANCAP rated (<i>higher is better</i>)	The traffic weighted percentage of State road length which meets AusRAP standards (<i>higher is better</i>)
Data Requirements	Data on fatalities from current records Data on seriously injured people from police and hospital matched records	ANCAP crash ratings by passenger car type New passenger car sales numbers	AusRAP road assessments for State roads AADT traffic counts or for State roads
Timing	Fatality data is available at reasonably short notice Collection of data on serious injuries will take time to implement when agreed Collection of data on serious injuries will have a delay in reporting as data is cleaned and matched	Short-term indicator of policy outcomes Long-term indicator of safety outcomes Reasonably short delay in reporting	Long-term indicator of network safety Reasonably short delay in reporting
Reliability	Fatalities are generally consistent across Australia and internationally Serious injuries require agreement of definition	Quite reliable, but may need interpretation or estimation for some vehicle types	Reliability is dependent on the quality of data which may be quite variable.
Relationships	This data is required for other safety indicators which follow relating to exposure	Contributes in the long-term to other road safety indicators	Contributes in the long-term to other road safety indicators
Future Developments	Serious injuries are a development of existing reporting This data can be usefully disaggregated into many categories including State and Territory, owner group (government, corporate, private), mode (car, truck, rail, motorcycle, cyclist, pedestrian), region, road type, etc.	Could be extended to commercial vehicles and trucks Could possibly be used for international comparisons, although inconsistencies in crash analysis exist.	Could be extended to local roads, perhaps by sample

Note: Indicators 1.2, 4.3, 6.2, 7.2, 8.2 and 9.1 refer to related rail safety performance measures for railway operations, but are not included in the description above.

Table 1b. Road Safety Performance Indicators (4-6)

Component	Details	Details	Details
Indicator Title	4. Safe Drivers 4.1 Seatbelt use 4.2 Alcohol and drugs (road drivers)	5. Safe Speeds	6. Fatality and Serious Injury Rates for Passenger Travel 6.1 Road passenger safety
Purpose	To indicate the level of driver safety	To indicate the level of safe road use	To understand relative levels of passenger safety between modes and related to travel
Object	Driver safety	Safe speed of road use	The number of people killed and seriously injured in passenger vehicles compared with the amount of passenger travel
Metric and Direction	Percentage of vehicle occupants using seatbelts (<i>higher is better</i>) Percentage of drivers not exceeding drug and alcohol thresholds as assessed by test (<i>higher is better</i>)	Percentage of vehicles not exceeding the speed limit (<i>higher is better</i>)	The number of people killed and seriously injured divided by the passenger kilometres of travel (<i>lower is better</i>)
Data Requirements	Number of occupants and number properly restrained Number of drug and alcohol tests and number of people who pass the test	Speed and traffic volume data	Fatality and serious injury numbers (as above) Passenger travel by road
Timing	Long-term indicator of driver safety Reasonably short delay in reporting	Short-term indicator of driver safety Medium delay in reporting, data will take time to collate	Travel data will take time to collect and collate The indicators using serious injuries are not yet possible
Reliability	Reliability is dependent on the quality of data which may be quite variable.	An accurate indicator when reported properly	Fatality and injury data as above. Travel data reliability is varied, but likely to be sufficiently accurate and has been used previously
Relationships	Contributes in the long-term to other road safety indicators	Contributes in the long-term to other road safety indicators	These indicators provide additional information to the first safety indicators and rely on these for data
Future Developments	Methodology for restraint surveys needs development	None identified	Definitions of people included (in passenger travel) need to be agreed Data on passenger travel needs to be verified for accuracy

Table 1c. Road Safety Performance Indicators (7-9)

Component	Details	Details	Details
Indicator Title	7. Fatality and Serious Injury Rates for Freight Travel 7.1 Road freight safety	8. Social Costs of Transport Crashes 8.1 Road	9. Signal Violations 9.2 Traffic Control Signal violations 9.3 Railway Level Crossing Signal violations
Purpose	To understand relative levels of freight transport safety between modes and related to travel	Economic costs are an important measure for governments and for comparisons with other sectors	To measure the compliance of drivers to control signals and therefore the level of risk which occurs
Object	The number of people killed and seriously injured in crashes involving freight vehicles compared with the amount of freight travel	The total cost of crashes to the community	The proportion of red control signals which are passed by drivers
Metric and Direction	The number of people killed and seriously injured in crashes involving freight vehicles divided by the freight tonne kilometres of travel (<i>lower is better</i>)	Annual dollar costs (<i>lower is better</i>)	The proportion of signals passed by train and road drivers (<i>lower is better</i>)
Data Requirements	Fatality and serious injury numbers Freight travel by road Freight travel by rail	Methodology for road crashes has recently been reported by BITRE Data is available if updated annually, but should be reviewed regularly (e.g. 5 yearly) Data for rail crashes is out of date and needs to be recalculated	Number of SPADs and number of signals passed provided by railways through the Rail Safety Regulators(s) Number of Traffic Control Signal and Railway Level Crossing Signal violations and traffic volume
Timing	Travel data will take time to collect and collate The indicators using serious injuries are not yet possible	It is unlikely that all data can be recalculated annually, however, regular updates (say 5 yearly) supplemented by annual incremental changes should be adequate	Rail SPAD data is routinely available and should be available within months of the end of the reporting period Road signal data will take time to collect and report
Reliability	Fatality and injury data as above. Travel data reliability is varied, but likely to be sufficiently accurate and has been used previously	If a common national assessment is undertaken the reliability is dependent on the data described above	Data should be reasonably consistent across sources
Relationships	These indicators provide additional information to the first safety indicators and rely on these for data	These indicators provide additional information to the first safety indicators and rely on these for data	This indicator should be a leading indicator of fatalities and serious injuries for serious crashes
Future Developments	Definitions of people included (in freight travel) need to be agreed Data on passenger travel needs to be verified for	The current methodology is likely to change from 'Human Capital' approach to a 'Willingness to Pay to Avoid Risk' approach	Data details should be verified with providers

accuracy

As a result of these considerations, it may worthwhile to undertake further investigations to assess a much wider range of measures for inclusion, **However, all of the proposed measures meet the objective criteria suggested by the investigation of management and practice.**

5 Conclusion

Implementing the proposed performance measures will be challenging due to inaccuracies in reporting and inconsistencies between agencies. Some indicators can be reported currently while others will require considerable negotiation and agreement prior to use. Collecting information on performance will always involve a cost, and while many measures are currently available within existing cost structures, others will involve some additional cost. However, none of these issues are insurmountable for any of the indicators. The greatest impediments may be to move towards outcomes based measurement or an unwillingness to change.

Difficulties in providing suitable data abound in performance measurement. Data which is desirable may be unavailable, costly, delayed, inconsistent, inaccurate and/or sensitive (politically, personally or to an agency). Notwithstanding these limitations, the performance measures proposed are comprehensive and practical for policy and operations management, and can be used by any safety focused road transport policy agencies, regulators, infrastructure owners and operators. While these will primarily be in government, the measures are also valid, useful and necessary for use within but also in the private sector.

In this study, a consideration was data which was relevant across indicators and to both road and rail safety, despite differences of approach in the different transport modes. For instance, the number of people killed and seriously injured is relevant to both modes, but seatbelt use is only relevant to road vehicles. Signals passed at danger (SPAD's) are a widely used measure in the rail industry, partly due to the very low number of actual incidents which result in harm. Such 'near miss' measures would represent a massive number for road safety and probably impossible to collect in practice, even by sample. However, measuring violations at traffic signals is analogous to SPAD's and very relevant at railway level crossings.

The proposed measures are contemporary, reflecting current management concepts, government requirements and modern transport and road safety practice. Despite many measures being possible, suggested or used, clearly the highest level indicator is the number of people killed and injured (or seriously injured). The study met the requirements of the NTC in developing performance measures consistent with contemporary practice to be: meaningful, understandable, timely, comparable, administratively simple and cost effective, accurate and hierarchical.

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Appendix 7

**Data foundations for relationships between economic and transport
factors with road safety outcomes**

Paper V

Data foundations for relationships between economic and transport factors with road safety outcomes

by Brett P Hughes¹, Stuart Newstead², Sahar Shafiei³ and Sandra Hopkins⁴

¹School of Occupational Therapy and Social Work, Curtin Health Innovation Research Institute, Curtin University

²Monash University Accident Research Centre, Monash Injury Research Institute, Monash University

³Curtin - Monash Accident Research Centre, Curtin University

⁴Centre for International Health, Curtin University

Abstract

Economic conditions and policies affect transport, resulting in road safety consequences. This paper describes the selection, acquisition, description and assessment of available, appropriate and suitable data for research of this topic.

Data on economic, transport, and road safety were collected and subjected to exploratory analysis and basic diagnostic tests, finding it to be generally suitable to support further analysis, with qualifications and limitations. Appropriate, and suitable data were found to support analysis of the relationships between economic and transport factors and road safety outcomes.

Simple regression models identified initial, basic relationships between four road safety outcomes and nine economic activity factors reinforcing the importance of these factors as determinants of road safety outcomes. Characteristics of the data dictated more sophisticated analysis is required to produce more reliable results. The data and initial information provides a solid foundation to base further investigations of relationships between economic and transport factors with road safety.

Keywords

Estimate, Fatality factor, Macroeconomics, Model, Road safety

Introduction

The need for people to travel and goods to be transported is described as a 'derived demand' meaning it is not an end in itself, but serves a more fundamental purpose. Transport is a necessary facilitating activity for industrial, community, commercial or other 'economic activity'. Travel generally results in crashes, with human, financial and other intangible consequences. Relationships between economic factors, transport factors and road safety outcomes have been investigated previously, but employing different methods and with varying results.

Many subsequent analyses can occur if economic factors can be related to road safety outcomes, so this work provides a foundation for further research, including:

- forecasting future safety outcomes;
- estimating the effect of changing economic conditions;
- estimating the effect of strategies and policy or program countermeasures; and
- assessing the effect of economic, transport, land use or social policies (such as taxation, or road pricing).

Before embarking on investigation of relationships, it is essential to understand the purposes of identifying relationships and the suitability of the data for the analysis. Both the analysis and the data must be 'fit for purpose'. This paper describes the selection, acquisition, description and assessment of available, appropriate and suitable data for further research of the economic influences on road safety, and some initial results.

The objectives of the early stages of this study include:

- identifying key findings relating from previous work regarding the association between changes in the economy and road crashes;
- describing the association between economic variables of the Western Australian economy and serious casualty crash outcomes; and
- preparing data and estimates suitable for further policy and forecasting analysis.

The following data were collected and used as the parameters in this study:

- economic factors (production, consumption, employment, fuel, etc.);
- transport system variables (vehicle kilometres travelled, speed camera use, etc.); and

- road safety outcomes (crashes, crash severity, crashes by road user).

This paper reports the following first stages of a larger, more comprehensive research project and includes:

- the description and review of data;
- diagnostic testing to ensure suitability of data;
- investigation of interrelationships within economic, transport and road safety data groups;
- initial investigation of relationships between and within economic and transport factors and road safety outcomes; and
- discussion and description of results.

This work is consistent with robust analysis producing sound conclusions, by recognising and dealing with three essential, distinct and complementary elements:

- a rationally based conceptual and analytical framework;
- the appropriateness and validity of data; and
- a valid statistical analytical method.

The first of these requires description and explanation beyond what is possible here, in order to provide a justifiable logical basis. Therefore this description based on theory and practice is to be described in further papers which are in preparation, although the concepts are based on previous literature.

Background

There are a great many measures representing economic factors which can be considered as explanatory variables in analyses. A review of aggregate models for road safety accidents (1) identified 14 studies which had considered various macro-economic and other factors in explaining road accidents. Additional transport, and road safety policy or other factors are also included in some studies. The most common factors found to be relevant were the amount of vehicle travel, vehicle population, income in its various forms and the percentage of young drivers. These studies were not entirely consistent in either the factors considered or the analytical methods used, with some studies reporting contradictory results with respect to certain parameters, such as fuel price.

Road safety measures which have been investigated more commonly include fatalities per vehicle or per vehicle mile travelled (VMT) and injury crashes per vehicle or per VMT (1). Economic factors have not so consistently been related to road safety outcomes but economic activity has been represented by disposable income, Gross National Product

(GNP), industrial manufacturing, income and consumption with additional factors including unemployment size or rate and fuel costs (1).

The number of road fatalities has been positively correlated with per capita disposable income (2), as has fatal injury rates with gross domestic product (GDP) per capita (3), and GDP (4) (5). Unemployment rate has been correlated with reduced road fatality rates (5) (6) (7) (8) (9). An inverted U-shape relationship between national economic growth and road fatalities has been observed, with low income countries exhibiting high fatality rates compared with high income countries (11) (12) (13).

Analytical methodology has evolved from earlier simple methods to more sophisticated techniques and frameworks in more recent years. Initial research often uses ordinary least squares (OLS) linear regression (2) (3) (4) (5) with few variables, including time. Auto-Regressive Integrated Moving Average (ARIMA) (6) (7) and the more general Structural Time Series Modelling (STSM) (8) has been used to effectively account for autocorrelation between observations in a time series. Poisson and Negative Binomial forms of regression analysis have been used in a range of studies (9) (10) (11) (12) (13).

Sequential modelling frameworks have been developed based on motor vehicle travel as the major factor representing exposure to road crashes, to which the various analytical techniques could be applied, such as the 'DRAG' framework, from the French words for travel demand, accident frequency and severity. The DRAG concept combines separate functions of vehicle travel, crashes per unit vehicle travel and crash severity per crash (14). However, to describe the effect of economic factors, the framework is expanded to include the relationship with economic factors which affect the amount of vehicle travel. A revised DRAG model indicated that employment and real retail sales increase personal injury road accidents (15).

Results of all these studies support the hypothesis that economic factors can affect road safety outcomes, although intermediate stages are recognised which may be investigated independently, such as suggested by the DRAG concept. These previous studies suggest a wide variety of road safety outcomes may be related to economic factors and that various methodologies may be applied to analyse their relationships. There are inconsistencies between the analyses where different forms of relationships and different relevant factors were found. The most common economic factors which relate to road safety are reported to be economic activity (real GDP), population, disposable income, unemployment and transport (travel and vehicles). Some factors including industrial production, fuel consumption and fuel prices have been less commonly found to be related. Other factors have been postulated but not yet found to be related. The most common analytical

techniques reported include single and multi-variable OLS linear regression, structural time series modelling (STSM), auto-regressive integrated moving average (ARIMA) and Poisson and Negative Binomial models.

It is also evident throughout the literature that the elements of data suitability and modelling which ensure valid results are, at best, not clearly described. In most cases, consistency with these requirements is not described at all, questioning the validity of the results (1). One of the most important unresolved issues is the choice of explanatory variable, for which no rational basis is often described, raising the question of whether spurious relationships have been developed and reported in the literature (16).

Data and methods

The initial data analysis is based on the proposition that economic activity is a driver of travel, which results in exposure to crashes. This essentially adds a travel generation element to a consolidated DRAG framework. The important distinctions within the DRAG framework are intended to be separated in later developments of the project. The overall relationships between economic factors and road safety outcomes reported here implicitly combine the individual DRAG elements.

Data selection

The research objectives defined the desirable range and preference for type of data. Data were collected from public and restricted sources for 16 economic factors, 12 transport system variables, and 15 road safety outcome measures, either quarterly or annually for the period from 1985 to 2009, shown in Table 1, some of which have been combined. Other scaled measures often used in road safety, such as fatalities per capita could be derived for further investigation or comparison. Commonly used measures of economic activity are real gross domestic product (GDP) or real gross national product (GNP). GNP however, is only estimated at the national level whereas we wish to use data for the State of Western Australia.

Thus, real gross state product (GSP) is the relevant similar measure. Various other factors, such as alcohol sales, could potentially be relevant to road safety, but were not available. Relevant transport variables were also collected, but are beyond reporting here. The categorisation of some factors, such as fuel sales and price is uncertain since they could be considered as economic or transport system factors.

Many measures have been used to describe road safety outcomes, each with advantages and weaknesses. Fatalities are probably the most common and reliable measure, but suffer from low frequencies which challenges the validity of statistical analysis. All suffer from definitional issues

and data inaccuracies. While data are available for various crash outcomes, road safety effects and policy has more recently focussed on the number of people killed and seriously injured (KSI). KSIs is a preferred, but emerging metric, which is intended to reflect the major human cost of road safety as opposed to measurable or direct costs (17). The definition of KSIs alone is an important issue and the subject of considerable discussion regarding definitions and data collection and is therefore too complex to be discussed further here. KSIs are represented by the number of people reported to have been killed or hospitalised, based on Department of Health records. The validity of the hospitalisation statistic is fraught with many measurement issues, particularly regarding thresholds of severity of injury and definitional changes although the data series will be accepted as presented for analysis without further dwelling on these issues. Other measures are available but are generally not preferred by users. KSI crashes represent the number of crashes where people are killed or seriously injured, based on reports to Police.

The number of crashes is available for particular road user groups (passenger vehicles, trucks, motor cyclists, cyclists and pedestrians). Various other outcome measures are also available, including fatalities, and intermediate measures, such as vehicle kilometres travelled, and could be used for analysis if appropriate.

Initially, the data were summarised according to common introductory exploratory analysis describing the number of observations, mean, variation, and bounds, for both annual and quarterly data. The data were reviewed visually to identify the form of relationships, possible outliers, or other abnormalities. No major issues were identified. Seven of the annual parameters are available for less than the 25 year annual observations and one of the quarterly parameters is not available for the whole period. These limitations need to be taken into account during sophisticated analysis, but do not affect the introductory analysis.

Data assessment

In order to avoid model misspecification and misleading results several diagnostic tests are performed on the data to ensure that they are valid for analytical purposes. Tests for correlation, multicollinearity, normality and stationarity were conducted.

Within one of the groups (economic, transport and road safety) data may be subject to correlations which may affect the relationships with factors in other groups which needs to be taken into account. The correlations between economic factors show that most macro-economic factors are very closely related with correlation coefficients often nearing or exceeding 0.9. The correlations with petrol sales and unemployment are slightly less strong and negative for the latter, indicating that unemployment falls as other

Table 1. Summary of annual economic factors and road safety outcome measures

Parameter (1985-2009)	Mean	Standard Deviation	Lowest Observation	Highest Observation	Observations (annual/ quarter)	Metric (units)
Economic Factor						
Gross State Product	123448	30820	81442	180008	20/100	\$ Million
Gross State Product /capita	65529	10147	50861	81317	20/100	\$ Million
Gross State Income	20139	3368	15202	25748	18/100	\$ Million
Gross State Income /capita	53902	13147	38300	81317	18/100	\$ Million
Gross Disposable Income	45359	18474	24375	91729	20/100	\$ Million
Industrial Value Added	115732	31333	73459	172437	20/100	\$ Million
State Final Demand	21915	7783	12813	38775	25/100	\$ Million
Net International Exports	4837	3213	1187	12646	22/88	\$ Million
Retail Turnover	3873	1428	2030	6394	25/100	\$ Million
Employment	878.2	160.6	642.6	1179	25/100	No. of people
Unemployment	59.35	13.20	34.45	87.51	25/100	No. of people
Unemployment Rate	6.632	1.940	3.048	10.69	25/100	Percent
Population	1815775	229958	1436900	2269655	25/100	No. of people
Fuel Consumption	2594	521.7	1737.4	3506	25/100	Gigalitres
Petrol Sales	1805308	142359	1521956	1995565	25/100	Litres
Petrol Price	82.52	24.80	52.4	141.4	25/100	Cent/litre
Road Safety Outcome Measure						
Fatalities	207.3	23.24	163	247	25/100	} Number
Crash - Total number	37439	2156	31914	41636	25/100	
KSIs	3752	570.8	2916	5016	25/100	
Crash - Passenger vehicle	35994	2096	30514	39794	25/100	
Crash - Heavy vehicle	2633	347.2	1949	3408	25/100	
Crash - Motorcycle	1222	221.0	929	1788	25/100	
Crash - Bicycle	701.8	138.6	544	1058	25/100	
Crash - Pedestrian	671.4	112.3	511	849	25/100	
Crash - Fatal	186.6	20.27	151	220	25/100	
Crash - KSI	2300	216.1	1678	2650	25/100	
Crash - Major property damage only	21090	3229	15702	27147	25/100	
Crash - Minor property damage only	7901	2163	3623	13437	25/100	
Road Injury - Motor vehicle	2598	531.6	1794	3713	25/100	
Road Injury - Bicyclist	569.6	156.1	265	841	25/100	
Road Injury - Pedestrian	376.3	48.78	292	449	25/100	

economic factors increase. The strong cross correlations suggest caution when developing multivariate relationships or mathematical models.

Assessment of correlations between transport factors indicate many correlations with coefficients exceeding 0.8, although travel for different types of vehicle is less strongly correlated and motorcycle travel least strongly correlated. While there is a correlation between general transport factors with the policy factors of speed cameras and random breath tests, it is likely to be spurious since such measures are discretionary (subject to control by government and potentially subject to change at any time), so are unlikely to be structurally linked to other economic or transport factors.

Most road safety outcomes measures are not highly correlated. The numbers of passenger vehicle crashes

are correlated with the total number of crashes since the majority of crashes involve cars. The numbers of property damage only crashes are correlated with both these factors for the same reason that the majority of crashes are minor. The number of KSIs is highly correlated with the number of people hospitalised since the number of fatalities is very small. The number of fatalities is correlated with the number of fatal crashes and other correlations also exist.

As groups, general economic factors are strongly correlated with transport factors. Road safety outcome measures as a group are not highly correlated with economic factors. Multicollinearity occurs when two or more predictors in a model are correlated and provide redundant information about the response which was tested by calculating variance inflation factors (VIF) for each predictor. The results indicate considerable multicollinearity between factors,

so related factors should be used together cautiously in multivariable estimation. At the same time, there are sufficient differences between factors (such as the employment and fuel factors) to suggest valid multivariable models could be developed. Based on these results it is at least reasonable to include one economic activity factor, one fuel use factor, fuel price, and two employment factors in such estimations.

Normality (normal distribution of data) is a required attribute of data for many common statistical techniques, but not all. For the analysis of sensitivity and robustness, the Skewness and Kurtosis test, is employed to test normality. Almost all annual data, including the key road safety outcome measures reported below, and the majority of the quarterly data, were found to be normally distributed.

An important assumption often made when analysing time series data is that it is stationary, meaning the means and variances of the random error component of the data are constant over the period. Variables whose random error mean and variance changes over time are known as non-stationary or unit root variables. If the assumption is not true a resulting model may be misspecified and the results may be inappropriate. Time-series data can be conveniently described by the number of times it must be differenced to make it stationary. Stationarity of the selected main parameters was tested with the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Optimum lag length is determined by Akaike Information Criterion (AIC), Schwarz Bayesian Information Criterion (SBIC), and Hannan and Quinn Information Criterion (HQIC). The results indicate that most of the variables are non-stationary in their levels. However, the stationarity property was found in the first difference of the variables. Therefore the time series nature of the variables needs to be respected during analysis.

Results of alternative analysis model forms

The availability and suitability of data and whether it is relevant to meet the research objective should be understood in the light of the issues described in the introduction and previous studies. Both the alternatives for the outcome measures and explanatory factors (or independent and dependent variables) need to be carefully considered, in conjunction with the data characteristics and quality. Subsequently the modelling commences with the simplest forms following the principle of Ockham's Razor, but with the potential to move towards more sophisticated techniques to take account of additional factors which may be relevant. In this case the investigation covered the most fundamental economic factor; economic activity, although even this is described in nine available forms which were considered against four alternative measures of road safety

outcomes. While the available data extends to many more factors, it is beyond the scope of this paper to do more than describe the basic characteristics of relevant available data and explore the first of a potentially large number of alternative models.

In the first instance, relationships between economic activity and road safety factors were estimated using OLS regression. Alternative forms of model were initially investigated for key relationships followed by all economic activity parameters. These or similar model forms have been used in previous analyses, generally without justifying applicability. The forms reflect non-linearities in the data although many other forms may be valid and could be further investigated. Some forms suit further analysis such as multiplicative or additive effects of additional factors which could possibly be included in multivariable analysis. These assessments identify any preference of model form or economic activity for modelling.

Statistically valid models and closer fit to observations were preferred. Only models with statistically valid coefficients ($P > 0.95$) were considered valid. Adjusted R^2 and root mean squared error (RMS Error) were used as the primary measures to compare the quality of fit between the observations and the estimation. These measures are not perfect however, particularly since transformations change the R^2 value numerically, so direct comparison between models is not always possible. In general terms, simpler models are preferred over more sophisticated estimations unless an overriding rationale exists.

Alternative forms of model for estimation

Seven different forms of model were compared for the estimation of four key road safety outcome measures based on Gross State Product as the measure of economic activity:

$$\text{Linear model} \quad y = b_0 + b_1 \cdot x \quad [1]$$

$$\text{Log - linear model} \quad y = b_0 + b_1 \cdot \ln(x) \quad [2]$$

$$\text{Linear - log model} \quad \ln(y) = b_0 + b_1 \cdot x \quad [3]$$

$$\text{Log - log model} \quad \ln(y) = b_0 + b_1 \cdot \ln(x) \quad [4]$$

$$\text{Exponent model 1} \quad y = b_1 \cdot b_2^x \quad [5]$$

$$\text{Exponent model 2} \quad y = b_0 + x^{b_1} \quad [6]$$

$$\text{Log exponent model} \quad \ln(y) = b_0 + b_1 \cdot x \quad [7]$$

The results of the alternative model forms are summarised in Table 2, which indicates that more complex models are often not statistically valid ($P > 0.95$) and do not consistently produce better explanations of the

observations. Only the exponent model 1 [5] and the log exponent model [7] consistently produce valid models and the quality of the estimations from these models is consistently high. The normality of the data means transformations are not necessary to ensure validity of the estimations.

These models are illustrated together in Figure 1 which visually confirms the statistical measures and the high similarity between different model estimates, despite the non-zero axes overemphasising the degree of variation in the observations and hence the differences from the estimation. Similar graphs for other factors confirm little differences between the forms of models for estimations of other road safety outcomes based on economic activity.

Alternative explanatory economic activity factors

Estimates of road safety outcomes (KSIs) based on nine different measures of economic activity were compared and are summarised in Table 3. These results indicate that any of measures of economic activity produce valid models and the quality of the estimations from these models is consistently high. The similarity between the economic measures as explanatory variables is likely to be due to

Table 2. Statistical comparison of alternative models forms

Relationship and Model	Valid Coefficients (P>0.95)	RMS Error	Adjusted R ²
Fatalities v GSP			
Linear model	-		
Log-linear model	-		
Linear-log model	-		
Log-log model	-		
Exponent model 1	b ₁ , b ₂	21.65	.9886
Exponent model 2	-		
Log exponent model	b ₂ , b ₁	.1082	.9996
KSIs v GSP			
Linear model	b ₀ , b ₁	459.7	.4403
Log-linear model	b ₀ , b ₁	.1211	.4240
Linear-log model	b ₀ , b ₁	471.3	.4118
Log-log model	b ₀ , b ₁	.1231	.4045
Exponent model 1	b ₁ , b ₂	453.7	.9862
Exponent model 2	b ₁	466.2	.9854
Log exponent model	b ₂ , b ₁	.1209	.9998
Crashes v GSP			
Linear model	b ₀ , b ₁	1763	.4002
Log-linear model	b ₀ , b ₁	.0484	.3969
Linear-log model	b ₁	1686	.4514
Log-log model	b ₀ , b ₁	.0462	.4503
Exponent model 1	b ₁ , b ₂	1776	.9977
Exponent model 2	b ₁	1699	.9979
Log exponent model	b ₂ , b ₁	.0484	1.000
KSI crashes v GSP			
Linear model	-		
Log-linear model	-		
Linear-log model	-		
Log-log model	-		
Exponent model 1	b ₁ , b ₂	228.3	.9900
Exponent model 2	-		
Log exponent model	b ₂ , b ₁	.1072	.9998

Note: Errors and R² are not comparable between models with different transformations

the high correlation between the factors. Many of these factors (e.g. retail turnover, industrial value added) are subcomponents of other factors (e.g. gross state product).

The results of these models are combined with the observed value of economic activity for each year to produce estimates of KSIs yearly as illustrated in Figure 2. This visually confirms the statistical measures and the high similarity between different explanatory variables, again despite the overemphasis resulting from the non-zero axes. In this figure, the number of KSIs annually are calculated based on the estimated relationship between the economic factor and KSIs then using the observed level of economic activity for each year.

Some particular issues need to be understood in the comparison of the alternative models shown in Table 2 and Figures 1 and 2. The best measure and model may be determined in the case when only a single explanatory variable is used, but this does not imply that the same variables, analytical techniques or models remain the most appropriate when multiple variables or transformations are applied.

All except the linear model involve transformations of at least one of the variables. However, results of statistical analyses are only directly comparable in terms of fit via the R-squared value if they involve the same transformation, or none. The lower statistical values of some models do not imply they are necessarily poorer representations of the data. As noted above, with models which use transformed data, the statistical measures are representative of the transformed data rather than the original data. The axes in Figures 1 and 2 are drawn with axes which are not at zero, in order to highlight the differences between the models, which are clearly very minor. If axes were extended to zero, the differences in the lines of each model would be indistinguishable. At the same time, if the axes were extended to zero it would also be clearer than the models closely represent the data, with small differences between the observations and any of the models, as indicated by the high R² values. The differences between the alternative models is best understood from the graphical representation rather than the statistical values.

Road safety outcomes are often reported against time, particularly annually. Trends over time may be reported based on OLS which will not necessarily adequately accommodate autocorrelation. Doing so also hides the nature of underlying factors which may be also be changing. One benefit of the assessment described here is to ‘decouple’ the estimate from time as a dependent variable, while still allowing estimations to be displayed against time.

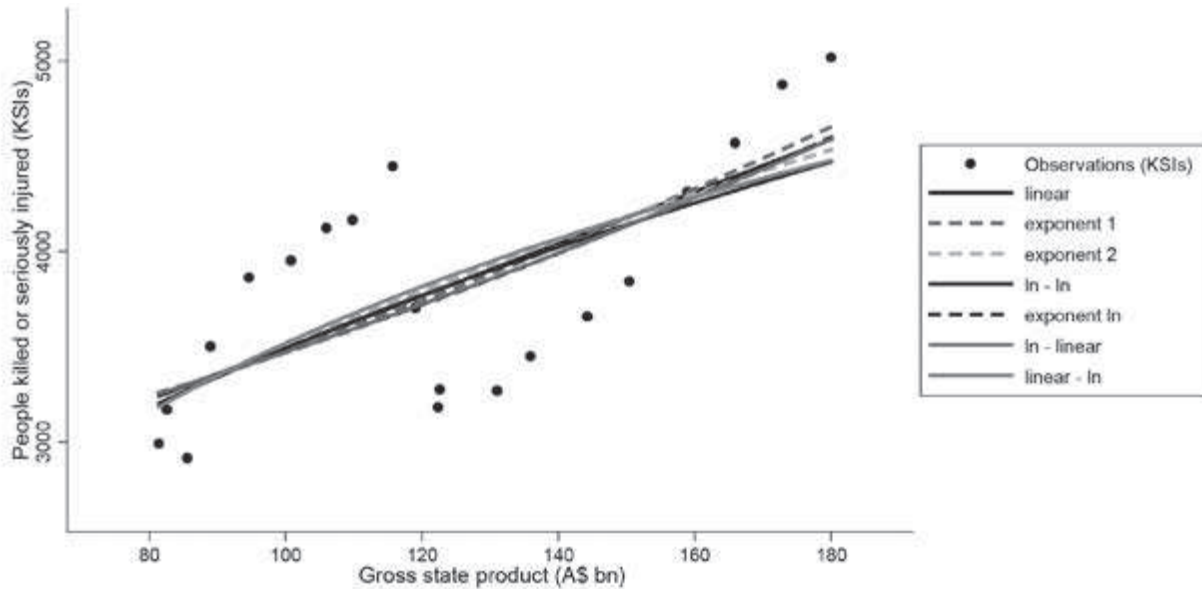


Figure 1. Graphed comparison of alternative forms of model

Table 3. Comparison of alternative economic activity as explanatory factors

Economic Activity Measure with model parameter	Coef.	Std. Err.	P>t (t test)	95% Conf. Interval		RMS Error	Adjusted R-squared	
				low	high			
Gross State Product (GSP)	b_1	2420	272.6	0.000	1848	2993	453.7	.9862
	b_2	1.000004	8.18e-7	0.000	1.000002	1.000005		
GSP per capita	b_1	1848.9	340.1	0.000	1134	2563	460.4	.9858
	b_2	1.000011	2.65e-6	0.000	1.000005	1.000017		
Gross State Income (GSI)	b_1	2311	446.2	0.000	1365	3257	506.3	.9835
	b_2	1.000026	9.17e-6	0.000	1.000006	1.000004		
GSI per capita	b_1	2540	284.7	0.000	1936	3143	441.4	.9874
	b_2	1.000008	1.90e-6	0.000	1.000004	1.000012		
Gross Domestic Income (GDI)	b_1	2896	200.8	0.000	2474	3317	444.3	.9868
	b_2	1.000006	1.28e-6	0.000	1.000003	1.000009		
Industrial Value Added (IVA)	b_1	2525	269.9	0.000	1958	3092	461.9	.9857
	b_2	1.000004	8.23e-7	0.000	1.000002	1.000005		
State Final Demand (SFD)	b_1	2750	174.4	0.000	2389	3111	396.3	.9900
	b_2	1.000014	2.51e-6	0.000	1.000009	1.000019		
Retail Turnover (RT)	b_1	2845	202.1	0.000	2427	3263	438.6	.9866
	b_2	1.000007	1.61e-5	0.000	1.000037	1.00001		
Net International Exports (NE)	b_1	3178	142.2	0.000	2881	3474	423.5	.9877
	b_2	1.000003	6.76e-6	0.000	1.000002	1.000005		

Discussion and conclusions

This introduction to a larger project which will involve further analysis followed a robust and thorough process to prepare and understand the suitability of data for the purposes of relating economic effects to road safety outcomes. Considerable amounts of relevant, appropriate and suitable data were found to be available to support the intended future analysis.

The assembled data was found to be suitable for the purpose based on visual assessments, descriptive statistics and statistical tests. Apart from minor issues, two important

characteristics need to be taken into account when using the data. Collinearity between variables and groups of variables exist, so caution should be exercised when developing multivariate models. Much of the data is autocorrelated, (i.e. related over time) so attention should be given to respecting the time series nature of the data during further analysis.

Seven alternative forms of model for estimating relationships were investigated and found to produce similar results, but only an exponent model and a log transformed model were statistically valid in all four cases tested. Based on the similarity of the results of different

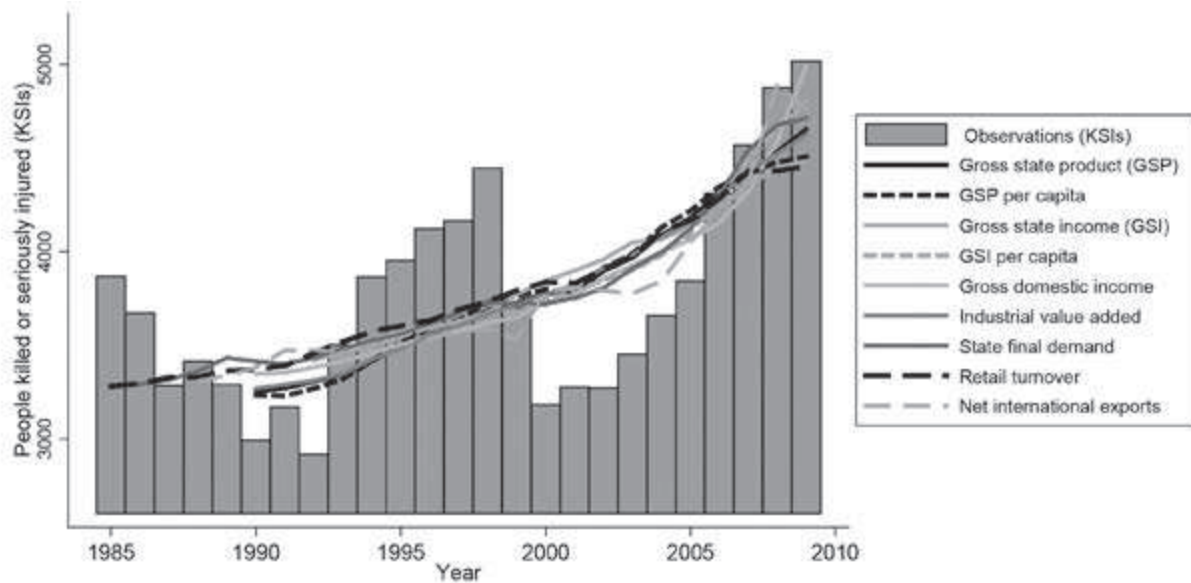


Figure 2: Estimate of people killed or seriously injured each year based on different measures of economic activity

forms of model, the exponent model 1 (equation [5]) is preferred due to statistical validity and consistency across estimates of all measures. Also, previous literature and the expectation that linearity has not been evident in many road safety outcomes over a longer period suggest linear models may not be appropriate. Compared to a linear model, the exponent model diverges at the extremities and the centre of the range which better matches the characteristics of the outcome variables being examined.

Nine alternative measures of economic activity were investigated and all found to be valid as explanatory variables, with each explaining a significant amount to the variation in the road safety outcome measures. Gross state product (GSP) is preferred as an explanatory variable due to it being a broad measure, frequently used, commonly understood and widely available. Consistent with previous studies economic activity has previously been positively correlated with increasing road safety measures (1) (2) (3) (4), however other studies have not directly compared different measures of economic activity.

Relationships were found between road safety outcomes and economic factors supporting the importance of considering these factors as relevant for understanding road safety outcomes and during investigation. While good levels of explanatory power have been found, other factors could be important in estimating road safety outcomes. Multivariate and other non-linear estimates may produce more informative results.

The data and initial information investigated in this study provides a solid foundation on which to base further investigations of relationships between economic and transport factors with road safety and subsequent investigations.

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Appendix 8

A comprehensive conceptual framework for road safety strategies

Paper VI



A comprehensive conceptual framework for road safety strategies



B.P. Hughes^{a,*}, A. Anund^{b,c}, T. Falkmer^{a,c,d}

^a School of Occupational Therapy and Social Work, Curtin University, Perth, Australia

^b Swedish Road and Transport Research Institute, 581 95 Linköping, Sweden

^c Rehabilitation Medicine, Department of Medicine and Health Sciences (IMH), Faculty of Health Sciences, Linköping University and Pain and Rehabilitation Centre, UHL, County Council, Linköping, Sweden

^d School of Occupational Therapy, La Trobe University, Melbourne, Australia

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ABSTRACT

Road safety strategies (generally called Strategic Highway Safety Plans in the USA) provide essential guidance for actions to improve road safety, but often lack a conceptual framework that is comprehensive, systems theory based, and underpinned by evidence from research and practice. This paper aims to incorporate all components, policy tools by which they are changed, and the general interactions between them. A framework of nine mutually interacting components that contribute to crashes and ten generic policy tools which can be applied to reduce the outcomes of these crashes was developed and used to assess 58 road safety strategies from 22 countries across 15 years. The work identifies the policy tools that are most and least widely applied to components, highlighting the potential for improvements to any individual road safety strategy, and the potential strengths and weaknesses of road safety strategies in general. The framework also provides guidance for the development of new road safety strategies, identifying potential consequences of policy tool based measures with regard to exposure and risk, useful for both mobility and safety objectives.

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1. Introduction

Road trauma continues to rate as a severe social and economic issue globally, despite recognition of the significance of it and the need to reduce the burden of death, injury and other costs. Contrary to the successes in many western countries, road safety still needs continuing efforts to be maintained and further improved. Worldwide, road crashes are estimated to cost 1.2 million lives each year with possibly as many as 50 million people injured (WHO, 2013). In Europe, nearly 25,700 fatalities were reported in 2014 and more than 200,000 people sustained serious injuries (European Commission, 2015). In the USA more than 30,000 people die and more than a million more are injured in road crashes each year (Evans, 2014). Globally, the number of road traffic deaths has plateaued since 2007, while road safety has been deteriorating in many developing countries (WHO, 2015). The full extent of road trauma's economic and social consequences defies description or estimation, with the average cost to governments alone approximating 3% of Gross Domestic Product, and up to 5% in some cases (WHO, 2015).

Worldwide, road trauma is a leading cause of preventable death and is regarded as a public health issue that has been neglected. It is forecast that road trauma will continue to deteriorate worldwide, imposing an even greater burden on society as a whole (WHO, 2013). However, this burden will fall disproportionately greater on lower income countries. It is estimated that deaths from road crashes globally could rise by around 50% from 2010 to 2020 to 1.9 million per annum (WHO, 2013). Many countries have therefore developed road safety strategies or plans as a response to this human and economic disaster. Some appear to have been successful, for example in the European Union with an 18% reduction in fatalities from road crashes from 2010 to 2014 (European Commission, 2015).

Road safety shares the attributes of many 'wicked' problems with characteristics including a multitude of contributing causes and intersecting external influences, and resistance to resolution (Di Stefano and Macdonald, 2003; Agarwal et al., 2013). Road trauma is a complex and intractable problem which cannot reasonably be reduced by easily implemented, simple solutions without taking account of the multitude of consequences for society, beyond individual types of crashes. As such, road safety may fall into a category of non-routine and non-standard problems not amenable to solution by rational-technical approaches that governments most commonly and comfortably apply (Eliasson and Lundberg, 2012; Albalade et al., 2013).

* Corresponding author at: 5/296 Mill Point Rd, South Perth, WA, Australia.
E-mail address: brett.hughes@transport.wa.gov.au (B.P. Hughes).

Road safety strategy and policy have evolved from focusing on the driver, mainly through enforcement and publicity based on human error being the primary cause. Later on, attention was given to road design standards before it was redirected in the 1970s to the motor vehicle industry to improve vehicle standards (Hakkert and Gitelman, 2014). Conceptual frameworks have been described for certain specific road safety issues, such as for cycling (Scheper et al., 2014) and in occupational safety (Stuckey et al., 2007), but not for the system as a whole for the purposes of road safety strategies. Bliss and Breen (2012) described the evolution of road safety strategy over the past decade, and the alignment with reduced road trauma in selected countries using the most recent approaches. However, there is no assessment of any cause and effect relationship between recent types of strategies (i.e., frameworks and processes) and the desired outcomes. Moreover, while individual strategy actions have a sound basis in theory and evidence it is not evident that the fundamental frameworks of strategies have the same scientific foundation. This leads to the potential that road safety strategies are incomplete or suboptimal.

Whilst there are many possible approaches to road safety, some recent road safety strategies have evolved to be described as systems approaches (Hughes et al., 2015a), essentially based on principles that refer to aspects of system theory (Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009). Contemporary road safety strategies are consistent with some of the key principles of systems theory, although they also include aspects that are inconsistent with it (Salmon and Lenné, 2015). The various styles of modern road safety strategies include many components (such as drivers and vehicles), and their individual characteristics (such as age) which contribute to the consequences of road crashes. They also include the policy tools (such as programs and projects) to change the components, in order to reduce road trauma. At the same time, there are differences between the content of road safety strategies and how they are described. Individual strategies may not include actions to address all of the issues that may contribute to road safety. Therefore, a comprehensive conceptual framework has the potential to guide the development of road safety strategies to ensure they are complete, effective and efficient.

The widespread use of frameworks in road safety and elsewhere in safety management generally, such as those described by Haddon (1980), Road Research Laboratory (1963), Limpert (1978) and Baker and Fricke (1986) is an inherent indication of their value and applicability for practitioners in road safety. Therefore, the objective of this paper is to present a framework for road safety strategies that is further developed based on systems theory and underpinned by evidence from research and practice. The framework is comprehensive, incorporating all components, policy tools by which they are changed, and the general interactions between them. It addresses:

1. Components of the road safety system that comprise the constituent parts which alone, or in combination, cause road crashes.
2. Policy tools by which these components may be affected, in order to improve road safety and reduce road trauma.
3. Recent road safety strategies with regard to components and policy tools being applied.
4. Possible potential for improving road safety strategies.

It should be noted that it is not sufficient in itself to ensure that effective and efficient road safety strategies are developed; they must also be properly implemented and evaluated. Strategy development requires a sound process to ensure that all actors who contribute to development or implementation the strategy are recognised, including individual people, government agencies, companies, industry associations, interest groups and others who can make a contribution to improving road safety. This paper,

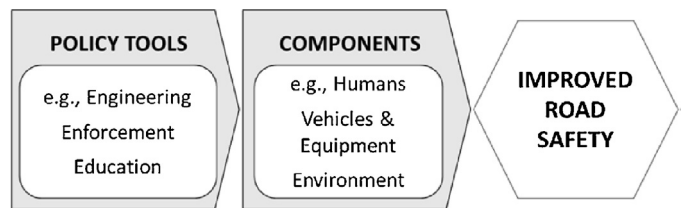


Fig. 1. Applying policy tools to components to achieve outcomes.

however, does not go beyond the description of a comprehensive framework to further describe the participants in road safety strategies, how it should be developed in order to be efficient and effective, or the subsequent evaluation.

Policy tools, such as engineering, enforcement and education (Nader, 1965; Booth, 1980), have previously been applied to components of the road safety system, such as humans, vehicles and equipment, and environment (Haddon, 1972). Road safety strategies describe policy tools applied to individual components to improve road safety. Therefore, the underlying rationale in this paper, derived from these approaches and consistent with systems theory, is that a comprehensive suite of policy tools have the potential to be applied to all relevant components in order to reduce road trauma, as illustrated in Fig. 1.

2. Method

This paper builds on two basic concepts recognised in the literature; the nature of models used for safety strategy and road safety policy tools. Firstly, there are several types of models that could be applied to road safety strategy, and each of them can incorporate different details (Yannis et al., 2015). Secondly, there are numerous policy tools that can be applied to improve road safety (Elvik et al., 2009a).

The conceptual framework provides a comprehensive description of the components that contribute to crashes, and the policy tools by which they can be influenced. The conceptual framework also provides the opportunity to consider all of the possible policy tools that could be applied to any of the relevant components in the development of road safety strategies. In doing so, it increases the likelihood that all valuable actions are included for all components and it reduces the risk that any valuable actions are omitted. However, it does not mean that a road safety strategy necessarily must include all policy tools or target all components.

The conceptual framework is applied to assess 58 road safety strategies, mostly at the national or state level, to determine the degree to which they apply policy tools and target components. This approach highlights the potential for improvements to any individual road safety strategy, considers the potential strengths and weaknesses of road safety strategies and provides guidance for the development of road safety strategies in general, potentially improving road safety outcomes.

2.1. Components of road safety

Given the variety of types of road safety strategy and the large number of components that they comprise of, the first task is to identify and describe all components. Haddon (1980) famously described a logical system, the Haddon matrix, for the prevention of road trauma according to a sequence of events in three phases (pre-crash, crash and post-crash) and four types of factors (human, vehicles and equipment, physical environment and roadway, and socio-economic environment). However, the matrix does not describe how these factors interact. In contrast, systems theory (Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009)

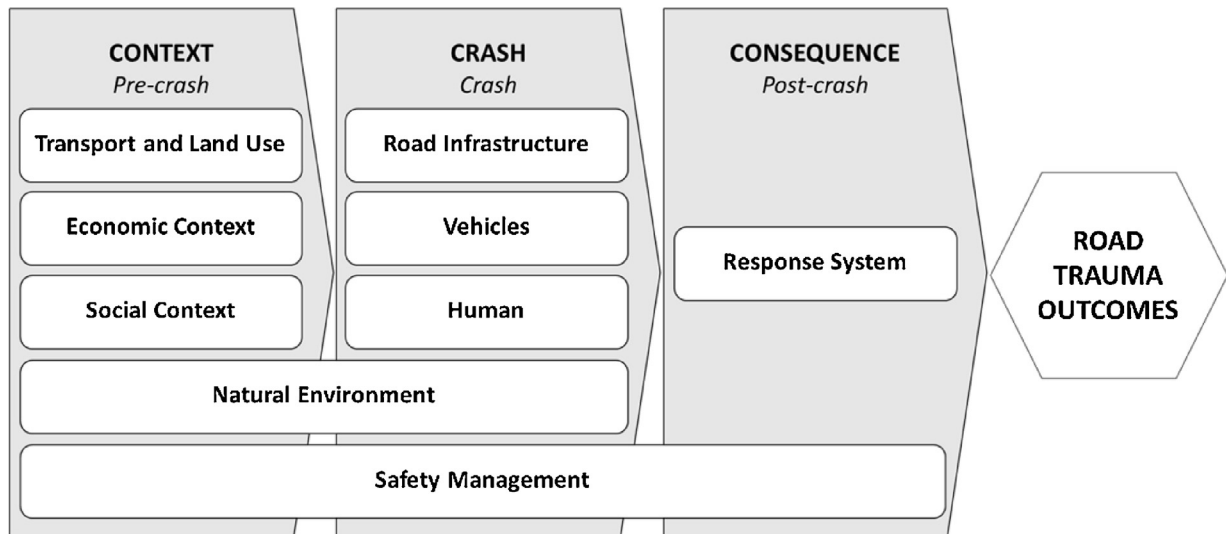


Fig. 2. Road safety phases and components.

describes both components and their interdependencies to achieve the desired outcomes. Unfortunately, common practice in road safety strategies only describes a specific policy tool applied to an individual component and does not take account of systems theory requirements to describe interdependencies between components or policy tools which interact.

More detailed descriptions of road safety components are therefore needed, and underpinned by research (Road Research Laboratory, 1963), crash analysis (Baker and Fricke, 1986) or individual road safety measures (Elvik et al., 2009a). Since these perspectives are different they do not cover all of the components that apply to road safety. Consequently, a comprehensive description covering all of the potentially contributing components is described in Table 1. In doing so the more common, but limited, description of road transport is considerably expanded in terms of breadth to other road infrastructure, the natural environment, the management of road safety and several stages of crash response. In addition, the wider economic, transport, land use and social context were also described.

Haddon's (1972) initial logical framework; human, vehicle and equipment, environment, and the human, machine environment component approach (Wang, 2010) has been strongly reflected in road safety strategies for a long time. Yet, road safety strategies have tended to limit the people involved to the driver, pedestrian or rider, as opposed to other people such as passengers, or those who might otherwise influence the system, such as those who design vehicles, load trucks, set policies or enforce the law. Systems theory requires identification of components that interact to achieve a specified outcome, so it is essential that all contributing components of the system are specified (Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009).

Models can describe crashes as a sequence of events over time or a process, such as Haddon's (1972) framework; pre-crash, crash and post-crash phases. In this case, as illustrated in Fig. 2., generally the *context* phase prior to the event would include the Transport and Land Use, Economic, and Social Contexts, the *crash* phase at the time of the time event would include the Road Infrastructure, Vehicles, and Human while the Crash Response occurs in the *consequence* phase after the event. Some aspects of the Natural Environment are constant over time (such as topography) represented in the *context* phase, while others are temporal (such as precipitation and sunlight) represented in the *crash* phase. Safety Management occurs pre-crash but is applied to all three phases; *context*, *crash* and *consequence*.

Components from other safety domains to be included in road safety strategies have been identified (Yannis et al., 2015), such as public health's concept of determinants (Gordon, 1949; Bonita et al., 2006), control systems inclusion of institutional structures (Bax et al., 2014) and the wider view of the environment beyond the road to encompass social and economic factors (Haddon, 1980). These wider views identify model components not traditionally incorporated in road safety strategies, even though they are all represented in road safety research and practice. The references in Table 1 attest to the legitimacy of all of the individual components, each of which has been independently identified as being a component relevant to road safety.

2.2. Road safety strategy policy tools

Road safety strategy policy tools are activities, generally executed by governments, which aim to reduce road trauma. Policy tools may be described as policy measures, instruments, countermeasures, interventions, actions, responses or other terms. Road safety strategies are a combination of policy tools which are applied, although different road safety strategies describe the policy tools differently, or apply them according to different perspectives, such as whichever are the primary focuses. In addition, an approach to designing safer systems would extend the application of the policy tools to private companies, other organisations and individuals (Leveson, 2004).

Measures for regulating social behaviour have been categorised as detectors (tools for collecting information about target behaviour) and effectors (sanctions or rewards for changing or modifying the behaviour detected) (Durant and Legge, 1993). These approaches rely on the premise that human action (or behaviour) is a component in all aspects of road safety, not only as the road user. For example, road and vehicle designers are responsible for vehicle and road engineering. They, together with road users, respond to the broader natural environment, and the social and economic context components.

The means by which road safety outcomes can be improved have been considered according to different approaches or perspectives. One broad approach to policy instruments has suggested a threefold typology; economic means (carrots), regulations (sticks), and information (sermons), but also noted other broader and more detailed categorisations, listing up to 63 individual tools (Vedung, 2003). Following previous Engineering (or non-interacting), Economic (or utility maximizing, or danger compensation) and Risk

Table 1
Road safety components.

Component	Subcomponent Description	Example Reference
Transport and Land Use Context	Transport alternatives, other modes, company operations	Andersson (1994), Stuckey et al. (2007), Elvik et al. (2009b), Stradling (2011), Shan and Xi (2014), Bouaoun et al. (2015), Moeinaddini et al. (2015)
	Spatial arrangement, co-location	Henning-Hager (1986), Ossenbruggen et al. (2001), Flahaut (2004), Cho et al. (2009)
	Accessibility—remoteness, location, service levels Transport integration	Brodsky (1983), Maio (1992), Cheffins (2007), Palamara et al. (2013), Thekdi and Lambert (2015) Whitelegg (1983)
Economic Context	Economics, finance, funding	Forjuoh (2003), Chen (2005), Garg (2005), Kopits and Cropper (2005), Elvik (2006), Paulozzi (2007), Traynor (2008, 2009), Chi (2011), Rangel et al. (2013)
	Population, employment structure	Partyka (1984), Wagenaar (1984), Hakim et al. (1991), Noland and Oh (2005), Krüger (2013), Stipdonk et al. (2013)
	Environment, energy, climate change Legal—regulation, liability, privacy, insurance, courts, corrections	Schulte and Chun (2009), Chi (2011) Kenkel (1993), Blows (2003), Elvik (2006), Dionne (2011), Eriksson and Bjørnskau (2012)
Social Context	Politics and government	Køltzow (1993), Timpka et al. (2009), Belin et al. (2011), Bliss and Breen (2012), Hyder et al. (2012)
	Law—role and response	Gaygisiz (2010), Kim et al. (2011), Mullen et al. (2014), Smith et al. (2014)
	Social norms, nurture, background, traditions, rituals	Dobson et al. (1999), Bianchi and Summala (2004), Iversen (2004), Rosenbloom et al. (2009), Fries (2012)
	Ethnic practices Spiritual beliefs	Chung (1990), Rasanathan (2008), Boufous (2010), Steinbach (2011) Forjuoh (2003), Melinder (2007), Yang et al. (2008), Akanbi et al. (2009), Kayani et al. (2011)
	Literacy, intellect, education	Forjuoh (2003), Borrell et al. (2005), Emerson et al. (2012)
	Employment—practices, demands, restrictions Activities, travel purposes	Mitchell (2004), Stuckey et al. (2007), Clarke (2009) Wilks et al. (1999), Elias et al. (2010), Rosselló and Saenz-De-Miera (2011), Møller and Haustein (2013)
Natural Environment	Daylight, dawn, dusk, night, sun	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a), Eriksson and Bjørnskau (2012)
	Weather and atmospheric conditions—rain, fog, snow, smoke, wind, temperature	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Fridstrøm et al. (1995), Khan et al. (2014)
	Adjacent environment—topography, trees, grass, water Wildlife	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a), Zou et al. (2014) Wentz et al. (2001), May et al. (2011), Shiftan et al. (2012)
Human	Driver, passenger, witness, acquaintance, occupant, road workers Age and sex	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986) Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Impairment—alcohol, drugs, medicines, carbon monoxide, drowsiness, sleep, disablement (seizures, pain, blackouts, disabilities), fatigue	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Driving process*—strategy, tactics, perception, alertness, reaction, attention, distraction, error correction, response to incidents and conditions	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a), Chan and Singhal (2015)
	Abilities—physical, vision, hearing, mental state, injury, illness, disability, health	Road Research Laboratory (1963), Baker and Fricke (1986), Wijesuriya et al. (2007), Elvik et al. (2009a)
	Capability—natural, learned, skill, intelligence, education, experience	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Attitude, motivation, demeanour, emotion, psychological state, behaviour	Road Research Laboratory (1963), Baker and Fricke (1986), Wijesuriya et al. (2007)
	Time (day, week, month, season), type of trip	Road Research Laboratory (1963), Baker and Fricke (1986), Eriksson and Bjørnskau (2012)
	Capability—licence, restrictions	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986)
	Helmets, clothing and other protection	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Clothing—visibility, protection, interference	Gowens (2003), De Rome (2011), Khan et al. (2014)
Vehicles	Type- car, truck, trailer, motorcycle, bicycle, bus, farm machinery, other	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a), Bouaoun et al. (2015)
	Design*—standards, maintenance, damage, modifications, inspections	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Wheels and tyres*—size, type, tread, pressure, condition, chains	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Brakes*	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Controls*—steering, pedals, levers, switches	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Body type* and mass	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)

Table 1 (Continued)

Component	Subcomponent Description	Example Reference
	Seat belts, child restraints and other protection	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Lights*—external, internal, type, performance, colour, reflectors	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Cargo—type, characteristics, mass, strength, shape, hazardous	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Structure*—frame, doors, panels, safety features, crashworthiness, fittings, mirrors, mountings, flammability	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Suspension	Limpert (1978), ElMadany and Abduljabbar (1989), Elvik et al. (2009a)
	Engine, transmission, fuel type	Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Instruments	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Electrical components and circuits	Limpert (1978), Baker and Fricke (1986)
	Colour	Baker and Fricke (1986), Lardelli-Claret et al. (2002), Newstead and D'Elia (2010)
	Glass—colour, type	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Movement—speed, direction, angle, acceleration, coasting, deceleration, turning, overtaking, reversing, force, vibration	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Liquids and fluids	Radlinski et al. (1971), Treat and Joscelyn (1973), Baker and Fricke (1986), Lee (1998)
	Type of impact—speed, angle, physical dimensions	Baker and Fricke (1986), Elvik et al. (2009a), Candappa et al. (2015)
	Active safety and other technology—antilock brakes, electronic stability control, adaptive cruise control, speed control, etc.	Limpert (1978), Elvik et al. (2009), Jermakian (2012)
Note 1: *Generally applicable to motor vehicles, but may be applied to others		
Road Infrastructure	Surface—friction, colour, smoothness, cracks, edges, shoulders, unsealed, pothole, concrete asphalt, seal, manhole, drain, repair, cycle facility, drainage, grit, spills, footpaths—wet, dry, snow, ice, other	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986)
	Geometry—alignment geometry, curve, crest, dip, gradient, level, lanes, crossfall, physical dimensions, dual carriageway, passing lane, shoulder, median	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Signs, regulatory, advisory, pavement marking, signal, manned, speed limits, active/passive, reflectors, colour, illumination, reflectivity, access control, street design, bus lanes, roadworks	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Lighting—roadway, features and adjacent	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a), Wanvik (2009), Jactett and Frith (2013)
	Obstacles—pylons, gutter, kerb, culvert, bridge, pole, other street furniture, safety barrier, tunnel, building, overpass, tree, bus facilities	Road Research Laboratory (1963), Limpert (1978), Baker and Fricke (1986), Elvik et al. (2009a)
	Intersection type—intersection, junction, roundabout, grade separation, merge, railway crossing, crosswalk or crossing point, angled, pedestrian crossing, island	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Road type—Freeway, highway, city street, residential, rural, bridge, tunnel	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Miscellaneous—driveway, midblock, parked cars, stopped buses, lighting, glare, road debris, previous collision, landslides, work zones, tram/light rail	Road Research Laboratory (1963), Baker and Fricke (1986), Elvik et al. (2009a)
	Traffic volume, type, interaction	Ceder and Livneh (1982), Baker and Fricke (1986), Golob et al. (2004), Elvik et al. (2009a)
	Safety devices—guardrail, barrier, rest stop, fence, service area, route guidance, landslide protection	Lee and Mannering (2002), Elvik et al. (2009a), La Torre et al. (2012), Zou et al. (2014)
	Maintenance	Tighe et al. (2000), Elvik et al. (2009a), Usman et al. (2012), Agarwal et al. (2013)
Crash Response	Emergency & rescue services	Brodsky (1983), Wilminck et al. (1996), Sánchez-Mangas et al. (2010)
	Crash reporting and incident management	Golob et al. (1987), Giuliano (1989), Allred (2004), Lee and Fazio (2005)
	Health treatment—first aid, emergency treatment, injury treatment	Coats (2002), Khorasani-Zavareh et al. (2009), Sánchez-Mangas et al. (2010), Adelborg et al. (2011)
	Rehabilitation, permanent care & adaptation	Clarke (1995), Piccinelli (1999), Ameratunga et al. (2004), Fitzharris et al. (2007), Tournier et al. (2014)

Table 1 (Continued)

Component	Subcomponent Description	Example Reference
Safety Management	Risk management—identification, assessment, countermeasures, revision	Bluff (2003), Bubbico et al. (2006), Dawson et al. (2014), Fernández-Muñiz et al. (2014), Jamroz et al. (2014)
	Information—research, data, investigations, benchmarking	Bluff (2003), Chapelon and Lassarre (2010), Papadimitriou and Yannis (2013)
	Capability—skills, knowledge, experience, of all participants	Bluff (2003), Bliss and Breen (2012), Jähi et al. (2012)
	Capacity—financial, human, system, technology	Bliss and Breen (2012), Jähi et al. (2012)
	Systems—processes, structures, procedures, standards	Bluff (2003), Crackel and Small (2010), Jamroz et al. (2014), Mooren et al. (2014)
	Integration—collaboration, coherence, synergy, co-ordination, optimisation	Niskanen (1994), Bluff (2003), Bliss and Breen (2012), Hyder et al. (2012), Canoquena (2013)
	Implementation—policy, planning, design, installation, maintenance, monitoring, revision	Bluff (2003), Hyder et al. (2012), Bliss and Breen (2012), Jähi et al. (2012)
	Communication—content, contact, medium	Niskanen (1994), Bluff (2003), Belin et al. (2011), Hyder et al. (2012)
	Culture—attitudes, beliefs, values, commitment	Niskanen (1994), Bluff (2003), Wills et al. (2006), Fries (2012), Canoquena (2013), Atchley et al. (2014)

Note 2: The examples in this Table may not be comprehensive—i.e., not all subcomponents within the description may be exemplified.

homeostasis approaches, Evans (1985) developed a theory that policy tools were applied to improve road safety outcomes, but are affected by human behaviour responding to the results of applying the tools. Leveson (2009) alternatively described five levels of control mechanisms that generally can be applied to improve safety in systems: physical, operational, managerial, organizational, and manufacturing-based.

Elvik (2003) investigated a broad range of measures used in road safety and found 132 potential road safety tools for Norway, applicable to many individual components of the road safety system, but without a categorized general system. Tools that focus on the road network as a whole, including institutional management functions, which achieve road safety outcomes have been described (Bliss and Breen, 2012).

Road safety strategies investigated in the present paper revealed hundreds of individual activities, typically according to the categories of target groups, safe systems approaches, and traditional descriptions described above. However, it is not evident that a single taxonomy is complete, since some policies or components exist outside the known categorizations. Consequently, despite the years of research, investigation and policy development, there is no categorization covering all policy tools applicable to road safety

strategies. To the best of our knowledge, broad descriptions do not describe the complexity that is required when developing road safety strategies, but descriptions available currently are incomplete.

The current paper adopted a taxonomy based on three categories; Incentives, Disincentives and Influence, as shown in Fig. 3. Table 2 describes these categories of all road safety strategy policy tools, particularly in accordance with Vedung (2003), and detailed descriptions of policy tools in general use or for road safety, such as described by Elvik (2003) and others.

As shown in Table 2, road safety strategies suggested a strong emphasis on Disincentives (regulation, enforcement and penalties), Influence (ensuring driver competency) and Incentives (funding and investment to improve roads). Experience from other domains suggests a lack of a general classification of policy tools, but also a lack of comprehensive identification of available policy tools. Other domains focus on tools related to financial, cultural and tools to improve system objectives. This has led to the classification and sub-classifications of policy tools described in Table 2, in which all of the individual policy tools were represented in road safety research and practice.

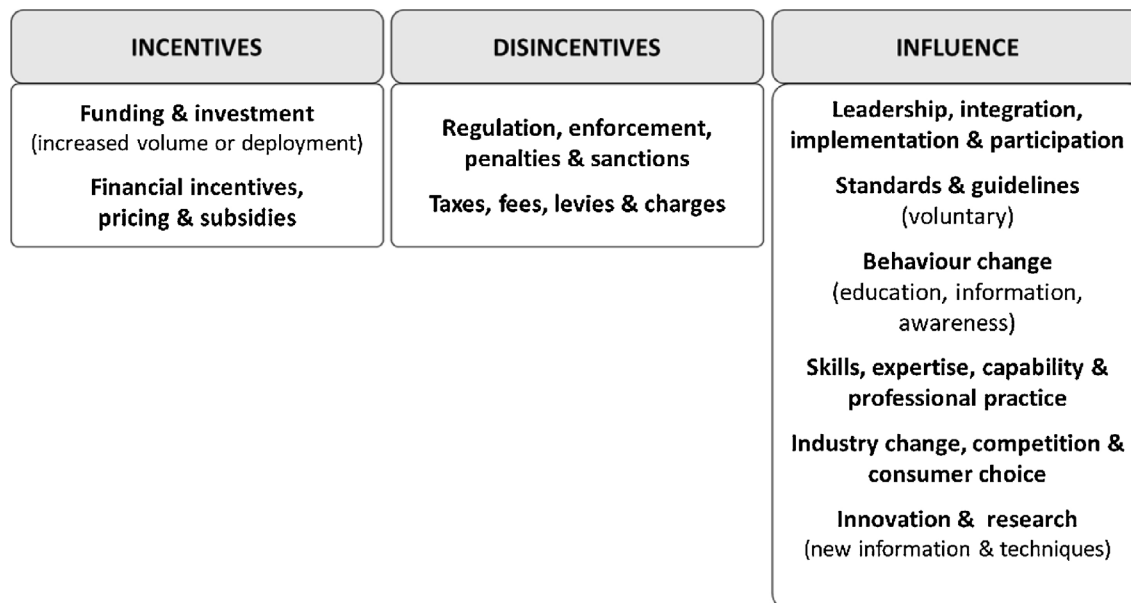


Fig. 3. Categories of policy tools.

Table 2
Policy tools.

Policy Tool	Description	Example reference
Funding and investment <i>Includes:</i>	Application of finances to increase the amount of facilities, services, assets, product or level of deployment Purchasing of vehicles, tools, systems and equipment, infrastructure investment, services delivery, deployment of staff, engineering production, maintenance and product delivery	ETSC (1999), Lambert et al. (2003), Mock et al. (2005), Hyder and Aggarwal (2009), Odeck (2010), Eliasson and Lundberg (2012), Agarwal et al. (2013), Albalade et al. (2013), Bax et al. (2014), Nguyen-Hoang and Yeung (2014), Yannis et al. (2015)
Financial incentives, pricing and subsidies <i>Includes:</i>	Voluntary monetary or in-kind payments, costs and rewards to encourage desired behaviour or practice. Financial transfers and cross subsidies Disincentives or penalties for poor behaviors and inducements or rewards for good behaviors Taxes and charges which provide road safety benefits (e.g., alcohol excise) Discounts for insurance and registration, payments to service providers	Wilde and Murdoch (1982), Boyer and Dionne (1987), Koornstra and Christensen (1991), Thompson et al. (1993), Gregersen et al. (1996), Wesemann (2000), Elvik (2010), Grayson and Helman (2011), Mooren et al. (2014)
Regulation, enforcement, penalties and sanctions <i>Includes:</i>	Activities to develop and apply a legislative authority Legislation, rules, orders, enforcement, penalties, sanctions, mandatory application of standards	Lee (1998), Bagard (2004), Macpherson and Spinks (2008), Mehmood (2010), Wilson et al. (2010), Dionne (2011), Langford and Koppel (2011), Sze et al. (2011), Albalade et al. (2013)
Taxes, fees, levies and charges <i>Includes:</i>	Financial charges applied to discourage undesirable behaviour or practice Payments for costs incurred, fees to encourage behaviour change, levies to fund policy tools	Dionne (1987), Wesemann (2000), Blows (2003), Linnakangas (2003), Thomas (2003), Elvik (2006), Boyer and Shiftan et al. (2012), Rangel et al. (2013)
Leadership, integration, implementation and participation <i>Includes:</i>	Desktop, office, personal and relational activities regarding the planning and delivery of policies, programs and projects to optimise safety outcomes. Excludes actual delivery of a policy Leadership: advocacy, campaigning, general background information, strategic planning, development, assessment, selection of effective and efficient policies, programs and projects, outcomes monitoring Integration: coordination, optimisation, information exchange, output management Implementation: planning, programming, timing, impact assessment Participation: dialogue with stakeholders, negotiation, agreements, engagement	Hakim et al. (1991), Wegman et al. (1995), Elvik (2003), May et al. (2008), Holló (2010), Larsson et al. (2010), Belin et al. (2011), May et al. (2011), Jähi et al. (2012), Agarwal et al. (2013), Canoquena (2013), Papadimitriou and Yannis (2013), Bax et al. (2014), Thekdi and Lambert (2015)
Behaviour change <i>Includes:</i>	Activities which encourage people to behave more safely Separate from, but may be linked to incentives, pricing, subsidies and regulatory mechanisms Education, information, awareness, rational encouragement, individualised information, mass campaigns	Henning-Hager (1986), Gregersen et al. (1996), Bianchi and Summala (2004), Delaney et al. (2004), Bertelli (2008), May et al. (2008), Grayson and Helman (2011)
Skills, expertise, capability and professional practice <i>Includes:</i>	Development of personal capacity, competency and fitness to undertake a task Development of professional skills and practice Training, experience, knowledge, skilling Medical, physical and intellectual fitness for duty	Baas et al. (2000), Arnold and Hartley (2001), Di Stefano and Macdonald (2003), Washington et al. (2011), ISO (2012), Beanland et al. (2013), Martin et al. (2013)
Standards and guidelines	Voluntary application of written authoritative agreements or references with respect to design and practice Formal and informal standards and guidelines for good practice. May be recommended, desirable or minimum	Haworth et al. (2000), FHA (2006), Crackel and Small (2010), Lamptey et al. (2010), Marshall and Garrick (2011), ISO (2012), Kafka (2012)
Industry change, competition and consumer choice <i>Includes:</i>	Application of strategic advantage to provide a market advantage. Influences in markets which result in a desired outcome Performance enhancement, lower costs, improved service, provision of market information (price, performance or quantity)	Haworth et al. (2000), Koppel et al. (2008), ITF (2011), Thompson et al. (2011), Atchley et al. (2014), Fernández-Muñiz et al. (2014), Rangel and Vassallo (2015)
Innovation and research <i>Includes:</i>	Investigation and development of new information with respect to behaviour, practice, product or operations and initial deployment to prove and refine applicability Basic and applied research, pilots, trials, evaluations, new general and specific information, continuous improvement	Wentz et al. (2001), Elvik et al. (2009b), Chapelon and Lassarre (2010), Hinchcliff et al. (2010), Johnston (2010), Schulze and Koßmann (2010), Weijermars and Wesemann (2013), Shen et al. (2015)

3. Result and analysis of road safety strategies

Identification of the components and policy tools is potentially useful for developing and assessing road safety strategies. Based on the components and policy tools identified, a matrix was constructed and used to analyze both the components and policy tools identified and described in 58 road safety strategies from 22 countries dated from 2000 to 2015, as shown in Table 3, in which

each cell represents at least one policy tool targeting one component. The count in each cell represents the number of strategies which include at least one policy tool for that component, with a percentage comparing to the total number of strategies. Many strategies include several policy tools in certain cells, such as regulation of drivers for licences, speeding and acceptable blood alcohol levels. Each cell was shaded to highlight the levels of effort road strategies generally according to quartiles (black—more than 75%

Table 3
Component and policy tool analysis of road safety strategies.

Policy Tool: Component affected:	INCENTIVES				DISINCENTIVES				INFLUENCE										Total number of strategies with Component			
	Funding & investment		Financial incentives, pricing & subsidies		Regulation, enforcement, penalties & sanctions		Taxes, fees, levies & charges		Leadership, integration, implementation & participation		Behaviour change		Skills, expertise, capability & professional practice		Standards, guidelines		Industry change, competition & consumer choice			Innovation & research		
Transport and Land Use Context	12	21%	1	2%	2	3%	0	0%	33	57%	25	43%	5	9%	20	34%	3	5%	10	17%	41	71%
Economic Context	2	3%	1	2%	4	7%	0	0%	5	9%	10	17%	8	14%	3	5%	5	9%	5	9%	18	31%
Social Context	1	2%	1	2%	6	10%	1	2%	17	29%	27	47%	15	26%	5	9%	3	5%	6	10%	33	57%
Natural Environment	7	12%	0	0%	2	3%	0	0%	2	3%	1	2%	2	3%	8	14%	0	0%	5	9%	16	28%
Road Infrastructure	57	98%	3	5%	23	40%	0	0%	53	91%	26	45%	27	47%	47	81%	8	14%	50	86%	58	100%
Vehicles	29	50%	7	12%	38	66%	0	0%	41	71%	35	60%	18	31%	35	60%	24	41%	45	78%	53	91%
Human	29	50%	4	7%	53	91%	4	7%	50	86%	56	97%	50	86%	22	38%	14	24%	45	78%	57	98%
Response System	17	29%	2	3%	2	3%	0	0%	19	33%	11	19%	20	34%	9	16%	3	5%	18	31%	32	55%
Safety Management	21	36%	2	3%	26	45%	0	0%	54	93%	39	67%	30	52%	18	31%	6	10%	41	71%	56	97%
Total number of strategies with Policy Tool	56	97%	16	28%	55	95%	3	5%	56	97%	56	97%	54	93%	55	95%	32	55%	54	93%		

Note: The count in each cell represents the number of strategies which include at least one policy tool for that component, with a percentage comparing to the total number of strategies.

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of strategies, dark grey—between 50% and 75% of strategies, light grey—between 25% and 49% of strategies, and no shading—less than 25% of all strategies).

The matrix in Table 3 displays the emphasis of road safety strategies, with more than 90% of strategies focusing on road infrastructure, vehicles, human and safety management. More than 50% of strategies also included some actions regarding the social context, transport and land use context or response system, but 25% or less of the road safety strategies engaged in changing the economic context, the natural environment, or the social context. More than 90% of the strategies analyzed included a leadership approach, integration, implementation, participation, funding, investment, regulation, enforcement, behaviour change, skills, expertise and capability, innovation, research, standards and guidelines. Other policy tools including financial incentives, pricing, subsidies, industry change, competition and consumer choice were less commonly used, while taxes, fees and charges were only identified in three strategies.

The individual strategies are noted in Appendix A, together with the number of components affected and policy tools employed. These are illustrated in Fig. 4. for all strategies across time. The analysis indicates that road safety strategies have been increasing in complexity over the past 15 years as illustrated by the trend lines shaded. More policy tools are being applied to more components. A few recent strategies either affect all components and/or employ all types of policy tools.

4. Discussion

Road safety strategies provide essential guidance for actions to improve road safety, but lack a conceptual framework that is comprehensive, systems theory based, and underpinned by evidence from research and practice. A framework based on nine mutually interacting components that contribute to crashes and ten generic policy tools which can be applied to reduce the outcomes of these crashes was developed. Looking into 58 road safety strategies from 22 countries across 15 years for completeness, found they were narrowly focused and could be improved by extending both the policy tools and the components to which they are applied.

The use of components and policy tools is based on systems theory (Perrow, 1984; Rasmussen, 1997; Leveson, 2004, 2009) and other fundamental principles (Vedung, 2003; Elvik et al., 2009a; Bliss and Breen, 2012), but the descriptions presented are more than a speculative invention, since they are all evident in road safety research and practice. Policy tools and the components to which they are applied have therefore been robustly proven over time to be appropriate for inclusion. The comprehensive conceptual framework is a thorough illustration of the complexity of road safety previously recognized (WHO, 2013), but not previously described.

The presented framework extends the common three components (humans, vehicles and roads) to nine key components, and by expanding them, resulting in 74 individual subcomponents, all of which have been described as affecting road safety, but

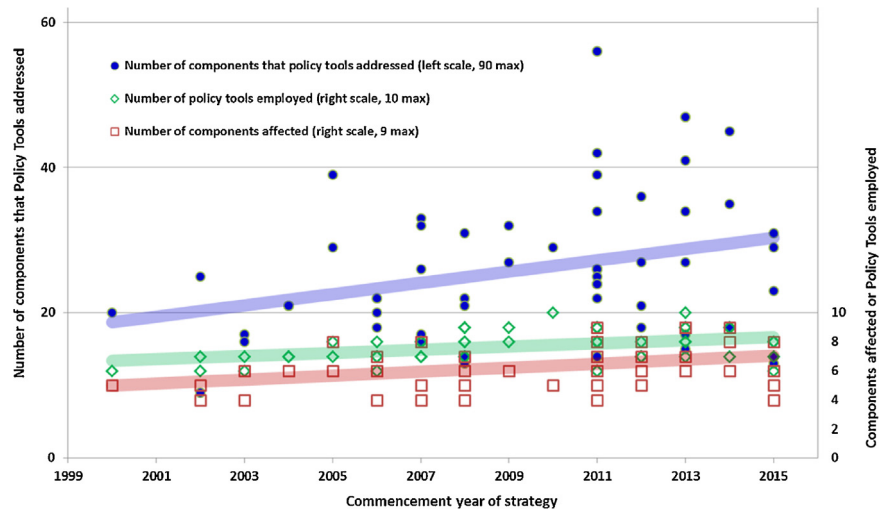


Fig. 4. Components affected and Policy Tools employed in individual road safety strategies over time.

not commonly included in road safety strategies. Secondly, the framework identified describes ten policy tools applicable to improve road safety, some more commonly applied than others (Hughes et al., 2015b).

Policy tools for improving road safety have not previously been comprehensively described or categorized. The traditional strong emphasis on enforcement, ensuring driver competency and improving roads was therefore extended to include financial, cultural and other tools to improve system objectives, all of which have been employed in road safety, but not commonly included in road safety strategies.

The components and policy tools demonstrate that road safety is complex and subject to many determinants, themselves influenced by other policy tools. The framework matrix of components and policy tools might be used to develop road safety strategies. The framework is consistent with the conclusion that “the application of systems thinking and methods affords the opportunity to take a far more holistic approach to road safety” (Salmon and Lenné, 2015; p247).

The analysis of road safety strategies’ policy tools and components found that a narrow range of policy tools were applied to a few components. Vehicles, human (the driver in this case) and roads were most commonly targeted with strategic approaches, integration, implementation, participation, funding, investment, regulation, behaviour change, skills, expertise and capability, innovation and research. Standards and guidelines were used to a lesser extent, but other policy tools including financial incentives, pricing & subsidies were rarely used. Very few of the road safety strategies analyzed engaged in changing the economic system, transport and land use, or the social system. While this assessment does not demonstrate any strategy as inadequate, neither is it obvious that a strategy has been developed to ensure that it is complete. The framework includes policy tools and components which are described in other safety domains.

Road safety strategies in the USA (or Strategic Highway Safety Plans—SHSP’s) are guided by Federal Law and guidance material including *A Champion’s Guide to Saving Lives—Guidance to Supplement SAFETEA-LU Requirements* (FHA, 2006). Consequently, SHSP’s are required to follow a collaborative process and develop a strategy with goals that comply with the template format. Development of the strategy is required to focus on “key emphasis areas” (FHA, 2006, p8) (e.g., occupant protection, pedestrians, intersections, roadway departure, impaired or distracted driving, data management, motorcycles, etc.). The Guidance suggests use

of the four ‘E’s’ (Engineering, Education, Enforcement and Emergency Medical Services). Consequently, road safety strategies in the USA could be more limited in scope than strategies that have less rigidity and a wider guidance structure. Such strategies could be less likely to include economic policy tools, such as incentives or taxation, and not take account of the wider social, economic, transport and urban form contexts, since there is no guidance on such policy tools and components. Conversely, road safety strategies from other jurisdictions do not clearly demonstrate collaboration with other relevant agencies or organizations, the application of a thorough process or a robust and comprehensive structure of policy tools, components, or the most important topics of focus. The differences suggest that there is potential to investigate whether variations in the types of strategies affects the efficiency or effectiveness of achieving strategy outcomes.

The breadth or detail of policy tools applied to improve individual components do not describe the effectiveness of any strategy, as a whole, to achieve the outcomes intended. It is possible for a strategy to employ a narrow range of policy tools across a few components if the tools are effective and sufficient resources are applied to substantially improve the components. It is possible that the effectiveness of any strategy has as much to do with the resources applied in its implementation, as it has to do with the level of sophistication of any strategy. That is, the success of recent road safety has been dependent on the level effort (such as the amount of enforcement as an example) rather than the quality of the strategy itself.

The analysis indicates that road safety strategies have been constantly increasing in complexity over the past 15 years, and some recent strategies include hundreds of individual actions, see Fig. 4. Where the focus of a strategy is limited (e.g., due to the agency span of responsibility like Police departments) or scope of interest is limited (like heavy vehicles alone), it can reasonably be expected that the road safety strategy will be simpler. Again, complexity does not necessarily indicate that the strategies are becoming more effective. However, it is known that road safety has been improving over the same period in many of the countries represented. Further work could assess the effectiveness of road safety strategies, such as whether more comprehensive strategies are more effective than simpler strategies, the levels of resourcing applied to execute the strategy and the effectiveness of management of implementation. One way to progress this might be to build on the knowledge about successful strategies (Hughes et al.,

2015a), which identified similarities and differences between road safety strategies in countries which had improved road safety.

While each of the components and policy tools is described, some overlaps remain. For instance, an action to encourage parents to talk with their children about the risks of alcohol and other drugs (in the *Washington State Strategic Highway Safety Plan 2013-Target Zero*) aims at changing behaviour for young road users, by changing the social norms, perhaps with better parental expertise. In this case the action crosses both Human and the Social Context components, as well as the behaviour change and capabilities policy tools.

This paper highlights the potential to assess the strengths and weaknesses of road safety strategies, individually and collectively. It also provides clear guidance for the development of road safety strategies generally by providing a description of the full range of components of road safety and the policy tools by which they can be affected. It appears there are opportunities for road safety strategies to target components currently ignored, and apply policy tools not yet commonly applied.

The widespread use of frameworks for road safety management in the past indicates their utility, so it is the authors' expectation that the framework presented here can be applied to determine how much value it can add in improving road safety strategies. Therefore, future research should investigate whether use of the framework results in improvements to road safety outcomes, especially compared with existing strategies. In the same way, an index or scoring system could be devised from the framework, in addition to other relevant factors (such as participants or process) and compared with the results of the strategy to determine best practice for widespread use.

Another element, sometimes included in road safety strategies, is the anticipated future level of road trauma outcomes, which is a complex topic also worth further investigation. Some strategies anticipate or forecast the expected results of successful implementation, while others propose a visionary outcome, such as zero deaths or serious injurious, which may not be achievable within the term of the strategy. The strategies themselves should be evaluated for their efficiency and effectiveness, as opposed to the more common situation where individual actions are evaluated in isolation. Furthermore, essential factors for a successful road safety strategy, such as the involvement of all actors, should also be investigated to ensure the frameworks or processes themselves are valid. The framework could be used to investigate the relationship between how a program 'scores' according to the conceptual framework and how much it succeeded in improving safety.

While this paper has described a comprehensive component–policy tool framework for road safety strategy development, analysis, research or beyond in practice, further work is required to apply it and assess its utility. The framework can provide a prompt to potential road safety policy tools and which components they can be applied to, that otherwise might be overlooked. It is, however, not expected that all the policy tools will be included in any road safety strategy or all components will be targeted for intervention. The framework might also be used to ensure that useful policies have been included. Furthermore, the framework has the potential to guide road safety research, analysis and routine investigations in similar ways. Finally, given the generic approach, it is possible that the framework can be adapted for use in similar ways in other domains including industrial, mining and occupational safety.

Strategies for road safety are applicable to particular user groups (such as heavy vehicles), subordinate jurisdictions (such as States within countries or cities), advocacy or coordinating organizations (such as the United Nations, or automobile associations),

individual industries (such as tourism or mining), particular commodities (such as hazardous goods, or individual companies for workplace road safety as part of occupational safety). Further work could explore the adaptation, implementation and utility of the framework to these domains. The strategies investigated were from developed countries, so strategies from other jurisdictions may be different. It is expected that the initiatives which have proven successful in developed countries can be successfully applied in developing countries that are subject to different social and economic contexts. Even in developing countries, it remains to learn whether the traditional policies and emerging opportunities, particularly offered by electronic information and communication technologies, will continue to result in reducing road trauma. Given the challenges of complexity, context and scale, perhaps different road safety frameworks will be required to recognize additional factors contributing to safety and to employ policy tools not yet applied. Given the challenges that road safety presents in developing countries, further work could be to consider differences between developing and developed countries, particularly in terms of the underlying social, economic, land use and transport contexts. A limitation here is the knowledge of the effect the stakeholders involved putting the policies into place to affect the described components. A complementary control system approach describing a hierarchy of actors and organizations has recently been developed for road safety (Salmon et al., 2015) based on more general systems theory (Rasmussen, 1997), which could be applied to the proposed framework as a complementary approach. Consistent with systems theory, further research could investigate the relationships between individual actors with the policy tools and subcomponents in the framework, which offers the potential to increase the efficiency and effectiveness of road safety strategies.

The components, policy tools and hierarchy of stakeholders (actors and organizations) clearly demonstrate the complexity in addressing road safety. It highlights that simplistic approaches to a narrow range of components, from a few actors, has at least the potential to be inadequate. It is a signal to road safety strategists that they are likely to need to move beyond the span of their own control into fields where they do not have direct responsibility. Furthermore, they are likely to need to employ policy tools which are beyond their direct authority. These move beyond the focus and activity of traditional road safety strategies will therefore require road safety strategists to start exerting influence indirectly and more widely, rather than relying on exercising on their own authority directly.

The proposed comprehensive framework for road safety strategies might be applied by road safety practitioners, and subsequently evaluated for utility. Application could take several forms, such as using the framework in its 'blank' form to identify potential policy tools which could potentially be applied to subcomponents to be targeted. The framework might also be used to review past strategies to identify which policy tools and subcomponents have not previously been applied. Researchers might use the framework as a guide to identify complementary or confounding factors which may be influencing individual policy tools or subcomponent being investigated. Finally, the framework might be used to further guide comparison, assessment and contrast of road safety strategies, extending the assessments in this paper.

The authors expect the framework contributes to holistic thinking, innovation, and a comprehensive strategy involving a range of coordinated and interrelated responses required for road safety (Eliasson and Lundberg, 2012). The results of this paper support what is stated by Salmon and Lenné (2015) p247 that "adopting 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".

Appendix A. Summary of road safety strategies and framework analysis.

Title	Period of the strategy or date	Authority	Number of components affected (9 max)	Number of policy tools employed (10 max)	Number of component—policy tools used (90 max, % of 90)
Safe Roads for Development: A policy framework for safe infrastructure on major road transport networks	Not stated	World Bank Global Road Safety Facility	3	5	10 11.1%
Every Accident Is One Too Many	2000	Danish Ministry of Transport for the Danish Road Safety Commission	5	6	20 22.2%
Road Safety in Norway: Strategy	2002–2011	Ministry of Transport and Communications	4	6	9 10%
Northern Ireland Road Safety Strategy	2002–2012	Department of the Environment Road Safety Branch	5	7	25 27.8%
The South Australian Road Safety Strategy	2003–2010	Transport SA	6	7	17 18.9%
National Heavy Vehicle Safety Strategy	2003–2010	Australian Transport Council	4	6	16 17.8%
National Road Safety Strategy of the Czech Republic	2004–2010	Ministry of Transport of the Czech Republic	6	7	21 23.3%
Queensland Road Safety Action Plan: safe4life & Queensland Road Safety Strategy	2004–2011	Department of Transport and Main Roads	6	7	21 23.3%
Via sicura – Federal Action Programme for Greater Road Safety	2005	Federal Roads Authority FEDRO (Switzerland)	8	8	39 43.3%
AASHTO Strategic Highway Safety Plan (2004 update)	2005	AASHTO—USA	6	7	29 32.2%
Safe Traffic: Vision Zero on the Move & “Vision Zero” from concept to action	2006	Swedish Road Administration	6	8	20 22.2%
National Road Safety Strategy	2006	Transport Department (South Africa)	4	7	22 24.4%
Safer Roads: A Territory Imperative	2006	Northern Territory Government	6	7	22 24.4%
Strategic Plan: New Ideas for a Nation on the Move	2006–2011	Department of Transportation (USA)	7	6	18 20.0%
White Paper on Traffic Safety in Japan	2007	International Association of Traffic and Safety Sciences	4	7	16 17.8%
Strategic Framework for Road Safety & Tomorrow's roads—safer for everyone	2007 & 2011	Department for Transport (United Kingdom)	8	8	33 36.7%
Road Safety Strategy	2007–2012	Road Safety Authority (Ireland)	5	8	26 28.9%
Our Safety Our Future, Tasmanian Road Safety Strategy and Action Plan	2007–2016	Department of Infrastructure, Energy and Resources	5	8	17 18.9%
Strategic Highway Safety Plan: Target Zero (SHSP)	2007–2030	State of Washington, Office of the Governor	8	7	32 35.6%
Towards Zero Deaths	2008	The American Traffic Safety Services Association	5	7	13 14.4%
UNECE Transport Review: Road Safety	2008	United Nations	4	7	14 15.6%
National Road Safety Strategy	2008–2015	Autoridade Nacional de Segurança Rodoviária (ANSR—National Road Safety Authority, Portugal)	6	9	31 34.4%
Victoria's Road Safety Strategy: Arrive Alive	2008–2017	Victoria Police, Victoria, Transport Accident Commission, Department of Justice	7	8	22 24.4%
Road Safety Strategic Plan, From, for and by everyone	2008–2020	Minister of Transport, Public Works and Water Management (Netherlands)	5	8	22 24.4%
Towards Zero – Road Safety Strategy	2008–2020	Road Safety Council Western Australia	6	9	21 23.3%

Austrian Road Safety Program (2009ed)	2009	Federal Ministry for Transport, Innovation and Technology	6	9	32	35.6%
Scotland's Road Safety Framework	2009–2020	The Scottish Government	6	8	27	30%
Safer Journeys NZ Road Safety Strategy and Action Plan	2010–2020	National Road Safety Committee New Zealand and Ministry of Transport	5	10	29	32.2%
Road Safety Programme	2011	Federal Ministry of Transport, Building and Urban Development (Germany)	8	8	24	26.7%
Kentucky Strategic Highway Safety Plan	2011–2014	Kentucky Transportation Cabinet, Office of Highway Safety	6	8	26	28.9%
Canada's Road Safety Strategy 2015	2011–2015	Canadian Council of Motor Transport Administrators	4	6	14	15.6%
Road Safety Plan	2011–2015	Stirling Council (Scotland)	8	6	26	28.9%
Austrian Road Safety Programme	2011–2020	Ministry for Transport, Innovation and Technology	9	9	56	62.2%
Road Safety Strategy 2011–20 & ACT Road Safety Action Plan 2011–2013	2011–2020	ACT Government	7	8	34	37.8%
South Australia's Road Safety Strategy 2020: Towards Zero Together	2011–2020	Road Safety Advisory Council (South Australia)	7	8	25	27.8%
National Road Safety Strategy	2011–2020	Australian Transport Council	5	9	24	26.7%
National Road Safety Programme	2011–2020	Republic of Croatia	8	8	39	43.3%
Spanish Road Safety Estrategy	2011–2020	Traffic General Directorate	7	9	42	46.7%
Development of a Strategic Plan for the improvement of road safety	2011–2020	Hellenic Republic, Ministry of Infrastructure, Transport and Networks	6	8	22	24.4%
Policy Document Road Safety: working together as one	2012	Ministry of Infrastructure and the Environment (Netherlands)	7	8	36	40.0%
Strategic Highway Safety Plan	2012	Florida Department of Transportation	5	7	21	23.3%
Strategic Highway Safety Plan	2012–2016	State of Nebraska	6	7	18	20.0%
Strategic Highway Safety Plan	2012–2016	Commonwealth of Virginia, Department of Transportation	8	7	27	30.0%
State Strategic Highway Safety Plan 2013 • Target Zero	2013	State of Washington	9	10	47	52.2%
Traffic Safety Plan	2013–2015	Office of Traffic Safety, Alberta Government	9	8	41	45.6%
Strategic Highway Safety Plan	2013–2017	Massachusetts Department of Transportation	6	7	17	18.9%
Every Accident is one too many – a shared responsibility. National Action Plan	2013–2020	Danish Road Safety Commission	6	9	27	30.0%
National Road Safety Programme	2013–2020	National Road Safety Council, Ministry of Infrastructure and Development (Poland)	7	9	34	37.8%
Road Safety Strategy	2013–2020	Road Safety Authority (Ireland)	9	9	47	52.2%
Victoria's Road Safety Strategy	2013–2020	Victoria Government agencies	6	8	15	16.7%
Road Safety Strategy Final Technical Report	2014	City of London	6	7	18	20.0%
Strategic Highway Safety Plan	2014–2016	Wisconsin Department of Transportation	8	9	35	38.9%
National Plan of Action for Road Traffic Safety	2014–2017	Norwegian Government	9	9	45	50.0%
Road Safety Strategy	2015	Bermuda Police Service	4	6	13	14.4%
Alaska Highway Safety Plan	2015	Alaska Highway Safety Office	6	8	23	25.6%

California Highway Safety Plan	2015	California Office of Traffic Safety	6	8	29	32.2%
Road Safety Strategy: Toward Zero Tolerance	2015	Transportation and Infrastructure Renewal (Prince Edward Island)	5	8	14	15.6%
A Safe Systems Approach to Road Safety in Bristol: A 21st Century Approach	2015–2024	Bristol City Council	8	7	31	34.4%

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