Towards a Complete Description of the Safe System

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Abstract

The Safe System has been described in a range of strategies and other publications. Consistently, these describe a number of factors, typically infrastructure, speed, people and vehicles, to indicate that a safe or safer system will be achieved by actions across all of these. This paper examines an alternative model in which these "pillars" are not inputs to achieve safety but are outputs of the interactions within the system. Speed, vehicle and environment describe the system state for each individual. Some implications of describing system risk as a function of these three variables are then discussed to illustrate the complexity of interactions that can be influenced in working towards a Safe System.

Introduction

Early representations of the Safe System, such as those originally included in Australia's National Road Safety Strategy, showed the components of the system in ways that reinforce the linkages and interactions between them (ATC, 2009). More recently, these linkages have been simplified and adapted to focus on the main areas in which actions will be based. These are commonly described through solid structural metaphors such "cornerstones" (ATC, 2011) or "pillars".

While this simplified representation may be more effective as a public communication tool, it de-emphasises some of the complexities within what is a dynamic system and, in particular, does not demonstrate the key principle in the Safe System to design for human fallibility. These later representations generally introduce road users as an equal component of the system (Figure 2).

This might be considered as contrary to a central concept of the Safe System approach, in which individuals cannot be relied upon to behave safely and that the system designers must therefore strive to protect all road users from the impact of those behaviours (OECD, 2008, p109). Consequently, it is unclear when practitioners state that they are using a "Safe System approach" whether they are merely considering a number of factors within the system representations shown in these figures or whether they are truly working towards the more challenging objectives of a Safe System.

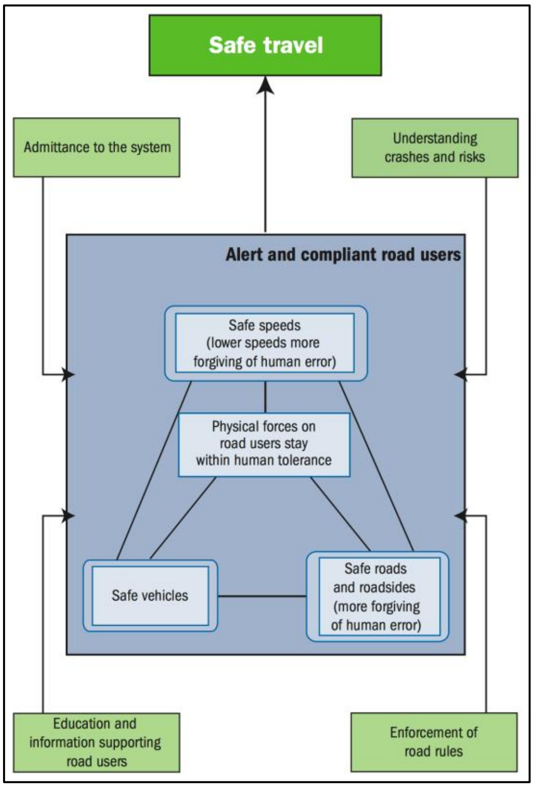

Figure 1. The Safe System Framework (ATC, 2008)

Figure 2. The Safe System approach (NRSS, 2016)

The need for a system-based approach to create a new paradigm for road safety research and practice has been recognised (Salmon and Lenné 2015). Their paper provides a detailed description of the application of systems thinking to road safety but concludes: "*The challenge for the road safety community (researchers, practitioners, stakeholders) now is not only to further investigate systems thinking applications in road safety research, but also to translate research of this kind into practice*".

This is not a new concept. Quoting in a paper discussing the semantics of the use of the term "accident", Haight provides an extract from some work by Little in 1966, which concluded: *"…we have abandoned the word "cause" and use the phrase 'contributing factor'… to mean any feature of the system, the variation of which will alter the risk of an accident"* (Haight, 1980). Contemporary Safe System thinkers might prefer the use of the term "harm" to replace the "accident" but the intent is similar.

If system thinking is to be applied to the Safe System, it is important to understand how this system behaves as a dynamic one, rather than the static representation built on pillars.

This paper returns to a more dynamic representation and goes further by proposing a mathematical model in which the original Safe System components of speed, infrastructure and vehicles are not areas of action but, instead describe the state of an individual within the system. They are the outputs of the complex interactions that form the road traffic safety system.

The paper is in three parts, the first describes a conceptual risk model to derive the risk for an individual in this system state. The second discusses the actions and interactions that influence the speed, infrastructure protection and vehicle protection that represent the system state. Lastly, the paper discusses how the thinking implicit in this model might alter the approach practitioners take when they adopt "a safe system approach"

The risk model

If the system state of an individual can be described by their combination of speed (s), the road environment (e) and the vehicle (v), system risk can be described as a function R(s, e, v).

For the purpose of this model, it is further assumed that this function can be described as $R(s,e,v)=R_s.R_e.R_v$ or that the overall risk is the product of individual risks associated with each factor. For example, on a typical undivided rural highway, with current vehicles, the product $R_e.R_v$ remains high and the only way a Safe System can be achieved is by reducing R_s; in other words, by reducing travel speed to the Safe System speed for that particular environment.

Conversely, if any one of these functions is zero (or effectively low enough to be considered "safe"), the other two functions can be unconstrained.

These individual risk factors could be considered to reflect the extent of protection provided by each of these components. This protection (1-R), is completed when R is zero.

The risk associated with the road system can therefore be described as a four-dimensional function. While this is difficult to represent graphically, more familiar relationships can be represented as cross sections through this function in two dimensions.

For example, as shown in Figure 3, if R_e is one, and R_v constant at values that represent a fleet average, this yields the relationship popularised by authors such as Wramborg, 2005, with different crash types having different R_v associated with them. Where R_v approaches one at all impact speeds, i.e. as no protection is provided by the vehicle and the road user becomes more vulnerable, the risk curve approaches the pedestrian one.

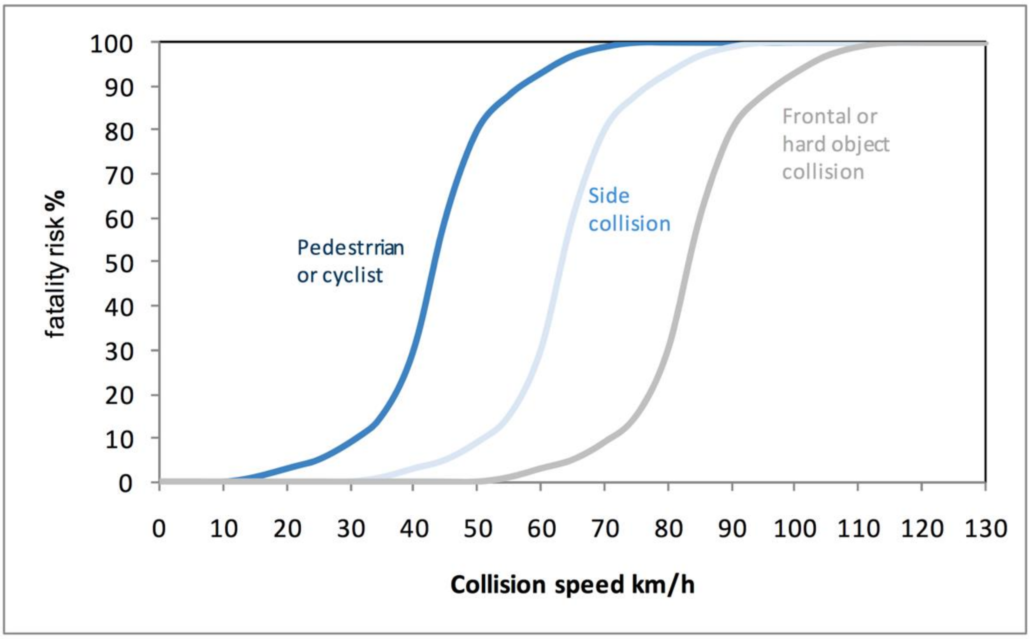

Figure 3. Fatality Risk from Wramborg, 2005 as shown in OECD, 2008

This model allows other relationships to be explored. Figure 4 shows the result of a cross section of the risk function in another direction. The differences between pedestrian risk curve and the curves representing different levels of occupant protection provides an estimate of R_v for each crash type. At low speeds, R_v is close to one and the vehicle makes very little contribution to risk reduction because R_s is low. The greatest protection is contributed by the vehicle at approximately 50 km/h for a side impact and just over 60 km/h for a frontal impact.

At higher speeds, the performance limits of the vehicle are exceeded, and R_v approaches 1.

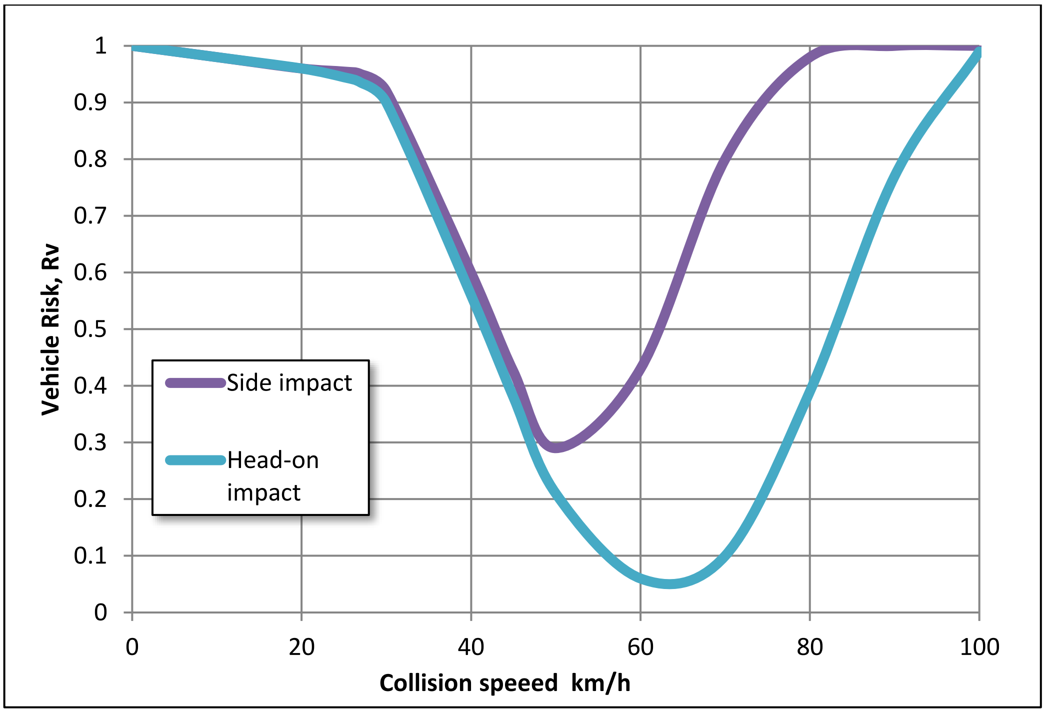

Figure 4. Vehicle risk, R_v, derived from Wramborg 2005

In other words R is a function of speed as well as of the individual vehicle characteristics, v. Hence the individual risk factors are not independent and demonstrate the complex interactions between variables that need to be understood for a complete understanding of the Safe System

While this model describes the risk inherent in the system for any individual, the overall risk experienced by that individual also needs to consider behavioural factors.

With our current road systems, this Overall Risk could be described for each individual as OR=R(s,e,v).B(i), where B(i) is the risk associated with the behaviour of each individual. This function would include the effect of factors such as inattention, impairment, risk appetite, and risk judgement etc. While this is obviously a very influential component of the Overall Risk function the Safe System approach reflects an understanding that B(i) will never approach zero and, consequently the system risk R(s,e,v) needs to be. Conversely, in a Safe System R(s,e,v) is zero and hence the overall risk will remain zero, despite human fallibility. However, until the system is safe, the behaviour component will remain a vital component of work to reduce harm. This component encompasses a wide range road user behavioural issues that will determine whether a system failure leading to a potential crash will in fact result in a crash and its likely impact speed. However, the eventual harm arising out of this crash is dependent once again on the system and its protective performance.

Some of the individual components of this behavioural function are well established, such as the risk associated with different BAC levels and work is continuing on other aspects, such as the development of a taxonomy for driver inattention (Engstrom and Monk, 2013).

The overall risk for an individual over a time period T, could then be described as:

$$\int_0^T \mathrm{R(s,e,v).B(i).dt}$$

For N road users in the system, the amount of trauma could be calculated as

$$\sum_{i=1}^{N}\left(\int_0^T \mathrm{R(s,e,v).B(i).dt}\right)$$

In a Safe System, this sum would be zero. In practice, it is likely that small error functions would be present to prevent this. It also demonstrates that for very large N, e.g. 5,000,000 for Victoria, and for significant T, e.g. 30 million seconds per year, small increases in any one of the risk factors, e.g. low level speeding, can result in significant system impacts.

In reality, these factors would also need to account for interactions between road users. The model provided in this paper is a simplified one in which these interactions are not explicitly included but could be factored within the individual risk factors. For example, a road that allowed significant interaction between road users would have a correspondingly lower R_e.

Describing the system

While extensive research would be required to validate this conceptual model and determine the exact shapes of the individual functions R_s, R_e, and R_v, there is strong consensus, based on proven practice and research evidence, to describe what each of s, e and v look like for a safe outcome. The speed-risk relationship is well known and the features of e and v for a Safe System are well promoted through programs such as iRAP and NCAP, respectively. In other words, we can describe a Safe System but the system interactions that lead to that result are less often explicitly described.

There are a few representations of this system. A widely used one is the World Bank's road safety management system framework (Figure 5).

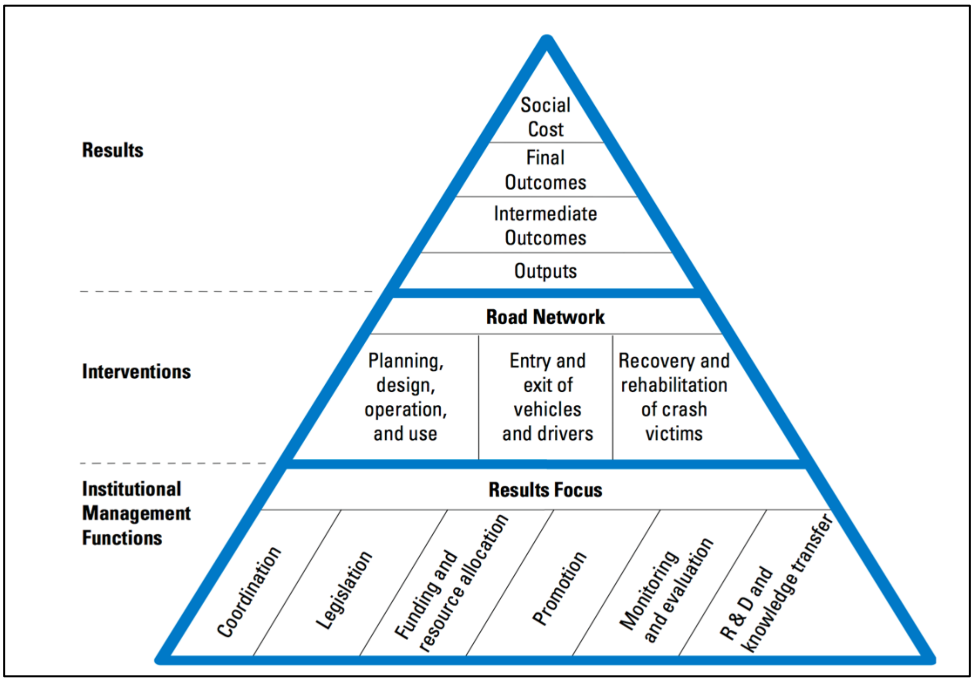

Figure 5. Road Safety Management System (Bliss and Breen, 2009)

This model emphasises the institutional arrangements necessary for the achievement of a Safe System, however this model itself, does not describe the detail interactions that define the system. It shows enablers to facilitate the building of a Safe System but does not describe the actual interactions involved. More detail is provided in papers such as Salmon, Read & Stevens (2016). However, the system representation within this paper focuses on prevention of the "fatal five" behaviours of drink and drug driving, speed, non-use of seat belts, distraction and fatigue. These largely relate to the factors that influence B(i), rather than those that determine R(s,e,v).

Nor is a complete description of the system provided by this paper and, perhaps, the effort required to do so may never be justified. Nevertheless, it may be productive for practitioners charged with improving the system to consider the part of the system that is relevant to their problem at hand.

To illustrate what this description might look like, a simple example is provided.

A road, within a Safe System, with characteristics, E, such that $R_e(E)$ is effectively zero, might be described as follows

- Has a single function,
- Is self-explaining consistent with that function,
- Provides protection within the limits of human frailty for all probable road user or vehicle failure,
- Maintains its performance in all probable environmental conditions.

The systems factors that can influence this are complex and relate to how the system is designed, how it is created, and how it is operated. Some examples of these interactions are shown in Table 1.

Table 1. System interactions influencing road infrastructure performance

Design	**Creation**	**Operation**
• Land use planning • Crash barrier research • Road design guidelines • Crash data	• Infrastructure investment levels • Prioritisation of investment • Construction techniques • Planning controls	• Route choice • Time of day • Vehicle choice • Speed selection • Traffic management • Road pricing

It should be noted that, while a number of these factors relate to design standards as is conventional the risk associated with the road environment at any point in time is also influenced by dynamic factors such as the route the driver has chosen.

The actual system is, in practice far more complex that this and each of the factors shown above, and others, will be dependent on a network of other systems interactions.

For example, the single factor "infrastructure investment levels" could then be analysed to identify systems interactions driving increased levels and those that are constraining those levels, as shown in Table 2.

In turn, each of these factors could be further analysed by, for example, examining the factors that lead to increased societal demand for safety.

Another potentially fertile area of analysis would be to examine current road safety policies and strategies and determine whether these can be made more effective by altering the systems settings that may be driving popular but ineffective interventions, through examining and then influencing the drivers of popularity rather than compromising effectiveness.

Table 2. System interactions influencing infrastructure investment levels

Driving factors	**Constraining factors**
• Gross domestic product per head • Societal demand for safety • Societal demand for mobility • Demonstrated benefits • Hypothecated revenue • Credit rating of funders • Availability of capital • Population density	• Demands for alternative investment, schools, hospitals etc • Land area • Network length • Asset maintenance demands • Interest rates • Lack of understanding of the need • Lack of understanding of the benefits

Discussion

If practitioners are adopting a "Safe System approach" in research, and policy development and implementation, there should be a shift in the issues being examined away from understanding B(i), towards an improved understanding of the factors influencing R(s,e,v)

However, there is a continuing focus in road safety countermeasures, messaging and research to focus on road user behavioural issues. An analysis by the author of 167 papers presented at the 2016 ACRS conference (ACRS 2016), indicates this continuing focus issues that, in a Safe System, would be irrelevant. Figure 6 shows a breakdown of areas covered by these papers, showing that a number of papers cover more than a single area.

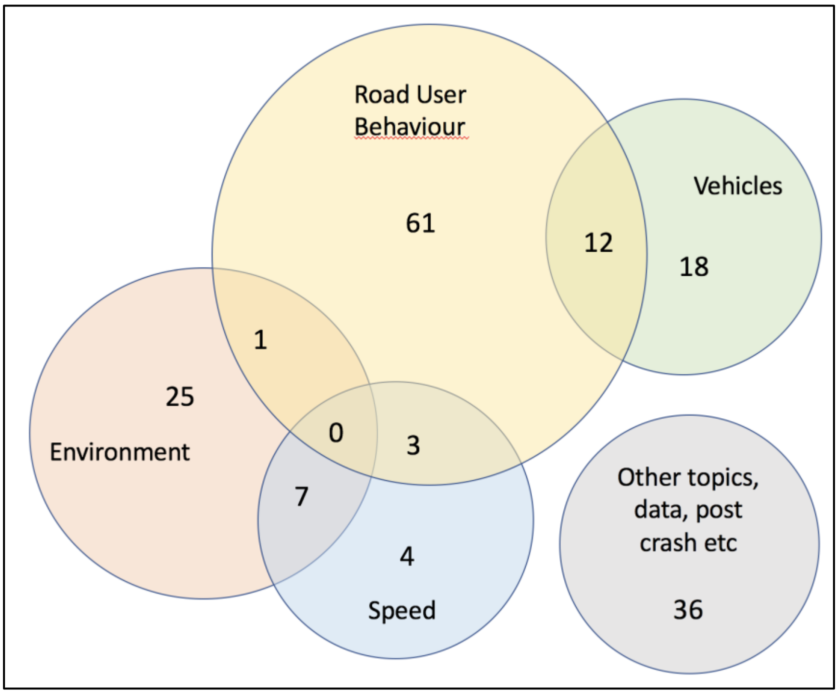

Figure 6. Topics covered at 2016 ACRS Conference

There is no suggestion that this focus is misplaced as changes to road user behaviour are essential to minimise harm, particularly in the short-term. These issues are in areas of proven benefit in contributing to a safer system but there are many other issues to be explored if we are to achieve a Safe System.

Conclusions

The model presented in this paper is incomplete and dependent on some very broad assumptions. It focuses on single-vehicle crashes and is limited in its treatment of individual differences in tolerance to serious injury. For example, older road users would require different risk outcomes for the system to be considered safe. There is also the question of what is a "Safe System": is it zero risk or risk below some threshold that represents an error function?

However, the model is presented to provide an alternative view of the Safe System and one that may assist practitioners in applying a Safe System approach to the development of effective policies and programs. These issues are those that influence the system state, not the issues relating to road user behaviour once their fate has been determined by the performance of the system. Of particular relevance are the behaviours not of road users but of those responsible for designing, building and operating the road traffic safety system that we are seeking to make Safe.

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