Chapter 2

Principles and description of a Safe System

The traditional approach to road safety accepts a trade-off between mobility and loss of life. The main reason for crashes is seen as "wrong" human behavior, and policy aims at influencing road users' behaviour towards full compliance with rules and requirements. A Safe System recognises that humans will make mistakes, and that the human body has a limit to which it can absorb crash forces without suffering injury. It posits that safety is a shared responsibility of all actors in a traffic system, not only that of a road user. Thus, all elements of the road traffic system should come together in an integrate safety chain in which the elements will combine to prevent a crash, or at least prevent serious injury, even if one or more elements fail.

Principles of a Safe System

In road safety analysis and crash studies, two approaches are possible (Hauer, 2016, forthcoming). The traditional approach takes a backward-looking perspective. Standard crash causation analysis strives to understand all the factors involved in a crash that happened in order to suggest ways how such a crash could have been prevented. Alternatively, a forward-looking view will consider what crashes might potentially happen in the future and identify all possible ways how such crashes can be prevented. This proactive approach is the basis of a Safe System. Table 2.1 illustrates the major differences between these two approaches.

Table 2.1. **Comparing the traditional road safety approach and a Safe System**

	Traditional road safety policy	Safe System
What is the problem?	Try to prevent all crashes	Prevent crashes from resulting in fatal and serious casualties
What is the appropriate goal?	Reduce the number of fatalities and serious injuries	Zero fatalities and serious injuries
What are the major planning approaches?	Reactive to incidents Incremental approach to reduce the problem	Proactively target and treat risk Systematic approach to build a safe road system
What causes the problem?	Non-compliant road users	People make mistakes and people are physically fragile/vulnerable in crashes. Varying quality and design of infrastructure and operating speeds provides inconsistent guidance to users about what is safe use behaviour.
Who is ultimately responsible?	Individual road users	Shared responsibility by individuals with system designers
How does the system work?	Is composed of isolated interventions	Different elements of a Safe System combine to produce a summary effect greater than the sum of the individual treatments- so that if one part of the system fails others parts provide protection.

Source: Inspired from New Zealand Transport Agency and VicRoads.

Four principles underpin a Safe System in road traffic:

1. People make mistakes that can lead to road crashes.
2. The human body has a limited physical ability to tolerate crash forces before harm occurs.
3. 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.
4. All parts of the system must be strengthened to multiply their effects; and if one part fails, road users are still protected.

Thus, the design and operation of the road transport system should guide the road user to safe behaviour and mitigate the consequences of common human errors.

Human error

Human beings can never be relied upon to repeatedly perform correctly in all traffic situations over many years, even if it is their intention to manoeuvre in a safe manner at all times. Hence the capabilities and limitations of the human being must be taken into consideration when designing and operating a safe road transport system.

There are numerous reasons road users commit errors and misjudgements. In many cases they originate from the interaction between the road user and the complex physical, social, organisational and technical environment that constitutes traffic and in which the road users act. Errors arising from interaction with the traffic and road environment can be limited by understanding these interactions and designing the road transport system from these interactions, in order to guide the road user to behave in way that is as safe as possible. Yet, as human error cannot be fully eradicated there is a need, at the same time, to mitigate the consequences of mistakes.

In simple terms, this basic principle of a Safe System starts with the insight that human error should no longer be seen as the primary cause of crashes. Instead, road crashes are seen as a consequence of latent failures created by decisions and actions within the broader organisational, social or political system which establishes the context in which road users act.

Limited physical crash tolerance

The human body has a limited physical ability to absorb the kinetic energy a crash exerts before harm occurs. As early as 400 B. C. the Greek physician Hippocrates noted:

> Of those who are wounded in the parts about the bone, or in the bone itself, by a fall, he who falls from a very high place upon a very hard and blunt object is in most danger of sustaining a fracture and contusion of the bone, and of having it depressed from its natural position; whereas he that falls upon more level ground, and upon a softer object, is likely to suffer less injury in the bone, or it may not be injured at all.

Behind Hippocrates' sentences lies the strong relationship between speed and the energy released when an object suddenly stops the movement, and an observation how resulting injuries can be avoided (or at least reduced): by lower speeds on the one hand and the composition of the obstacle on the other. Reduced operating speeds thus not only limit the risk of errors, they also result in a less strong impact and less serious injuries when crashes do occur. The risk of injury in crashes can be mitigated to a large extent by reducing dangerous kinetic energy, be it through low impact speed, contact surfaces that absorb kinetic energy in case of a crash, or a combination of both.

While this may be clear and logical, the road transport system has not been designed with the principle of mitigating common human error or absorbing the consequences as its foundation. For example, increased numbers of vehicles and higher travel speeds (often accompanied with smoother road surfacing) have negative consequences for road safety that have often overwhelmed efforts to improve the safety of road infrastructure, thus producing, on balance, reduced levels of safety.

Shared responsibility for road safety

There is a shared responsibility 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. While it is the individual responsibility of every road user to abide by safety-related laws and regulations (with education and enforcement being important factors to induce such behaviour), it remains a fact that human beings are not infallible and will always make mistakes, no matter how educated or law-abiding they may be.

In a Safe System, therefore, safe human behaviour in the first instance is informed and guided by the design, layout and operation of the road network, in addition to traditional education and enforcement actions for safe behaviour. Road designs and operations that provide feedback to users or are "self-explaining" can help create an environment that prompts safe road use. Chapter 5 deals extensively with this aspect.

In a system where user mistakes are compensated for in a way that they will not result in serious or fatal injury, a large share of the responsibility for safety automatically shifts from the road users themselves to all those who design the road transport system. These include road managers, the automotive industry, the police, transport operators, health services, the judicial system, schools and road safety organisations and, not least, politicians and legislative bodies. All these bear joint responsibility for providing a road environment that increasingly anticipates potential mistakes and deals with them in a way that avoids serious harm. Box 4.4 provides an example of shared responsibility and the various roles and contributors that different stakeholders or "system designers" make in a Safe System.

Strengthen all parts of the system

The fourth principle underlying a Safe System addresses the potential weakness that if one element fails, serious injury may occur. This is illustrated by the "Swiss Cheese model" (see Figure 1.1), in which a hole represents a latent error. In isolation, a latent error may not result in dramatic consequences. Latent error becomes a danger when they allow for a chain of event leading to a crash (Wegman and Aarts, 2006). To counter this, a Safe System strengthens all dimensions of road safety so that the combination of measures cover for each other in a way that if one element fails, road users are still protected due to the layered nature of the system and failures cannot result in "a trajectory of accident opportunities" (Reason, 1997). The dynamic interaction of the different elements of a Safe System instead combines to multiply the protective effect so that the overall safety is greater than that provided by adding up the effect of the individual elements.

To provide a greater overall effect, the layers that together build a Safe System – the design and operation of road infrastructure, operating speeds, vehicles, human behaviour – will be managed holistically and not as separate parts in "silos". In those countries at the forefront of Safe System thinking, the four guiding principles are being translated into concrete design principles for safety across the system safety, rather than for each component individually. This is a main difference with the traditional approach in which responses are often managed and implemented by different agencies.

The Integrated Safety Chain

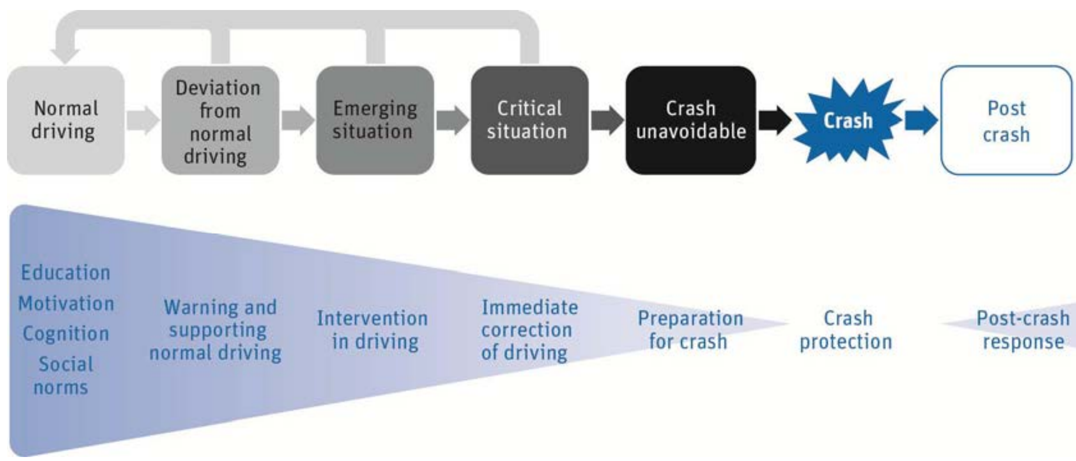
The Integrated Safety Chain (see Figure 2.1) is used in some advanced countries to match the first two principles of human error and human tolerance to force to progress implementation of a Safe System. The Integrated Safety Chain was conceived to encourage thinking about injury prevention in a way that takes a potential crash event as its starting point, and then works backwards to solutions that avoid such an outcome. The challenge then becomes to prevent the hazardous event at the earliest possible stage of the integrated safety chain.

It is, however, necessary to simultaneously acknowledge that this will not always be possible. Measures are also needed that can limit the amount of kinetic energy in case of a crash and thus the risk of injury. The key is to link the possible outcome with the speed that can be tolerated under normal driving conditions so that any kinetic energy released will not be larger than what can be managed through the chain. For each step, a systems approach must be taken in order to understand and integrate road user rules and behaviour, road and traffic environment, speed management, vehicle systems, post-crash response with the aim to combine them in an effective way.

The chain is described with a loop which symbolises the driver regaining control and then continuing to drive normally. If the driver's attempt to return to normal driving fails, there should be an action to avoid the next stage in the chain (emergence of a critical situation). Even if the return to a less dangerous stage fails and a crash becomes unavoidable, this situation can still be influenced in a way that mitigates the consequences.

It is important to understand that, while efforts should focus on all stages, it is not possible to always rely on solving the problems in the early parts of the crash sequence. The strong focus on upstream efforts in the safety chain inherent in a Safe System goes along with the acknowledgment that there will always be events that fall through and thus make it necessary to also include mitigation of crash consequences.

Figure 2.1. **The Integrated Safety Chain**

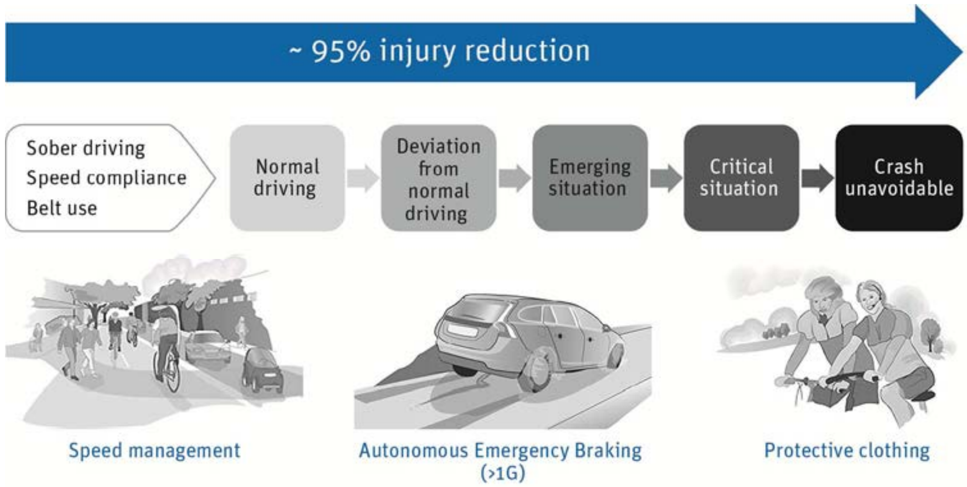


Source: Adapted from Tingvall et al.

An example of how the Integrated Safety Chain works to create a combined effect to protect cyclists in potential conflict with cars is given in Figure 2.2. What is substantially different from a risk reduction approach is that at the end of the chain, after the crash, there is no harmful consequence. This, in turn, puts the requirement on the chain that all steps are aligned to each other to form a complete net of protection, and more importantly, that the allowed top speed is not higher than the capacity of the chain to protect completely from death and serious injury. For example, if roads are not divided, or have intersections that allow oblique crashes, the speed must be kept below levels that will cause serious harm. In built-up areas, mixing vehicles and pedestrians and cyclists means that the maximum speed should be 30 km/h to protect vulnerable users.[1]

Finally, when a serious crash occurs, post-crash responses and appropriate emergency medical care are vital to ensure that injuries do not become more serious or life-threatening, and to aid in recovery from crash trauma.

Figure 2.2. **The combined effect of speed reduction, vehicle frontal design, autonomous emergency breaking and helmet use in reducing bicycle injuries**



Source: Adapted from Ohlin M, Strandroth J and Tingvall C. ICSC Gothenburg (2014).

Description of a Safe System

The term Safe System refers to:

- the vision or aspiration that zero fatalities and serious injuries from road crashes are ultimately possible;
- four principles to guide the design, operation and use of a road system with a view to reducing fatalities and serious injuries to zero;
- the implementation of practices, tools and their interactions that will deliver on the principles.

A Safe System moves beyond reactive, crash history based approaches to a proactive approach. A proactive approach includes designers understanding human behaviour to know when we can "rely" on people acting safely but also when they cannot act safely and take measures in the infrastructure, in the vehicles and in the management of operating speeds to support the road user to act safely.

A proactive approach also entails understanding risk and where the risk inherent in a road network is assessed and priority interventions are identified. A proactive approach also involves assessing infrastructure and where it is not in accordance with Safe System design principles; there is a plan for treatment on a priority basis before crashes begin to occur. Safety is a pre-requisite for the effectiveness of the transport system. By increasing safety it is possible to get greater efficiency and higher output.

"Vision Zero", "Towards Zero", "Sustainable Safety" and "Safe System" are different names for similar policies that fundamentally do not accept death and serious injury as an acceptable product of mobility. A discussion on the differences can be found in Vaa (1999).

The Safe System approach posits that road trauma is a public health issue, and one of epidemic proportions. It takes as a starting point the moral and ethical imperative to alleviate human suffering, and is, at least in the first instance, less focused on the aspect of financial cost. It postulates that human beings participating in road traffic should be seen as citizens with a right to safe mobility, not merely as road users with associated obligations. This right to safe mobility is linked to the notion that the different providers within the road transport system are ultimately responsible for its safety, too. A Safe System focuses on preventing the most serious, life-changing harms and accepts a certain amount of minor injuries caused by the transport system which cannot be overcome without exceptional cost. The clarification of which serious injuries should be prevented in a Safe System is thus a central issue.

Box 2.1. **Case study: Introducing seatbelts and airbags**

The first seatbelts in cars appeared during the 1950s, but their use remained voluntary. For a long time, seatbelt systems were not optimally designed. Only the use of lap belts or lap belts with detachable shoulder straps (in the United States) was initially advocated. Although the technology for automatic seat belt systems was already available in the 1980s, they were opposed by most of the industry.

The airbag was invented in 1951. Airbags were installed in some vehicles in the US as early as 1973, but it took until the 1990s for them to become standard equipment on many vehicles. Similar opposition occurred more recently with the introduction of centrally high-mounted rear brake lights, which have proven beneficial in reducing rear-end collisions (Somers and Hansen, 1984).

With respect to safe vehicle design and legislation, it has become clear that improving safety cannot be left to vehicle manufacturers alone. Government intervention is needed and, indeed, widely occurs now in the United States, Europe, Japan and Australia. Along this path, road safety research has accompanied vehicle safety legislation and provided evidence to support enhanced standards.

In a Safe System there is a clear distinction between the responsibility of the system designer and that of the road user. Whilst in conventional road traffic legal frameworks, the driver is ultimately held responsible for crashes, in a Safe System, the road user is responsible for following the rules for the safe use of the system and for behaving appropriately. This is a major difference in that conventional policies go downstream towards the sharp end while Safe System goes upstream towards the blunt end.

In some countries pioneering the implementation of a Safe System, the shared responsibility falls to the system designer. That is, if the road user does not follow the rules, the responsibility ultimately falls back to the system designer, and this is achieved through policy or practice. Policy states that the system designer is ultimately responsible and must take additional measures to account for when humans will make predictable errors so that crashes do not result in serious outcomes. A Safe System policy framework can be a common catalyst for system designers to influence the design and use of the road transport system. The user responsibility is often formulated in laws and regulations but the “system designer’s” responsibility is more of an ethical statement but could, if necessary, be a matter of legislation.

Of course pioneering countries adopting a Safe System are still faced with the realities of considering network mobility and efficiency with safety. However by focussing clearly on working towards a Safe System ultimately, these countries are identifying new possibilities and solutions that can be practically implemented today, that may not have been considered or possible if the thinking at the outset had been to “balance” safety with other criteria.

The dynamic and complex interactions among the various layers, actors, activities and components of a Safe System are illustrated in Figure 2.3. This diagram shows how the four principles of a Safe System come together in the design and operation of the road transport system. As the illustration shows, a Safe System places humans at the centre of the road transport system. This is the case regardless of what type of transport they are using – be it walking, riding to driving or as a passenger. The young and the elderly have different capacities to use the system safely and have increased frailty and vulnerability. While people are generally educated and compliant, they do make mistakes when moving on the road network (as they do in life generally), and there will always be mistakes that result in crashes. This illustrates the first principle of a Safe System: people make mistakes that can lead to road crashes.

The second circle of the model captures the relationship between speed, roads and roadsides and vehicles in a) nudging users to behave safely in traffic, then b) acting to ensure that when a crash occurs it does not have serious injury consequences. These two outcomes are achieved through the interaction of physical design, the layout and operating conditions of the road and roadside environment, and vehicles to enable safe operating speeds, safe vehicle operation and safe outcomes. Vehicles in a Safe System use active technology (e.g. intelligent speed assistance or collision avoidance systems) to assist the driver to take action (or to intervene if he does not) as well as secondary crash protection for occupants and people outside the vehicle.

The third circle represents the second Safe System principle that the human body has a limited physical ability to tolerate crash forces (for example, serious injury will often result from a collision between a vehicle and pedestrian above 30 km/h). A Safe System seeks to mitigate the risk of serious harm by anticipating potential causes and managing the three components of the second circle and their interactions to avoid collisions where the impact forces exceed dangerous levels. While they offer the most protection in combination, each of the components of a Safe System is expected to provide protection from impact forces so that when one component part of the system fails, the other parts will provide sufficient protection.

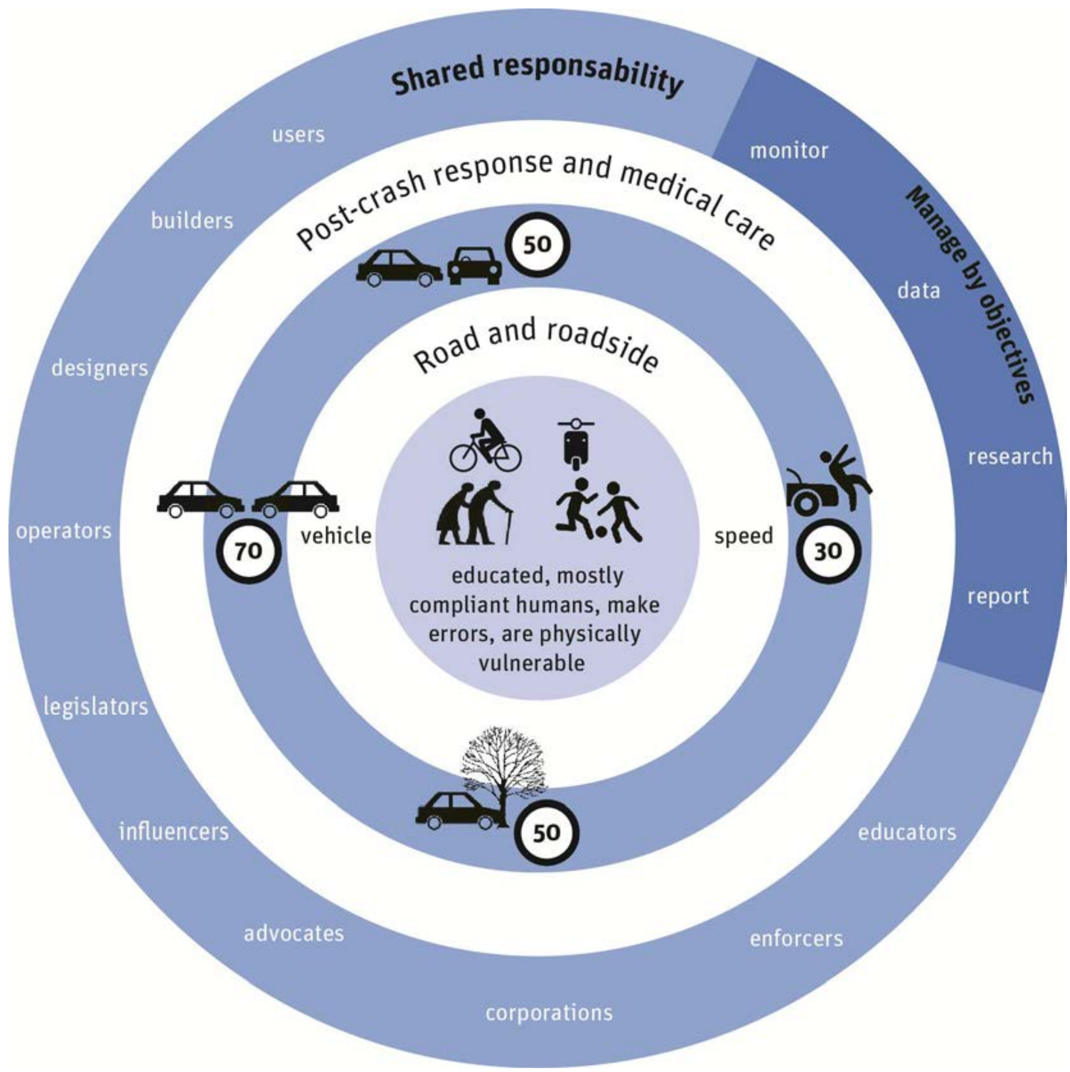
The fourth circle in the Safe System diagram covers post-crash medical care. This is a vital element where a system failure has permitted a crash with impact forces that have caused serious physical harm. In such cases, the health outcomes for crash victims depend on the ability of the emergency medical care system to quickly locate and provide emergency first responder medical care to stabilise the victim and then transport the person to appropriate emergency hospital treatment. Together, the second and fourth circles illustrate the third principle of a Safe System that all parts of the system must be strengthened to multiply their effects; and if one part fails, road users are still protected.

The fifth and outermost circle of the diagram illustrates the fourth principle of shared responsibility for a Safe System: 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. This is a responsibility of individuals as well as groups, and it comprises government as much as private-sector companies or civil society organisations. It pertains to educators who inform and motivate users to act safely; to legislators who design traffic and safety laws; to police and other government agencies who enforce them; to researchers, engineers, technicians, policy makers, advocates and opinion leaders. The use of data and evidence to inform practice and enable results-focused “Management by Objectives” is essential to underpin collaboration with shared responsibility.

Conclusion

A Safe System is a proactive, forward-looking approach to road safety that constitutes a departure from traditional ways of addressing safety on roads. A Safe System is based on four guiding principles that inform thinking and policy with a view to manage design and operation of the road network so that ultimately zero road deaths and serious traffic injuries will occur. Thus, unlike some approaches, a Safe System, in principle, does not accept a trade-off between road safety and other priorities, where traffic deaths and serious injuries are regarded as a price to be paid.

Figure 2.3. **Conceptualisation of the Safe System**



The Safe System principles acknowledge that people make mistakes in traffic and there are known limits to the capacity of the human body to absorb kinetic energy before harm occurs. A Safe System requires understanding and managing the complex and dynamic interaction between operating speeds, vehicles, road infrastructure and road user behaviour in a holistic way. The aim is that the sum of the individual parts of the system combine for a greater overall safety effect in which another part will prevent serious injuries even where one part fails.

In a Safe System, road users bear the responsibility to obey traffic rules and use roads with due care for safety. Those responsible for designing, building and operating the road system (the “system designers”) bear responsibility to ensure it encourages and supports safe use, addresses inherent safety risks, anticipates errors that users will make and ensure they do not result in serious harm. A safe and sustainable speed management and limit system that safely manages the interaction between vehicles, users and road infrastructure is a key feature of a Safe System. As crashes will still occur, optimal emergency response and post-crash medical care are part of a Safe System to prevent injuries from having serious health consequences and to ensure optimal recovery.

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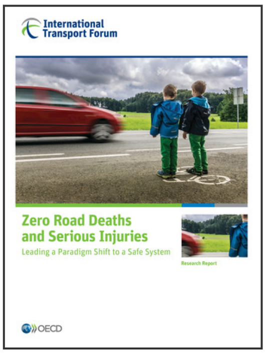
Note

1. Further examples of this concept and a more detailed discussion are included in a special edition of Safety Science (Wegman and Hagenzieker, 2010).



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