# Part III

# Management and Leadership for Vision Zero

# ISO 39001 Road Traffic Safety Management System, Performance Recording, and Reporting

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## Contents



**Abstract**

Traffic safety has shifted from being a solely individual issue to also include responsibilities from those organizations that influences the use and quality of the road transport system. This chapter explores the background of this and presents how ISO 39001 has been introduced as a tool to manage traffic safety in organisations. Further it is setting organizational road traffic safety into context of the 3rd Global Ministerial Conference on Road Safety, the Stockholm declaration and the decision of the United Nations general Assembly. The chapter also discusses how a value chain analysis can help organisations in understanding and tackling their road safety footprint and part of their sustainability reporting.

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**Keywords**

Vision Zero · Management systems · Traffic safety performance · Traffic safety footprint

## Background

The development of traffic safety has in recent decades gradually moved from an individual road user approach to a more systems and stakeholder perspective (WHO 2004). One of the major steps was the strategies and classifications developed by Haddon (1970; WHO 2004) pointing at a more widespread set of countermeasures, many times towards organizations, technologies, and management. With the introduction of Vision Zero (Tingvall and Lie 2017; Lindberg and Håkansson 2017) in the mid-1990s, this development became even more pronounced. The "system designers and providers" were given a key role to develop and take responsibility for the provision of safety for the citizens. The methods they are supposed to use must be evidence-based and without compromising safety in return for other benefits. This was and still is a different and radical policy in comparison with earlier policies (Hauer 2016; Swedish Transport Administration 2019).

The gradually more pronounced importance of how organizations improve the safety for citizens, employed, and customers is becoming more explicit with the introduction of 2030 Agenda (or the United Nations Strategic Development Goals). Traffic safety is a global goal since 2015, and in 2020 the United Nations General Assembly (United Nations 2020) expressed that organizations, both public and private, should improve safety by "applying safe system principles to their entire value chain." This is no doubt an expression emphasizing that organizations should apply a systematic approach to road traffic safety including employed, third parties, and customers in their attempt to eliminate road traffic deaths and serious injuries (in crashes). In doing so, the management standard ISO 39001 (ISO 2012) could be a valuable tool for the organization seeking to base its actions on sound principles and evidence-based solutions.

As part of the preparations for the 3rd Global Ministerial Conference on Road Safety, held in Stockholm in February 2020, the Academic Expert Group was formed by the Swedish Transport Administration. The "Academic Expert Group" recommendations (Swedish Transport Administration 2019) leading up to the Stockholm Declaration (2019) and the United Nations General Assembly Resolution (United Nations 2020) in 2020 stressed the importance of sustainability reporting for organizations that wish or must demonstrate progress regarding road traffic safety. Such sustainability reporting should preferably be based on known and standardized expressions of road safety goals, targets, performance, and results.

A key component in Vision Zero is the concept of shared responsibility. Every organization generating or having activities in the road transport system has an obligation to care for road traffic safety. As one cannot expect all of these organizations to have deep or even fundamental knowledge in the field of road traffic safety, support tools are essential. ISO 39001, “Road traffic safety (RTS) management systems,” is such a tool (ISO 2012).

The International Organization for Standardization (ISO) has extensive experience in developing international standards. In 2008, Sweden initiated the work to develop a management system standard for road safety, what came to be ISO 39001. The development work was coordinated by the Swedish Institute for Standards, and the Swedish Road Administration sponsored with a chairperson and extensive work. The first version of ISO 39001 was released in 2012.

At the time the ISO 9000 family for quality management standards and the ISO 14000 family for environmental management standards were widely used. The road traffic system standard for road safety was developed in the same structure as these at the time existing standards. The approach was strengthened as ISO during the process developed harmonized guidelines for all ISO management system standards. Today management standards from ISO have significant similarities making the use of more than one standard in any organization more straightforward.

Today in the year 2020 ISO 39001 is to some degree used even if it hasn’t been picked up to the same extent as the ISO management system standards for quality or environmental management.

Below some of the key components of ISO 39001 are described. They are chosen to have high relevance to Vision Zero. The complete standard can be acquired from ISO.

In the following we use organization to indicate any form of company, public or private, or any official body on national, regional, or local. ISO 39001 is usable for all of these.

ISO 39001 is a management system standard, the basis for the development of a management system. Like any management system standard, the aim of ISO 39001 is to set up a management system containing requirements that are documented and can be controlled. In a certification process, the organization should be able to confirm that it is living up to the demands in the standard and the management system they have developed. The certification can be done internally, or, in the most ambitious cases, the certification is performed by an accredited third party certification body.

The general structure follows the high-level structure of ISO management system standards starting with scope and terms/definitions. That is followed by sections on the context of the organization, leadership, planning, support, operations, performance evaluation, and finally continual improvements.

## Terms and Definitions

ISO 39001 uses some essential terms and definitions that emphasize the close links to Vision Zero. The most important definition aspect is how road traffic safety is defined.

In the management standard, road traffic safety is defined as "*conditions and factors related to road traffic crashes and other road traffic incidents that have an impact on, or have the potential to have an impact on death or serious injury of road users*."

Serious injury is defined as "i*njury with a long term health impact or non-minor harm caused to a person's body or its functions arising from a road traffic crash*."

These definitions point out a very clear direction in line with Vision Zero; it is the negative outcome in the shape of death or long-term health impact that road safety should focus on. Minor harm or harmless incidents have second priority.

It is also of importance that road users are defined as "*any person on the road*." Using this definition, organizations using ISO 39001 must take responsibility not only for their own staff and personnel but also for potential opponents in traffic that may be endangered by the operations of the organization. This responsibility includes the demand to follow up the effects on third party road users influenced by the operations of the organization.

## Context of the Organization

There are not many organizations or companies that completely lack interaction with the road transport system. On the contrary, most organizations have many interfaces to road traffic safety. The understanding of these interfaces and interactions is essential when focusing road safety-related actions. Few organizations have a good understanding of their influence on road traffic safety in their entire value chain. This is why ISO 39001 demands a mapping of activities and actions the organization have in relation to the road transport system. It is also demanding a mapping of needs and exceptions on the organization that other actors may have. This includes the legal and other requirements related to road traffic safety to which the organization subscribes.

The context of the organizations should form the basis for the ways to focus traffic safety actions and how to define and measure the most traffic safety relevant progresses.

For all organizations it is essential to map how road traffic safety interacts with their complete value chain. It isn't only about the organizations' own use of the transport system; it is also about incoming and outgoing transports of goods and potentially passengers. Furthermore the commuting of personnel is an important element.

Understanding the extent of interaction with the road transport system is essential for all organizations that want to improve their performance in the field of road safety.

## Leadership and Commitment

ISO 39001 is demanding a management system in which the top management (defined as: *person or group of people who directs and controls an organization at the highest level*) owns the highest responsibility. However, if the organization decides that the scope of the management system covers only a part of an organization, then the top management refers to those who direct and control that part of the organization.

There are high demands on the road traffic safety management system to be compatible with other strategies and actions in the organization. Further it should clearly state that elimination of death and serious injury in road traffic crashes is the long-term road traffic safety objective. Another fundamental basis is that the organization should develop strategic actions and select specific courses of action, building on the best available information.

It is the top management's responsibility that the road traffic safety actions have high priority and that these actions are result-oriented.

One important role of the top management is to develop and manage a road safety policy for the organization. The policy should be appropriate to the purpose of the organization, include a framework for setting road traffic safety objectives and targets, further include commitment to satisfy applicable road safety-related requirements, and finally include a commitment to continual improvement of the road traffic safety management system.

## Planning

ISO 39001, as most management system standards, are based on a plan-do-check-act procedure. The planning should be based on the understanding of the organization's role in the road transport system and in line with the policy decided by the top management.

The organization shall follow a process that reviews its current road traffic safety performance, determines the risks and opportunities, and selects performance factors.

The road traffic safety performance factors are essential to ISO 39001. The safety performance factors are a set of predefined areas that are relevant to most organizations. It is not an all-inclusive list, but the purpose is to guide organizations into the most important factors for road safety. On these factors targets should be based and performance measured.

There are three types of performance factors in ISO 39001. The first kind is related to the exposure of the organization to road safety-related risks. They can be related to exposure factors such as travelled distance and road traffic volume, including vehicle and road user type, whether influenced or not directly influenced by the organization.

The second type of performance factors is outcome-oriented. They are called final safety outcome factors and relate to real outcome such as the number of deaths and serious injuries occurring in the complete sphere of influence of the organization.

As most organizations will have no or very few actual fatalities or even serious injuries, there are challenges in working only directly towards these final outcomes. ISO 39001 is therefore also containing "intermediate safety performance factors." They are based on well-known and commonly used factors related to road traffic safety (Gitelman et al. 2014).

The concept behind the safety performance factors is that they should contain a known link between the factor and safety performance. By working towards improvements in the performance in the areas of the factors, real performance benefits will be generated. As the safety performance indicators are closer to operations than the final outcome, action can be better focused and followed.

ISO 39001 is presenting a set of predefined safety performance factors that organizations should choose from when developing their safety management system. Not all are relevant for all organizations, and there are organizations that potentially have a need to develop other safety performance factors, guided to their specific needs. The management system standard contains this possibility; however, the potential additional safety performance factors must be based on "best available informations" that is proven to be efficient in achieving the final outcome goals (fatalities and serious injuries).

The road safety management system standard ISO 39001 is using this wording to describe the intermediate safety outcome factors: "*these safety outcome factors are related to the safe planning, design and use of the road network and of the products and services within it, the conditions for entry and exit of those products, services and users, as well as the recovery and rehabilitation of road traffic crash victims*."

The following factors are presented:

- Road design and safe speed
- Use of appropriate roads
- Use of personal safety equipment (i.e., seatbelts, child restraints, bicycle helmets, and motorcycle helmets)
- Safe driving speed
- Fitness of drivers (fatigue, distraction, alcohol, and drugs)
- Safe journey planning
- Safe vehicles (occupant protection, protection of other road users, road traffic crash avoidance and mitigation, roadworthiness, vehicle load capacity, and securing of loads)
- Appropriate authorization to drive/ride the vehicle
- Removal of unfit vehicles and drivers/riders from the road network
- Post-crash response and first aid, emergency preparedness, and post-crash recovery and rehabilitation

In the management system standard, the intermediate safety performance factors are described at a relatively high level of abstraction. Some of them have to be further developed by the organization using the standard. One typical example is vehicle safety. In Europe the most relevant way to measure that is by using Euro NCAP stars or points. However, that Europe-centered specific rating system has low or no coverage or validity in other parts of the world.

For any organization the selection of safety performance factors, and the specific definition used and the way to measure status and progress, is very important and should be explained in the management system.

There are substantial differences in how different safety performance factors can be influenced, measured, monitored, and reported. Using seatbelt use as an example, activities can range from policy decisions, via surveillance/measurements, to the application of seatbelt reminders or even ignition interlocks. Today's technologies can be extremely helpful in both monitoring and supporting proper behavior.

The safety performance factors, exposure-oriented, outcome-oriented, or indicative, are used to determine, monitor, and measure road traffic safety objectives and targets. There should be clarity in what should be done, what resources would be required, who in the organization holds responsibility, when will results be available, and how the results are to be evaluated.

Achieving results demands not only focus but also resources, competence, awareness in the full organization, and its value chain and communication, internally and externally.

ISO 39001 is demanding relevant documentation of the traffic safety management system being developed and used. However, the documentation demands should reflect the size of the organization and its type of activities, processes, products and services, the complexity of processes and their interactions, and the competence of persons in the organization.

## Operations

The organization is expected to deliver towards the goals set up in the planning process – all in line with management system standards. However, ISO 39001 includes a demand concerning emergency preparedness and response when fatalities or serious injury happens.

## Evaluating Performance

A key component in any management system is to evaluate performance in relation to the specified goals. In ISO 39001 the demand is worded as: "*The organization shall establish, implement and maintain a process to periodically evaluate compliance with applicable legal road traffic safety requirements and other road traffic safety requirements to which the organization subscribes*." It is essential to note the importance of legal requirements.

One additional way to evaluate performance and initiate further development of the management system is to investigate and understand relevant crashes and road traffic incidents. As this could be very effort-consuming, ISO 39001 is only demanding such investigation of "*road traffic crashes and other incidents in which it is involved that lead, or have the potential to lead, to death and serious injuries of road users*."

The organization should make audits to verify that it is conforming its own requirements and demands with ISO 39001. The audit can be internal or external. The results should be reported to relevant management levels.

## Management Review

It is the top management that in the end holds responsibility for the delivery of improved road traffic safety. In the last phase of the plan-do-check-act cycle, they should consider if the traffic safety performance is in line with the plans and if needed take corrective action. This is done in the management review of management standards. The review should according to ISO 39001 contain:

- The status of actions from previous management reviews
- Changes in external and internal issues that are relevant to the road traffic safety management system
- Information on the road traffic safety performance, including trends in nonconformities and corrective actions; monitoring; measurement analysis and evaluation of results, including the extent to which RTS objectives and road traffic safety targets have been met; and audit results and evaluations of compliance with legal and other requirements to which the organization subscribes
- Opportunities for continual improvement, including consideration of new technologies
- Relevant communication(s) from interested parties, including complaints
- Road traffic crash and other road traffic incident investigation

The management review should be the basis for improvements, understanding of nonconformities, and corrective action. It is also the basis for continual improvements.

## Conclusion

ISO 39001 is available and has been tested and used on the market around the world. It is structured in a way that makes parallel use with ISO 9000 and ISO 14000 straightforward. There are accredited certification bodies that can certify traffic safety management systems to ISO 39001. In short, the system is available and used in organizations with traffic safety ambitions.

One potentially significant limitation of ISO 39001 is that the ambition level is defined by the organization itself. It is fully possible to work in a systematic way but with low ambition. The actual ambition level is not checked in a certification process. An organization can be certified but still have poor performance. This is important to bear in mind when/if ISO 39001 would be used on the market to further focus road traffic safety.

## Discussion

The need for a systematic approach to road safety within organizations is growing, and in particular large corporations are expected to improve and report on their ambitions, performance, and results of their efforts. This concerns the entire value chains from sourcing for raw materials to the end user experience. The need for standardized universal road traffic safety management systems is therefore growing.

The United Nations General Assembly Resolution 74/86 from 2020 express that: "*Calls upon* businesses and industries of all sizes and sectors to contribute to the attainment of the road safety-related Sustainable Development Goals, including by applying safe system principles to their entire value chain. . .." To apply "safe system principles" is simply setting a zero death and serious injury target for the organization and its value chain.

Using ISO 39001 to get to grips with the road traffic safety impact and progress of an organization can lead to a systematic approach to the problem not only for the persons directly employed by the organization but also for those contracted and otherwise dependent to the organization's processes and products. This is a radical step in the history of traffic safety and a strong complement to the traditional line of responsibility from the state/regulator to the individual driver of a vehicle.

The approach to traffic safety as defined by ISO 39001 is that the top management of the organization is responsible for road traffic safety performance and the way transports are conducted by the organization within their value chain. While the expression "value chain" is not used in ISO 39001, it is a relevant way to encapsulate what is the purpose of the wording in ISO 39001 like "context of the organisation." A basic ISO 39001 requirement is that road rules are not violated. Such an expansion of the influence of an organization goes far beyond how road rules are normally defined and enforced. In general, they are directed towards the individual road user, even if the road user is an employed driver driving for duty at the time for a legal offense.

Road traffic safety is only to a limited degree considered by occupational health and safety regulation. If a crash with personal injuries to a professional driver normally would be seen as a matter for the occupational and health legislation, an injury to a third party would not. And an equivalent event for a contracted organization would be even less relevant in this respect. ISO 39001 as well as the way "value chains" are defined would on the other hand include all such events as relevant for the organization wishing to adopt the principles of ISO 39001. Furthermore, it is even a requirement for the organization to monitor and correct non-compliance of road rules occurring within the value chain for the organization. This is a true and radical difference to the society's view of legal traffic-related offenses and who should be fined or otherwise subject to a legal or administrative intervention.

It is also a requirement within ISO 39001 to include and consider the traffic safety effects related to the customers of the organization, if relevant. Vehicle production and transports of goods and passengers and other products are subject to the responsibility of an organization. The definition of a value chain has the same basic inclusion criterion. This is a real challenge for a vehicle manufacturer that would have to keep track of the "safety footprint" of their vehicle production in terms of fatalities and serious injuries to their customers and third parties (Rizzi et al. 2019). The same would apply to all kinds of vehicle production like cars, trucks, buses, motorcycles, and bicycles. Statistical information based on police reports or hospital records would be complicated to use for collecting information classified by value chain. In most cases where someone has been killed or seriously injured, the value chain classification would fall into several value chains. This is an area where much efforts should be spent in order to support the introduction of ISO 39001 and other road traffic safety management systems.

One of the most striking characteristics of modern quality management is that the delivering of products and services also includes control of defects and non-compliance (and nonconformity). Sustainability reporting also includes reporting of unwanted events and negative impacts on the society, environment, etc. and also includes how such impacts will be managed and eliminated in the future. This is no doubt very different from most legal frameworks within the road transport systems where a fault, offense, or non-compliance are subject to the society's ability to show that the offense has occurred and that someone can be judged guilty in relation to regulation. A traffic safety-related offense seen through ISO 39001 is a matter for the top management and must be handled as a non-compliance, and the organization must act to eliminate further such offenses.

The high demands and complexity of ISO 39001 might detract large organizations to comply and certify the entire organization and its value chain to ISO 39001. The step for many organizations to move from the current viewpoint that the safety of transports for an organization is mainly an issue for the individual driver to that it is the organization's duty to secure that all transports are safe is too big. And the availability of data will be quite problematic for a large organization to gather in a short timeframe.

Taking the approach of ISO 39001 in steps might therefore be a successful way forward. The FIA (Federation Internationale de l'Automobile) has presented a "Road Safety Index" (FIA 2020) aimed at valuing and rating an organization's value chain in relation to traffic safety. In this valuation, ISO 39001 is the main building block together with the definitions of workforce, etc., from the GRI (Global Reporting Initiative). The valuation divides the performance of an organization into "commitment, footprint, plans, monitoring, and safety culture." The headings represent different parts of ISO 39001, and each part builds on the former part, so that the last step, safety culture, in reality means that the organization operates under the entire requirements of ISO 39001. In short, the FIA Road Safety Index is a stepwise ISO 39001, not only encapsulating the data-driven parts of the management standard but also valuing the overarching safety culture of an organization. This is an important characteristic for any safety management approach.

The main purpose of the FIA Road Safety Index is to standardize road safety sustainability reporting for large organizations in relation to the financial market. By introducing a standardized benchmark and ranking system, large corporations can strive for progress to show both the financial market and the wider society. This is a double function of the FIA Road Safety Index. Building on the definitions, content, and requirements of ISO 39001 is an important characteristic and helps organizations to apply a systematic approach to traffic safety, well in line with other management systems and principles. The most complex issue seems for both value chain safety footprint and the application of ISO 39001 to an organization to define the precise range of a value chain. How many layers of suppliers and contracted parties that should be included in the value chain and "interested parties" would be a matter for the organization to define. No doubt those that are directly influenced through contracts with the organization are relevant, even if their main service or product delivered to the organization is not a mobility service, logistic task, or a vehicle. It could, as an example, be the transport of a component or the travel of a maintenance staff to a facility controlled by the organization. How many tiers this should cover to be a relevant inclusion in a value chain and seen as an interested party might be a matter of common practice rather than defined in a systematic way. In any case, there needs to be a clarification.

The possibilities to use technology for monitoring and quality assurance of vehicles, drivers, and driving were limited at the time of the development of ISO 39001. This has rapidly changed, and to have vehicles connected in real time is almost unlimited today, across the globe. It is also possible to control vehicles, for example, their speed, geographically and also depending on time, etc. This kind of geofencing is a step forward in quality assurance and would from a management system perspective mean that a certain aspect of performance is guaranteed. For an organization, this would be quite attractive as less resources can be spent on monitoring and detection of non-compliance and nonconformity as well as corrective actions. Speed, fitness to drive, non-aggressive driving styles, etc. could all be controlled and seen to be quality assured.

Vehicle technology is also developed rapidly, at least for passenger cars. As there does not seem to be a matter of high costs for mass produced cars to have advanced driving assistance systems (ADAS), there is no obvious reasons not to have the highest standards prescribed within an organization, not even for low- and middle-income countries. What seems to be problematic is that car manufacturers sometimes do not offer vehicles they produce with the highest standard to all parts of the world. Furthermore, trucks and in particular buses do not have the latest standard of safety equipment available. This is something that could be stimulated by more organizations using ISO 39001. In any case, there are no legitimate expressions that accept a lower safety standard of vehicles and associated products or services in different parts of the world.

A systematic approach to road safety for organizations would also be relevant for procurement, in particular public procurement. While there does not seem to be a widespread use of safety requirements for public procurement, it is one of the nine recommendations of the Expert Group for the 3rd Global Ministerial Conference on Road Safety to do so. It is estimated that 10–20% of the global GDP is related to public procurement, and this could form a massive economic incentive for improving road safety. The principles of ISO 39001 would fit well with the general concept that it is the provider of a product or service that control the quality and that the transport of the product and service is included in this quality requirement. This would mean that in public procurement, it is an obligation to comply with road rules without any specific clause or contract specifying what road rules that must be followed.

In general terms, the gains in applying a systematic approach to road safety, with evidence-based solutions and treatments to a fixed set of factors, are large and sustainable. The safety factors in ISO 39001 are shown to have a major impact on traffic safety (Krafft et al. 2007; Gitelman et al. 2014). With traffic safety policies more related to organizations, it is natural to seek for management systems and standards that are widely accepted. And with the 2020 United Nations General Assembly Resolution explicitly pointing towards the role and expectations on businesses and industries and their entire value chains, the need for standardized practices and reporting will grow. It seems also natural that when organizations through the financial sector will be asked to publish their safety footprint, there will be an increased demand for action.

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# What the Car Industry Can Do: Volvo Cars 23

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## Contents



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**Abstract**

Motor vehicle manufacturers have a central and a very important role in reaching the target of zero fatalities and serious injuries in road traffic. Although the continuous development of safer products has made a significant contribution in reducing the number of casualties, the responsibility still remains profoundly with motor vehicle manufacturers in continuing the process of protecting car occupants and not harming other road users. However, the possible contributions do not end here. Sharing research data based on real-life traffic crashes and incident experiences, cooperating with other traffic safety stakeholders, and sharing real-time data on traffic information with authorities and other road users also have a role to play in reducing the number of road casualties. In addition to this, motor vehicle manufacturers will be able to contribute by assuming the corporate social responsibility in using safe transportation linked to producing vehicles, parts, and services and sharing the latest level of technology advancement with customers in countries without government mandates on safety.

It is important to stress that all these efforts need to have a global perspective. For the vehicle manufacturers, this implies that all the technical developments in motor vehicle safety, collaborating with governments and sharing knowledge on safety, must be performed and available also in parts of the world with a vehicle fleet of traditionally lower advancement levels.

In line with the efforts of reaching zero fatalities, Volvo Cars has defined its own Safety Vision. This states that no one is to be seriously injured or killed in a new Volvo vehicle.

The aim here is to share the view of Volvo Cars on the possible contributions and actions of motor vehicle manufacturers in the collaborative efforts of reaching towards zero fatalities and serious injuries within the road transportation sector.

**Keywords**

Overall safety strategy · Vision zero · New safety technologies · Future mobility · Autonomous vehicles

## Introduction and Background

Traditionally, cars have, ever since the launch of the first volume selling motor vehicles in the 1920s, been designed, built, and used to fit a generic traffic situation using an infrastructure that has gradually been developed with the mind and purpose to fit and encompass all road users and only slowly adapted to manage an increased, denser, and more intense traffic situation. This infrastructure did not, however, develop in a way needed in order to keep up with all the challenges of modern traffic in terms of pace, density, and traffic mix which has resulted in a continuous increase in the number of traffic casualties.

In addition to this, car manufacturers have viewed themselves as providers of consumer products that primarily needed to meet the customers' expectations with respect to comfort, speed, styling, and economy. Besides meeting the government standards, safety was not a prioritized area of development and not considered to be a unique selling point in customers' buying decisions.

However, this has radically changed during the last 20–30 years. Car manufacturers have realized that they are part of a bigger picture and being part of a transportation and societal structure that is more than just putting cars on the road. This was, however, not only forced upon them but was also a realization that their products not only did a very important task of transporting people and goods for the benefit of the society and supporting the civilization that modern people have gotten to know and become adjusted to but also created major challenges when it comes to increasing traffic casualties, major health problems due to air pollutions and stress, congestions, and unhealthy and unpleasant local environments. This also became very obvious in the early 1970s when traffic casualties escalated up to a level that was totally unacceptable both from the perspective of the society and its citizens. At the same time, the first government safety standards were issued, both in the USA and in Europe. Well-known obvious failures of car designs with resulting catastrophic consequences and major headlines gave rise to the creation of consumer groups pushing for safety and major safety recalls for repairing the unsafe products. Gradually this created a new way of looking at road traffic safety in that it needs a holistic perspective and more involvement of all stakeholders, including governments, vehicle manufacturers, consumer groups, insurance companies, road authorities, and academia. At the same time, more focus on safety evolved from customers supported by comprehensive and objective consumer information. The information was provided by a number of actors such as governments, insurance institutes, academia, motorist organizations, and consumer organizations. This type of consumer ratings gradually grew in importance and is now extensively used in the advertising for sales of new motor vehicles and has proven to be a useful tool for customers in their car-buying decision-making.

The development of safer motor vehicles has made a steady progress during the last 30 years and has today reached an impressive level of performance of protecting occupants. However, although the vehicles offer an elevated level of safety, parts of this performance do depend on the proper usage and behavior with respect to proper positioning and seating positions, usage of restraints, loading, number of occupants, vehicle modifications, and avoiding violations such as driving while under influence, speeding, and other traffic misbehaviors.

The modern motor vehicles do act in many ways in making road traffic safe and protecting occupants and other road users. New technologies in the form of systems helping and supporting the driver's handling of the vehicles, navigation and information systems aiding drivers to navigate and stay comfortable and with less pressure, stability systems assisting drivers in handling conflict situations, lateral and longitudinal support of the driving, automatically acting systems that autonomously brake or keep a safe distance to other vehicles, drowsiness and distraction alert systems, and drunk-driving interlock systems have been developed.

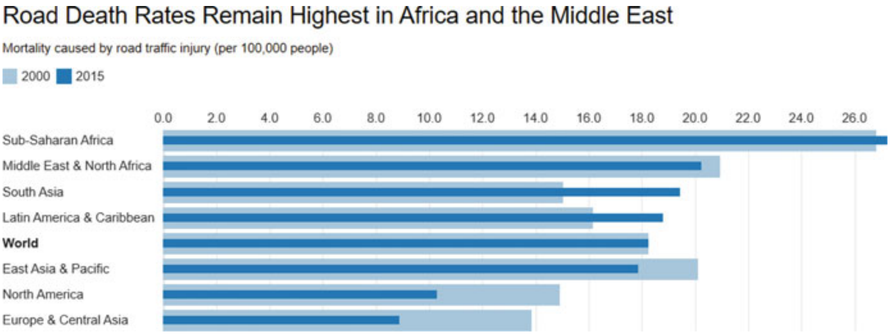


**Fig. 1** Road deaths per 100,000 in 2000 and 2015 (World Bank 2015)

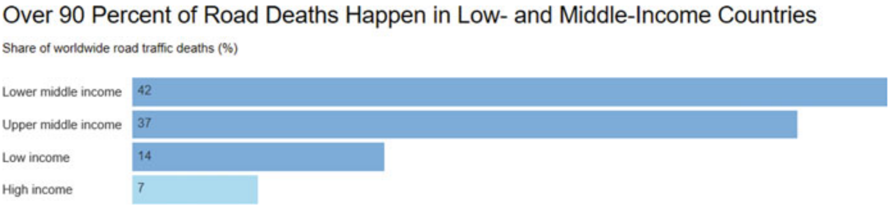


**Fig. 2** Share of worldwide road traffic deaths (%) (World Bank 2015)

In parallel to the increased activity of manufacturers to improve motor vehicle safety there have been extensive activities and efforts by governments and policymakers to reduce the number of road casualties globally. The estimated present level of fatalities in the world today (2019) is around 1.3 million people. A large proportion of this occurs in the low- and middle-income countries, and a large number of these are unprotected road users. It is estimated that 90% of the fatalities occur in the middle- or low-income countries globally (World Bank 2015).

Among the governments or policymakers run efforts is the Swedish Vision Zero policy which has been the role model for many other government initiatives ever since it was adopted in 1997.

In parallel to the government run safety initiatives, there are a number of anticipated major shifts in the different ways of being mobile, e.g., mobility as a service and ride-sharing. These will use different variations of more professional drivers, and ultimately there will be self-driven vehicles having an elevated level of safe driving incorporated into the core of the vehicles and are expected almost to eliminate the human error factor in the cause of traffic incidents and accidents.

In conclusion, many initiatives, both by governments and policymakers, are on-going or planned, the motor vehicle manufacturers are making impressive progress with improving the safety performance of their products, and significant progress has been made with reshaping the infrastructure in many parts of the world. The potential for this to be distributed globally and having an outcome closer to the Vision Zero goal is significant and encouraging.

## Traffic Safety Improvements: Past and Present

For the first decades after the beginning of the era of producing vehicles for mass consumption, no significant progress was made towards improving motor vehicle safety. During this era, traffic casualties were considered to be part of the picture of road transportation and something that had to be accepted.

In the 1950s and 1960s, the car industry focused mainly on impressive car designs, engine sizes, and speed. The American style of extravagant fins and lots of chrome peaked late in the shift between the 1950s and 1960s, but still, the focus was on other things than road safety. However, the most significant safety innovation of all times, the three-point safety belt, was engineered during this era. It was first introduced in series production by Volvo in 1959. Volvo also waived its patent on this restraint, opening up for a mass introduction in passenger vehicles which was to enable a significant reduction in traffic casualties. Alas, both the customer acceptance and the penetration of this important innovation were amazingly slow. Also, governments were slow in mandating both to equip the vehicles with the restraint and to introduce occupant belt usage requirements. In some countries, mandating belt use in the front seats did not occur until the mid- to late 1980s, and mandating rear seat belt usage on a broader scale did not occur until a decade later. Mandating the equipment of three-point seat belts for all occupant positions is still not the case for all markets.

Early in the 1970s, with the traffic casualties reaching staggering numbers, governments, car manufacturers, and the general public started to realize that this was not a sustainable development. With increasing numbers and increasing speed performance of the vehicles, if drastic measures were not taken, the projections of casualties for the next decades were abominable and simply unacceptable.

As stated earlier, governments started both to establish agencies dedicated to traffic safety and to create the first set of safety standards in the late 1960s and early 1970s. The US federal safety agency National Highway Traffic Safety Administration (NHTSA) was established in 1970 and its first set of Federal Motor Vehicle Safety Standards (FMVSS) the same year. In 1966, before the creation of NHTSA, another federal agency National Traffic Safety Agency, under the leadership of its first administrator Dr. William Haddon Jr., pushed for a more scientifically driven approach for reducing traffic casualties. Dr. Haddon created the concept of the Haddon Matrix which is looking at all factors – human, vehicle, and environmental factors – and pre-crash, crash, and post-crash interventions as a systematic strategy for cutting the number of injuries and fatalities in traffic.

Realizing the potential in exploring the possibilities of new safety innovations, NHTSA initiated the first global biannual safety conference named ESV (Experimental Safety Vehicles) in 1971. (In 1994 the name was changed to Enhanced Safety of Vehicles.) The focus here was to display vehicle safety concepts aimed for a later implementation in series production of vehicles.

As described in previous chapters, by the first years in the new millennium, the number of traffic casualties in the high-income countries in the world had been drastically reduced. The concept of reaching for zero casualties in the transportation

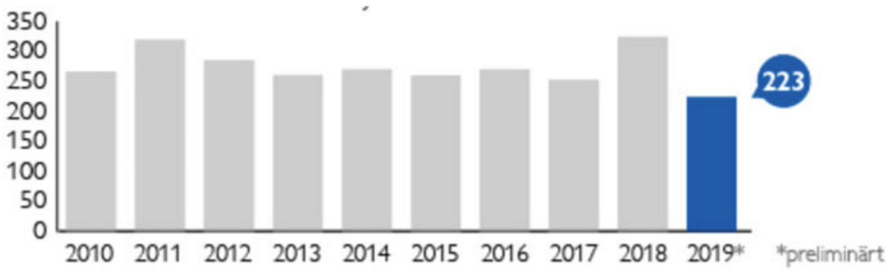


**Fig. 3** Road fatalities in Sweden, 2010–2019 (National Swedish Road statistics, Transportstyrelsen (2020))

sector was first introduced in Sweden in the mid-1990s. In 1997, the Swedish Parliament adopted the Vision Zero strategic principles as the aim and target for the efforts for the further efforts on improving traffic safety in Sweden. The Vision Zero plan, adopted by the Parliament, stated targets of reduced traffic casualties that have gradually been updated with time, but the plan with its principles has been successful in drastically reducing the number of fatalities and serious injuries in Swedish traffic and has become a model for many other government initiatives ever since it was adopted.

When introduced, the Swedish Vision Zero strategy was considered as a paradigm shift in that it transferred the focus from reducing the number of accidents to reducing the number traffic casualties and that traffic efficiency should not be in the way of reducing traffic casualties.

The number of traffic deaths in Sweden peaked during the period 1965–1970 with approximately 1300 fatalities, which means around 16 fatalities per 100,000 inhabitants. In the 1970s and 1980s, significant efforts were made, both by the authorities, manufacturers, infrastructure owners, and other stakeholders, to reduce the number of fatalities by initiating more cooperation, collecting and sharing data, and applying more of a holistic approach. By mid-1990s, the annual fatalities had been lowered to around 500. At the same time, the number of vehicles and the number of vehicle kilometers travelled had increased significantly.

These results were, however, still neither acceptable nor satisfactory. In 1996, the Swedish Road Administration (Trafikverket) presented its proposal for a Vision Zero, i.e., a vision that is stating that nothing else than zero fatalities should be the long-term target. In 1997, the Swedish Parliament adopted the plan for Vision Zero, and in 1998, it adopted a target of half the maximum number of fatalities by 2007 as compared to 1997. This would result in a maximum number of fatalities of 270 per year. Although this number was not met for the first decade, a new target of 220 fatalities by 2020 was adopted by the Swedish Parliament in 2008. In 2019, the number of fatalities was 223, i.e., close to the target set in 2008 and a significant reduction. The next step would be another halving of the number which would mean around 110 fatalities per year by the year 2030.

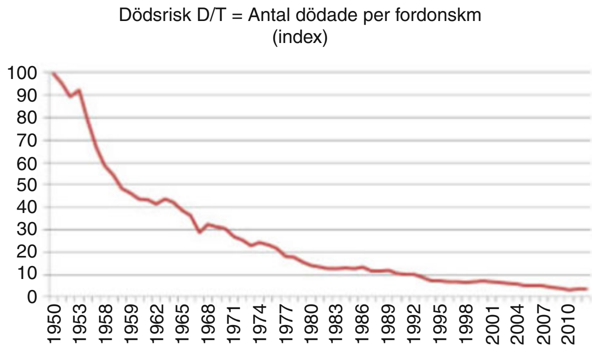


**Fig. 4** Ratio of number of fatalities to vehicle km travelled in Sweden (Brude 2012)

The achievement of getting close to the target of halving the road deaths is remarkable considering that the economy is booming again, and the effects of the level of economy can clearly be seen when looking at the fatality numbers.

The numbers of fatalities dropped dramatically for the years 2009–2010 which coincided with the global economic problems.

When analyzing the ratio of fatalities to the vehicle kilometers travelled, the result shows a reduction of around 5% fatalities per year which is indeed significant and must, in many ways, be considered to be an undisputable advancement of traffic safety in Sweden.

The figure below shows the relationship between the road fatalities and the number of driven vehicle kilometers. Although the available statistics does not cover the last decade, the results clearly show the value of having strong visions for the strategic work on traffic safety.

The ratio between the number of fatalities and 100,000 inhabitants is around 2.6 which is one of the lowest worldwide.

Much of this effort was linked to infrastructure improvements. By shifting the focus from avoiding crashes to reducing personal injuries, infrastructure measures such as replacing crossings by roundabouts and installing median fences on highways and creating so-called 2 + 1 roads, i.e., roads where there is an interchange between having two or one lanes in each direction, have proven to be highly effective in reducing personal injuries.

In parallel to the infrastructure improvements, the performance of the vehicles' occupant safety was considerably improved. In Sweden, a vehicle fleet with a high level of occupant protection has had a significant impact on lowering the reducing the number of fatalities and serious injuries.

What is still causing a concern is that some types of fatal crashes, such as bicycle and motorcycle crashes, do not show the same trend of dropping in numbers.

In addition to the Swedish Vision Zero, there are a number of initiatives to reduce the number of fatalities globally. Among those is the UN Decade of Action for Road Safety 2011–2020 which is adopting a global perspective and inviting all stakeholders into these efforts. Although the number of fatalities continue to rise globally, it can be assumed that the effects of these initiatives will make a clear footprint in the years to come.

After the peak of the number of traffic casualties in the high-income countries worldwide in the 1970s and 1980s, this has considerably and steadily declined, due to various measures, during the last decades. However, the global number of traffic fatalities and the number of injuries have steadily risen and are by 2019 estimated to be around 1.3 million fatalities and 50 million serious injuries.

So, in spite of the considerable efforts made by governments, policymakers, and vehicle manufacturers, the staggering levels of traffic casualties globally are continuing to rise. There are also other factors preventing a more successful reduction of casualties. One important factor is the status of the global economy which influences the travel distances (vehicle km or vehicle miles travelled, vkmt or vmt) which clearly influence the number of road casualties.

Obviously, ***all this is unacceptable***.

## Swedish Vision Zero from an Industry Perspective

Volvo Cars believes that the Swedish Vision Zero is one of the most profound groundbreaking principles for adopting a human approach to a sector where earlier intolerable levels of casualties and human suffering were accepted more or less as a fact and almost as the cost we had to accept to keep up the levels of transportation for a modern society.

By basing the Vision on the criteria based on human tolerances, i.e., that small mistakes should not lead to serious consequences and that all stakeholders must be involved in the process of creating a safe road environment, this creates an earlier unforeseen possibility to come to terms with the unacceptable levels of human suffering.

The approach of the Swedish Vision Zero has been one of the guiding principles for the company when setting the goals for the Volvo Cars Safety Strategy.

Already when the company was founded in 1927, it was stated that, since cars are driven by people, the focus therefore must be safety. Setting the targets according to the human tolerances was therefore to be the guiding principle. This is also adopted in the Swedish Vision Zero strategy.

With establishment of the Swedish Vision Zero, this gave the company more support for its endeavors for pushing the limits of motor vehicle safety. It also gave more support within the company that the adopted long-term strategy was the correct one. Another outcome was that it also opened up for a more strategic cooperation with the Swedish government on the basis that by sharing a vision for zero fatalities and serious injuries, a foundation was established for joining forces towards reaching this goal. More about this cooperation will follow in a later chapter.

Using the Swedish Vision Zero as a role model, a number of countries have established their own Vision Zero targets. This includes many of the European countries, the European Commission, many of the states in the USA, and many other countries globally. This in turn gives the industry clearer guidance on the way forward and the principles for the role of the industry in their efforts for improving road safety.

Volvo Cars believes that the Swedish Vision Zero has established both a mind-set and the tools for enabling reaching the goal of zero deaths and serious injuries. This has proven to be invaluable and will be the best support for the future in removing the unacceptable consequences of an unsafely designed road system.

## The Roles and Responsibilities of Car Manufacturers for Improving Traffic Safety

As discussed in the previous chapter, the major and primary responsibility of a motor vehicle manufacturer is to produce safe products, products that will protect occupants and vulnerable road users to a high level and to what is technically and economically feasible. The focus must always be to work towards real-life safety for occupants regardless of size, age, and gender. For in-vehicle occupants, the primary focus must be to optimize safety for those who are using the vehicle's restraints and are not violating any traffic rules and regulations, e.g., not speeding and not driving while under the influence and that are belted. However, to the extent possible, protection should be offered for all occupants if this does not impede the protection of other occupants. Strong encouragements and efforts should also be given to having occupants act in the proper manner. Seat belt reminders, alcohol detection and interlocks, and speed limiters are effective measures available that need to be offered to the car-buying customers.

However, the responsibilities of the manufacturers do not end with producing safe cars. Car manufacturers have an important role to play also when it comes to assuming their social responsibility for making sure that all the activities related to manufacturing, transportation of goods, service purchasing, and employee road travels on official business are made with a level of safety that is in line with the targets of eliminating road casualties. In practice this means that manufacturers have an opportunity to influence and set requirements on such activities as safety requirements on the vehicles for goods transports to factory facilities and supplier practices for safe transportations. The safety requirements on the goods vehicles could be, e.g., requiring measures for the protection of vulnerable road users, requiring speed limiters on delivery vehicles and trucks, belt reminders, and drunk-driving prevention measures in all vehicles.

In preparing for the 2020 UN Third Ministerial Conference on Road Safety: Saving Lives beyond 2020, The Next Steps, that is to be held in Stockholm in February 2020, a report of the Academic Expert Group has listed a number of recommendations for Stockholm Declaration that is to be the legacy of this conference. Recommendation number one discusses "Sustainable practices and reporting" and what policies and practices manufacturers, businesses, and enterprises should include both in their internal activities and also applied in the processes and policies of the full range of suppliers, distributors, and partners throughout their value chain or production and distribution system.

In the continuous process of designing and producing new car models and constantly improving safety, manufacturers are recording and gathering data from crashes and incidents that are in turn used to improve the next development of car design. Some manufacturers also go beyond this and carry out their own crash investigations and do detailed analysis including time histories and follow-up medical records of the involved persons in the accident. This means that extensive knowledge is available that may be used as a base for the good of the motor vehicle safety community.

Manufacturers have an obligation to share knowledge on how their products affect the well-being of any one exposed to the risks linked to transportation. A lot of data may be shared without violating antitrust laws or exposing company intellectual properties or infringing on the privacy of the individuals involved.

Manufacturers are encouraged to work with governments, authorities, academia, and other organizations in establishing research platforms for moving safety forward. These platforms or cooperations will offer the opportunity to create a more holistic view on how to move traffic safety forward. Many of those cooperations and research platforms exist already today but could and should be expanded. In Sweden there are both a national cooperation and a research platform as well as cooperations with individual manufacturers. In 2008, Volvo Cars and the Swedish Traffic Administration signed an agreement of cooperation. The aim was to get an overall view on the relationship between motor vehicles and the infrastructure and how this relationship could be improved and augmented. More information on this cooperation and outcomes will be discussed in a later chapter.

In 2019, Volvo Cars launched an initiative to share traffic safety research results with the traffic safety community. The initiative is called Equal Vehicle safety for All (EVA). The purpose of this initiative is to make Volvo Cars' collection of more than 100 research reports available and accessible to researchers, governments, and other vehicle manufacturers and suppliers. This is the collected research creating the foundation for a whole selection of Volvo's safety technology innovations.

In the case of modern vehicles, there is a high level of penetration of connectivity. This means that communication between vehicles or between vehicles and the infrastructure, either through cellular cloud connectivity or direct Wi-Fi connectivity (direct short-range communication, DSRC), will be useful for sharing data between vehicles.

Among the possibilities for sharing real-time data between vehicles are data on slippery road ways. The electronic stability systems, standard in most vehicles today, have the capacity to identify and measure icy patches on the road. This information can then be sent to central alarm centers that in turn can share this information with other connected vehicles. In parallel, information can be sent to the road maintenance units that can be dispatched to distribute sand or salt on these patches. This is a very efficient and accurate way of quickly acting against a road threat in a very precise manner. This type of arrangement is now already in operation in some places pioneering this type of data sharing, and there are also manufacturers who are ready for taking part in this type of cooperation.

Volvo Cars introduced the possibility for this type of data sharing with the car models produced in the mid-2010s and today covers all car models in production.

Having a large number of data probes out in traffic, there is also a large potential also in sharing other types of data, e.g., bad air quality, congestions, issues on the road, etc.

In summary, according to the view of Volvo Cars, the recommendations for motor vehicle manufacturers' responsibilities may be defined as:

- Making safe and reliable products that offer the highest level of safety regardless of age, gender, or size and both for people inside the vehicles and unprotected road users outside of the vehicles
- In line with the manufacturers' social responsibility, aim towards having all activities related to manufacturing, transportation of goods, service purchasing, and employee road travels on official business made with a level of safety that is in line with the targets of eliminating road casualties
- Sharing knowledge on research and data gathering from incidents and crashes that may be an asset for further research and product development
- Sharing real-time data gathered by modern connected vehicles to other cars, to road authorities, and to other important stakeholders
- Cooperating with governments, authorities, infrastructure owners, academia, and the motor vehicle industry in finding the most optimal way in creating a safe and efficient road traffic system
- Distributing the knowledge and advancements of modern motor vehicles globally by offering the same level of safety to all markets regardless of the existence of government standards

## Volvo Cars Safety Vision

The Volvo Cars Safety Vision states that no one should be seriously injured or killed in a new Volvo car. This vision was adopted in 2007 and was a result of the very encouraging safety work done for decades and the projections of what was feasible and achievable linked to the future technical potential developments. This is also in line with Volvo Cars' heritage. Already at the start of the company, Volvo decided to focus on safety as one of the core values of the company.

The Volvo Safety Centre is continuously monitoring the outcome of crashed vehicles by collecting data and by cooperating with a number of stakeholders, e.g., the authorities in a number of countries in order to gather data on Volvo cars involved in crashes and the outcomes of the occupants.

## Structured Safety Design of Vehicles

### Real-Life Safety: The Foundation for the Safety Design

The development of occupant safety must be based on the improved protection in real life. Having a structured way of learning how vehicles perform in real crashes and the relationship and behavior of occupants and other road users to the technologies, such as restraint systems, are key to this knowledge. In learning about the traditional occupant protection systems perform, Volvo is using an approach named “Circle of Life.” Crash and incident data, gathered since the early 1970s, are forming the base for setting the requirements for the performance of all safety systems, on complete vehicle level, as well as on system and component levels for the vehicles that are to be developed. Once the next generation of vehicles has been exposed to the real-life environment and exposed to crashes and incidents, new data is gathered which in turn will form the basis for the updated requirements which will form the foundation for the new vehicle development.

This way of using real-life data, naturally, needs a structured way of gathering data or having access to this data. For Volvo Cars, gathering crash and incident data was part of the company’s approach to vehicle design starting in the early 1970s. At this time, the company has, in its corporate accident data base, gathered data from more than 40,000 crashes involving 70,000 occupants. However, given a more cross-functional and more open relationship between manufacturers towards sharing vehicle crash data, and the availability for accessing other sources of data, all manufacturers now would be able to approach improved vehicle safety using the real-life safety approach.

Assessing the benefits of new technologies and innovations may, however, pose some challenges. In particular, to a large degree, this is the case for advanced avoidance and support technologies. Here, assessments and projections of technology effectiveness will be essential before the proper data is gathered. Using available research data and data from behavioral studies will indicate, without giving the precise level of effectiveness, that the introduction of a new vehicle technology will help to enhance safety and therefore has a value for being added to the vehicle’s overall occupant protection system.

## Overall Safety Strategy

Traditionally crash safety has been the focus for improved safety performance of vehicles for many decades. Although many systems for avoiding crashes existed, these systems primarily were based on basic technologies with none or limited use of advanced electronic components and intelligence.

From the advent of the new millennium, new advanced safety systems started to be engineered and introduced into the vehicle fleet. The first system to be introduced was ABS (anti-locking braking system) which was then followed by ESC (electronic stability control system). In particular ESC has proven to be a valuable contributor to increased vehicle safety by stabilizing the vehicles in a number of instability situations and helping to avoid conflicts and crashes.

The development of these systems was the starting point for a whole set of systems helping to avoid or mitigate crashes. At the same time, the crashworthiness systems continued to be developed, and also new post-crash systems, such as on call systems, started to be developed and introduced on the markets.

All these developments paved the way for a new playing field where manufacturers' safety strategies turned into viewing the overall picture instead of each safety mode separately. The target when using a more holistic view on the safety strategy is primarily to cut the chain of events leading to a crash as early as possible and to, hopefully, totally avoid a serious situation and the crash. As an example of this, see picture of Volvo's Safety Strategy below.

Even if the chain is not completely cut, the interaction of the avoidance or mitigation systems and the crash protection systems may significantly improve the chances of survival even if the end result is a crash. The action of the preventative systems may reduce the impact energy so that the vehicle's protection systems can handle the remaining energy. To exemplify this, e.g., a pedestrian detection and braking system may reduce the impact energy sufficiently in order to move the injury risk level significantly from a non-survival level into a level for only minor or intermediate injuries.

The different stages of the chain of events leading to a crash and the events after a crash can be divided into the following stages: risk management or normal driving phase, threat management or conflicts and near-crash phase, injury management or crash phase, and post-crash phase.

During the risk management or normal phase, many preventative actions could be taken, actions that would assist in ruling out any further negative development. Examples of those actions are improved comfort in the passenger compartment; improved ergonomics and HMIs (human machine interface); systems encouraging improved driver attention and reducing the risk of distracted drivers, e.g., the risk of driver's eyes not focusing on the road; alcohol interlocks and sobriety checks for reducing the risk of driving while intoxicated; and improved navigation systems helping to reduce the risk of stressed drivers. In additions to this, the systems for assessing the drivers' drowsiness levels and for helping drivers to steer back on the road when not paying attention also have the potential of cutting the chain of events leading to a crash.

For the conflict part or the threat management phase, the focus is to assist the driver in avoiding a collision and taking the situation back into the normal phase. Typical systems acting during the conflict phase are ESC (electronic stability control systems), BAS (brake assist systems), and FCWs (forward collision warning). All these systems interact with the drivers and are activated when the in-vehicle sensors are detecting a development moving away from the normal phase.

The near-crash or avoidance and mitigation phases occur during the time span starting 2–3 s before a crash (two to three TTC – time to crash) and until the crash occurs. This is the time span when it is too late for the drivers to act but still time for the systems to react and try to prevent or reduce the consequences of a crash.

If the chain of events is not cut, the vehicle will enter the crash phase. If the preventative systems have been active in reducing the level of impact, the restraint systems together with the occupant protection systems will be in a better position to reduce the risk of injuries to the occupants. Regardless of the impact reducing potential of the preventative systems, the potential of protecting the occupants in a

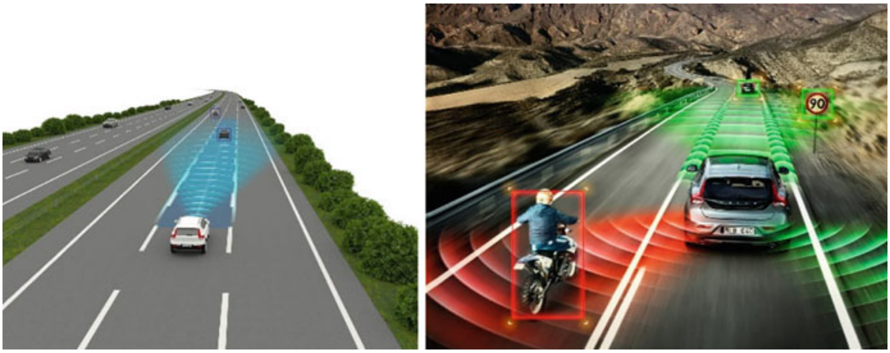

**Fig. 5** Examples of active safety support systems available on the market

modern motor vehicle with the most advanced crashworthiness system is undoubtedly high. Modern vehicles have a whole set of combinations of efficient crashworthiness protection systems that have proven to be giving elevated levels of occupant safety. Among other things, car manufacturers have spent extensive resources in adapting the body structure for an optimized level of energy absorption by using various steel qualities, among those a high level of ultrahigh strength steels. Also, the restraint systems, e.g., inflatable restraints, belts with load limiters and pre-tensioners, child seat restraints, and interior systems absorbing energy during impacts, all are part of the occupant protection while in a crash.

Numerous systems active during this time span have been developed, and more are in the pipe line to be developed or launched. Systems such as automatic emergency braking (AEB) systems, lane departure warning and lane keeping aid systems (LDW, LKA), and pre-crash belt tensioners and seat adjustment systems have all been introduced and have proven to be effective in reducing injuries and fatalities. As an example the effectiveness of low-speed autonomous emergency braking of these systems leads to a reduction of 38% of real-world rear-end crashes (Fildes et al. (2015)).

The last stage in the crash sequence is the post-crash phase. During this phase actions can be taken to, e.g., brake the vehicle in order not to create multiple crashes and reduce the risk of fires by minimizing the fuel leakage and automatically calling for assistance from rescue personnel by sending messages of locations and crash severity via so-called e-call systems.

Included in the overall strategy is also the need to protect vulnerable road users. This includes both minimizing the risk of crashing with a VRU and minimizing the outcome. Manufacturers have spent extensive resources on making the front part of the vehicles benign and also to develop systems for detecting and braking for pedestrians and bicyclists, preferably avoiding a crash; but in the case that it cannot be avoided, minimize the impact. Volvo Cars was the first manufacturer to introduce this type of technology in 2010, and since then the technology has cascaded into all segments of passenger vehicles. However, the heavy truck industry has been slow to react, and as of yet (2020), the technology is not available in this motor vehicle segment.

With further preventative technology advancements, this safety strategy will be even more dominant in the future. For this reason, it is important that the advancements are shared among all road users on all continents. Cascading strategies from the premium segment of vehicles to the large-volume production of vehicles are already occurring and will be more rapid with lower unit prices and more adaptions into newer vehicle platforms. Even though there is a significant time lag, the technologies are starting to penetrate both into the middle- or low-income markets and into the used car fleet, the reason why there should be hope for experiencing significant reductions in casualties rather close in time.

The development of self-driving or autonomous vehicles also has a potential of reducing the number of serious injuries and fatalities in the road transportation system. It is estimated that around 90–94% of all crashes have a human error as part of the causation. Since the human error part is estimated to be almost nullified when applying autonomous technology, it is estimated that 90–95% of the crashes occurring in today's traffic may be eliminated. Even before the AD technology has fully penetrated the vehicle fleet, the cautious behavior of the self-driving cars will have a soothing effect on the overall traffic management and vehicle speed.

Also, the advanced technologies developed for letting cars be self-driving, such as sensors, detection algorithms, and duplicate reliable data processors, may be active also when the cars are not in autonomous mode and will potentially help to significantly raise the level of awareness for the drivers, and the support systems may be even more efficient in assisting drivers and for acting when drivers are no longer able to be part in avoiding or mitigating the crashes.

In summary, a holistic safety strategy looking at all modes of driving and crash causations will be paramount in taking vehicle safety towards zero fatalities and serious injuries. Most of this development is driven by the market forces without government standards pushing manufacturers. In the past, government standards were the driving force for improving vehicle safety. Today, most of the new advanced technologies are not regulated but have been introduced on the market following high levels of customer demand due to the existing clear and comprehensive customer information, primarily through different vehicle rating programs, so-called New Car Assessment Program (NCAP). With more data sharing and more focus on the whole chain of events leading to a crash and by using this in the priorities of development of new advanced technologies, significant steps towards zero are expected by the efforts of vehicle manufacturers.

## Focus on Designing Around People

"Cars are driven by people, the guiding principle behind everything we make at Volvo therefore is, and must remain, safety." This statement was made early in the history of Volvo, at the time when a human-based focus was not the norm and common practice adopted by all other manufacturers.

By using this principle of designing around the humans, this emphasizes the focus on creating an environment in the vehicle around all occupants that enables, besides


**Fig. 6** Volvo safety strategy

comfort and convenience, the car to support a safe and pleasurable ride which enhances the trust of the occupants and a comfortable ride.

For many years, this was primarily done by making a very reliable and trustworthy design of the vehicles in addition to adding features that improved safety and gradually improving the ergonomic driving environment. Many of the early technical innovations for safety, such as the three-point seat belt, very clear in its message of safety and creating a feeling of making a difference when used, have been important in this strategy.

During the last decades, many technical advancements have been made in improving and adapting the ergonomic features within the passenger compartments, all helping to create a comfortable environment reducing the fatigue of both drivers and other occupants. For drivers, extensive research has been performed in order to reduce the risk of both distraction and avoidable driver mistakes due to inappropriate vehicle-to-driver communication. Among those features are, for drivers, assistance systems that both communicate all important information in a clear, comprehensive, and undistracted format that avoids both misunderstandings and unnecessarily increasing the drivers' anxiety and stress levels as well as improving the trust and level of assurance of the vehicle's safety systems and thus improving comfort and well-being.

Other systems could also act as safety features. For example, infotainment systems and navigation systems have a potential of assisting drivers, thus relieving tension and reducing stress and in this way giving the driver a better position in carrying out the driving task.

## Driver Distraction and Attention Selection

While cars are still driven by and in control by humans, safety is highly dependent on the driver being alert and focused on the driving. Drivers being distracted for various reasons such as carrying out secondary tasks in addition to driving, being exposed to high workloads, different distracting scenarios occurring outside of and around the vehicle, interaction with other occupants in the car, etc. may fail to be fully capable for a short or longer time to safely carry out the driving task. Examples of secondary tasks are dialling and texting using cell phones, web browsing, watching movies or television, selecting music on playlists, and inputting address on electronic displays, i.e., tasks that require the drivers to take their eyes off the road for a short or longer time. This kind of distraction may also be created by complicated vehicle controls requiring the drivers to move both the attention and eye view away from the road and the driving.

Accident statistics show that distraction is a major contribution or a part of the causation of a high number of fatalities in many countries. Only in the USA this number is estimated to be around 3500 per year. Distraction is also reported to be a factor in around 8.5% of all crashes involving fatalities.

Too low workloads may also be unsafe by creating a low attention level that in turn requires a longer time for drivers to act in case of the need of a critical action.

Legal restrictions have been imposed on what kind of secondary tasks and what driver activities are to be allowed while being behind the wheel. Those restrictions include banning the use of handheld cell phones, texting, watching movies or television, and performing secondary tasks in general while driving.

Most countries in both the Eastern and Western world, including local provinces and states, have these legal restrictions in place. Some jurisdictions are also actively enforcing these by actively monitoring and fining drivers found to be violating them.

In addition to formal legal restrictions, there are also guidelines being created in trying to guide manufacturers on the best standards for designing the vehicle's controls, displays, and electronic interfaces with the drivers. For example, the US federal agency National Highway Traffic Safety Administration (NHTSA) in 2013 published (Phase 1) guidelines for in-vehicle electronic devices. These were created as an effort to discourage manufacturers in introducing distracting devices in their vehicles. In 2016 NHTSA published Phase 2 of the guidelines covering distraction caused by devices brought into the vehicles such as cell phones and other electronic devices not part of the vehicles' original equipment.

Some trade organizations such as manufacturer trade organizations and consumer organizations have also created recommendations and guidelines for reducing the risk of distraction linked to vehicles' electronic devices.

With the development of new and advanced driver assistance technologies, driver monitoring is becoming a key for assessing the driver's attention to his/her driving task. With this technology it is possible to adapt a whole set of support systems and also assess if to lower the availability of the number of vehicle features that could possibly be distracting for drivers in a low-attention mode.

A number of other ways of reducing the workload for drivers and minimizing the risk for distraction will be offered, among those speech and gesture guidance.

Driver monitoring may also be linked to other useful support systems, such as drowsiness systems and systems for minimizing the risk for drivers being under the influence of drugs or alcohol.

**Fig. 7** Driver monitoring camera

Driver assessments of drowsiness or distraction may also be combined with other detection systems such as analyzing steering wheel movements. By combining various assessments of drivers' attentiveness and readiness to perform their driver duties in a safe way, decisions may be made also whether to increase the settings of warning and automatically activate systems to compensate for a lower driver performance.

Potentially, with more mature driver assessment system, this kind of support systems could also be extended for other ways of making the continuous ride safe, such as so-called limp-home modes, where the vehicle could be still driven and moving forward but only with reduced speed and raised vigilance levels of the support systems.

## Improved Protection for All Occupants, Independent of Age, Gender, or Size

One of the most important requirements in the principle "design around you" is that all occupants need to be given the same level of occupant protection regardless of gender, size, and age.

This implies that the restraint systems need to be adapted to the specific needs, geometric sizes, and tolerance levels of the full range of occupants likely to use the different seating positions in the vehicle. Many technical innovations have been developed and implemented for these adaptions, such as belt load limiters and adjustable seat belt anchorages as well as occupant sensing systems used for decision-making in deploying or not deploying the inflatable restraint systems.

Many of the protection systems implemented have a wide coverage in the efficiency of protecting the occupants without special adaptions. For example, whiplash protection systems have proven to give a good improvement in protecting the occupants even though generic testing tools and in-vehicle protection systems are used. However, further advancement can potentially be made by adapting the tools and criteria to both genders, sizes, and age differences. Actions have been taken to create a whiplash dummy more adapted to the typical female sizes and applying female tolerance levels. By using different dummy sizes in the testing and applying the tolerance levels for more fragile body constitutions, this would cover not only the gender aspect but also the age and fragility aspect.

Similar actions should be taken when it comes to other testing tools such as frontal and side anthropomorphic test dummies, new injury criteria, and updated, more stringent tolerance levels.

In 2019, Volvo Cars created an initiative named EVA (Equal Vehicle safety for All). Through this initiative, Volvo Cars is making a number of research reports public and is keeping a library open for other researchers and manufacturers. The reports cover findings from both testing and investigations of real-life accidents.

These reports basically make a number of data points available that may be puzzled together to be used for making significant advancements in knowledge that may be used both for safety design improvements and further development of test tools and test methods and setting injury criteria.

With further advancements of the technologies, in particular driver assistance systems, more possibilities and potentials for individual adaptions will be available. Already today, systems exist for measuring driver alertness and distraction levels and systems that can be set in advance. Among those are forward collision warning (FCW) systems and automatic emergency braking systems (AEBS) that offer different settings depending on the individual capabilities. Those settings do, however, basically require drivers to do this manually in advance, using their own view of their own capacity and capabilities.

The next step after this would possibly also include health assessments and alerts to the drivers given their health status. It is, however, very important always to use this with the full support of the driver and not to infringe on the drivers' integrity. If supported and appreciated by drivers, such adaptions would be seamless and dormant until needed and should preferably not to be used as a correction of the drivers' behavior but instead be considered as your invisible friend who is there to help you when needed.

For customers who want feedback on the driving performance and suggested improvements, such information could possibly be embedded in the vehicles' data recorder and provided upon request.

Already today, schemes exist for rewarding drivers who are following basic rules of safe driving performance, e.g., insurance company pay-as-you drive programs where car owners can get insurance premium discounts. This kind of incentive would have an even larger potential of being beneficial by giving continuous driving performance feedback by the systems developed as part of the designed-around-you principle.

### Child Restraints and Child Safety

As stated in the previous chapter, it is of paramount importance, and it is the responsibility of all car manufacturers to offer the same level of occupant protection for occupants in the vehicle regardless of occupant sizes, ages, and genders.

This creates a special focus on protection of children given their unique biomechanical characteristics with different body and mass proportions and different sustainability and resilience characteristics than adults and other more mature occupants.

This becomes very obvious from looking at the body proportions of children at different ages when comparing this with adults.

With this background, offering lower and insufficient protection for the most vulnerable category of occupants in a vehicle is simply not acceptable. Child restraints offering protection for all sizes of children is a prerequisite and necessity in order to reach a high level of protection for child occupants.

The first versions of child restraints giving an efficient protection for infants and toddlers started to appear in the mid-1960s.

Since the first prototypes in the 1960s, the design and development of efficient child restraints have resulted in enormous improvements in the knowledge on how to best protect infants and toddlers and how to best seat them in the vehicles and have also led to an array of available restraints in many countries.

In Sweden, by the late 2010s, the number of children dying in traffic when restrained in a child restraint annually is extremely low. In most cases there is some kind of misuse involved, and this normally is part in causing this tragic outcome.

There are many actions taken in order to reach this respectable record. One reason is that all major stakeholders in Sweden, i.e., authorities, safety advocates, road safety interest organizations, suppliers, vehicle manufacturers, and vehicle importers, share a common view on how to approach all aspects of protecting children in cars. Among those are the principles of how to position children in the vehicles at different ages and what kinds of child restraints are suitable at different sizes and ages of children. This in turn is used by the responsible institutions for direct communication with parents or parents to be, in preparation for how to best protect the children at different stages of development. One of the basic principles used in this communication is that children should be rearward facing as long as this is practicable and possible. A rearward-facing restraint offers support for the head

**Fig. 8** Body proportions. Children vs adults

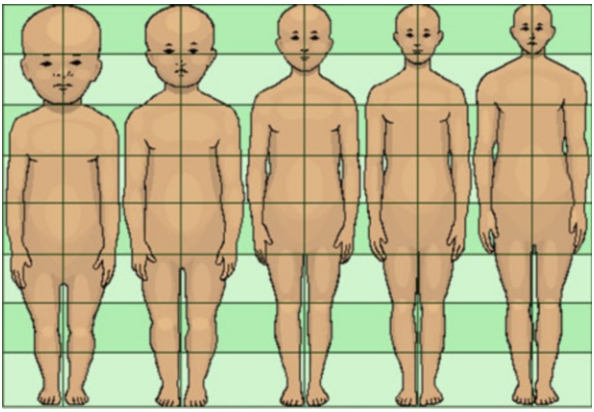

**Fig. 9** Early rearward-facing child restraint prototype

and the back of an infant in the case of a frontal crash. By giving this support, the risk of neck injuries, one of the most dominant injuries to small children, is substantially reduced.

Consequently, the recommendation for all parents and caretakers is to have all children, up to at least the age of 4 years or as long as practicable, positioned in rearward-facing child restraints.

Once the children are too large in size to be fitted in rearward-facing child restraints, appropriate forward-facing toddler seats, giving protection in all types of crashes, should be used.

In 2016, Volvo introduced a new generation of rearward-facing toddler seats. For these restraints the recommended ages are 9 months to 6 years and between 9 and 25 kg in weight.

Although the child has outgrown the toddler seat, it is still not readily prepared for using the adult seat belts without adaptions. The geometries of the belt anchorages are normally positioned in a way to offer good protection for adults. Children at the ages between 3 and 10 years do have characteristics which are not completely compatible with adult seat belts. Children at these ages do not have some skeleton features such as pelvic bones developed. The pelvic bones are used for transferring the forces from the lap belt portion of the three-point belts to the body skeleton for an adult occupant. In the case of a child, the hip should be raised in order to transfer the load into the thighs and the lower part of the skeleton.

All of this leads to the use of a platform for raising the children in order to better adapt the belt geometry of the seat belts and to give the children better protection, so-called booster seats. Those booster seats may have only a belt-positioning platform to position the lap belt or both a platform and a back that positions both the lap and shoulder belt parts of the three-point seat belts. The recommendation is that booster seats should be used up to the age of 10 years.

In order to have this type of restraint readily available, some manufacturers, among those Volvo, offer built-in child restraints, restraints that are incorporated in the car seats and that can be easily activated and placed in position for seating a child.

**Fig. 10** Volvo rearward-facing infant and toddler seats

**Fig. 11** Built-in booster cushion

These may be offered in one or more positions. Multi-stage booster seats have the potential of a better adaption to the size of a child.

Built-in booster seats are highly recommended restraints that should be adopted by all manufacturers in order to have an easy access to the best possible child protection.

One of the restraining forces for offering the best possible child protection is what is legally possible when it comes to certifying those restraints. Within the present legal framework, there are legal requirements that do not open up for the most efficient restraints offering the best protection for the children. There are a number of reasons for this, however not acceptable. Among those are that customers are not ready and capable of installing the more advanced in a way that is required in order to offer this protection and not being misused. The knowledge on how to best protect children in vehicles have come far since Volvo offered the first design of a child seat early in the 1970s. It is time to allow for more flexibility within the legal framework allowing for more advanced child restraints in the future.

### Adaptions for Occupants with Special Needs

The principles of a transportation system open for all and equal protection for all imply that vehicle manufacturers should make adaptions for occupants of different sizes and varied needs as far as this is practicably possible. These adaptions could be offered as optional equipment or part of the vehicle's built-in features. At Volvo, there is a special section of the company named Volvo Special Vehicles whose assignment is to redesign the production vehicles so as to be better adapted to individuals with special needs and other challenges.

These adaptions include special swerving seats for easier access for a person in a wheelchair and special arrangements of the seats and controls for addressing other physical challenges.

Other car companies also offer these kinds of modifications to their vehicles, either through factory-installed equipment or through aftermarket modifications using original accessories.

## Preventing Serious Violations

### Preventing Driving While Under Influence (DWI)

The three most common causes for traffic fatalities due to motor vehicle crashes are still failure to use the seat belts, speeding, and driving while under influence of alcohol or drugs.

Most countries in the developed world have laws for maximum blood alcohol content (BAC) while driving. The allowed levels vary significantly between different countries and different parts of the world.

Three different levels of allowed BAC can be identified: 0.02%, 0.05%, and 0.08%. There are also countries that have a limit of 0% but with low levels of enforcement.

Sweden is applying the 0.02% limit. This is a statement from the authorities that drinking and driving cannot be tolerated. This is also highly enforced by the police.

Many European countries apply 0.05%. The only major exception from this is Great Britain who applies 0.08%.

In the USA, most states also apply 0.08%. This level of allowed BAC is generally considered to be too high in relation to what are the acceptable levels found in human behavior and traffic safety research.

In the early 2000s, Volvo decided to develop and offer an alcohol interlock as an optional equipment for all new vehicles. This device, called Alcoguard, was launched to customers in 2008.

It consists of a wireless handheld device that is connected to the vehicle's ignition system. The device has a mouthpiece that the driver must blow into before the engine may be started.

**Fig. 12** Volvo Cars Alcoguard system

Volvo is so far the only manufacturer that offers an alcohol interlock of its own design as optional equipment, but many car manufacturers do, however, offer the cabling necessary for installing an interlock in the vehicle design.

The interlock devices presently offered within the automotive sector as an optional equipment all suffer from having a set of major issues making the device undesired by customers and drivers. Among those issues are high costs, low level of reliability, and the need for frequent calibrations. A design using a mouthpiece also suffers from the opportunity of an intoxicated driver to hand over the mouthpiece to another occupant, most likely to the occupant in the front passenger seat.

Significant research and product development efforts have been made focusing on less intrusive, more reliable, and less costly solutions than blowing into a mouthpiece.

Among those are designs for blowing into a faucet located in the center hub of the steering wheel, skin detection systems to be located on the steering wheel, and infrared beams placed in front of the driver's face.

Many of those solutions are still in the development stage and are not yet ready for commercial introduction. Some of them, however, look promising and may meet the requirements to be accepted by customers and drivers.

The US Federal Government in the form of Department of Transportation is looking at continuing its drunk-driving prevention project DADSS (Driver Alcohol Detection System for Safety) that they have been working on for more than a decade. The technology is still not ready for production, but is now sufficiently developed for pilot testing in fleets.

The device for detecting too high BACs also suffers from the fact that it only covers one of the factors for driver intoxication and lower driver performance. A number of other causes exist for drivers being under influence that would affect the driving capability. Misuse of different drugs is one of the primary causes of driver intoxication and lower driving capability. Although, in many cases, the persons misusing drugs are also likely to misuse alcohol, this still does not always go hand in hand.

A completely different way of approaching the ways for reducing the consequences of drunk-driving and all other types of drug misuse and intoxication in the traffic system would be to measure the drivers' driving capability in real time. This would focus on the main issue, the risk for creating incidents and crashes instead of measuring something ***leading*** to a risk of creating this. By doing this, other factors creating risks would be covered, not just intoxication but also, e.g., distraction and drowsiness.

As discussed in the section linked to distraction and drowsiness, driver monitoring is becoming key for assessing the driver's attention and capability to carry out the driving task.

Volvo Cars believes that the issues of driver intoxication and distraction should be addressed by installing in-car cameras and other sensors that monitor the driver and allow the car to intervene if a clearly intoxicated or distracted driver does not respond to warning signals and is risking an accident involving serious injury or death.

The intervention could involve limiting the car's speed, alerting an e-call assistance service, and, as a final course of action, actively slowing down and safely parking the car.

With this technology it is also possible to adapt a whole set of support systems and also assessing if to lower the availability of the number of vehicle features that could possibly be distracting for drivers in a low attention mode.

A number of other ways of reducing the workload for drivers and minimizing the risk for distraction will be offered, among those speech and gesture guidance.

Since a decade back, systems exist that have the potential to detect distracted or drowsy drivers. In 2007 Volvo Cars launched a system named Driver Alert. This system measures the way the driver is handling the steering in relation to the lane markings on the road. The basic theory is that fully alert drivers are making micro corrections using the steering wheel, while more drowsy or distracted drivers are making more jerky movements. This theory has proven to be valid, both in field operational tests (FOT) and in order research.

The potentials for these systems are considerable and obvious. Car manufacturers are therefore strongly encouraged to continue these efforts into balancing driver capabilities with the vehicle's driving features and the possibilities in order to reach a safe state of driving when looking at all conditions.

## Speeding

The issue of allowing the possibility of speeding on public roads instead of restricting the top speed of the vehicles close to the speed limits is something widely debated between policymakers and manufacturers. Systems, called speed limiters, are developed and available for assisting and encouraging drivers in selecting a speed corresponding to the actual speed limit of the stretch of road in question. Many manufacturers are offering these devices either as optional equipment or as a standard factory-installed device. The present highlighted discussion between governments and manufacturers is whether to require speed limiters that prevent a higher speed than the speed limit plus a margin regardless if the driver's wish is to drive faster. The argument is that there are no circumstances where speeding has any additional benefits for society or adding to traffic safety but instead leads to serious consequences for both the society and the individuals, and therefore speeding should be no option for drivers.

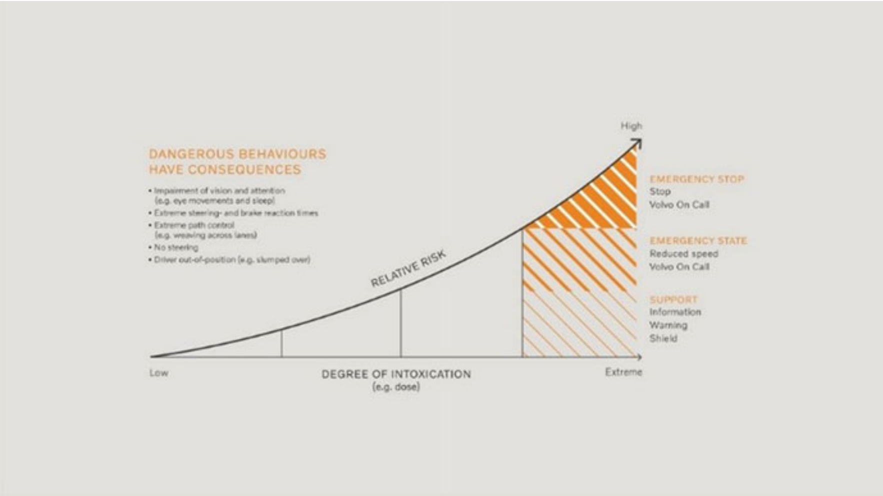


**Fig. 13** Graph showing the risk linked to intoxication and the possible measures. (Volvo Cars)

Even though the basic arguments for forcing a non-speeding road transportation environment are sound and wise, this should only be instituted when both the technology and the road infrastructure have matured sufficiently to offer a high level of reliability for applying an accurate speed for all situations, all road types, and all road sections. Forcing out new innovative systems that are not fully developed and sufficiently tested, and at the same time as the interface with the infrastructure is not fully reliable and quality assured, faces the risk of drivers and cars ending up in awkward situations with unintended speeds not matching the speed limits which in turn could lead to creating driver and customer opposition and distrust that might be long lasting and will be difficult to repair. An example of this occurring was with the seat belt interlock mandate for all new vehicles in the USA manufactured in the period 1972–1973. These mandated devices prevented the engine to start unless the driver was buckled up. Unfortunately, the reliability of the devices installed by the manufacturers was poor, and many cars refused to start even if the drivers were buckled up. The uproar and the customers' dissatisfaction resulted in a buying resistance and consequently to a revoked requirement for installment of these devices. It even got as far as ending up with an act in Congress prohibiting setting a new mandate for forcing the fitment of similar devices in the future. It also caused a delay in adopting mandatory seat belt laws in the states in the USA and a delay in the seat belt usage rate in the USA.

Actions for increasing enforcement of the speed limits are often put forward as an effective means of reducing the levels and the extent of speeding. Enforcement is, indeed, an efficient but expensive means for limiting speeding. Extensive number of traffic police, speed cameras, video recordings, and road appliances for tracking speeding vehicles – all these are costly and cannot cover all road sections. A larger penetration of driver assistance speed-limiting systems and, eventually, when the technology is mature and reliable and the road infrastructure has achieved a quality-assured speed limit posting, mandatory speed-limiting systems would offer a more efficient way of reaching a level of less speeding violations.

Although most countries and territories have adopted speed limits for all roads, there are still a few unique areas and types of roads that offer free speeds without limitations. The best-known type of road with free speeds is the German Autobahn. Discussions have been intense within the European community on the suitability of keeping this unique policy in the heart of the European continent. Still, this is applied, and although congestions reduce the actual speeds, appalling crashes occur, and the arguments of the possibility to drive fast legally prevents and deters many manufacturers in applying reasonable top speeds for their cars and to actively support mandatory speed-limiting devices.

Some manufacturers, including Volvo, have launched concepts where the vehicle's key could be programmed for adapting certain features such as the car's maximum speed. This kind of device allows the owners to set limitations on the car's top speed before lending their car to other family members or to younger and inexperienced drivers such as teenagers that only just received their drivers' licenses.

In 2019, Volvo Cars stated that it had made the decision to restrict the maximum speed for all its new cars and models to 180 kmh by 2020. This decision was made after careful considerations and market investigations on the customer preferences and needs. The company has received a lot of support for making this decision within the safety community. This is also a way for the company to assume its corporate social responsibility for protecting both the humans and the environment.

In the context of high speeds and protecting the occupants, belt usage is extremely important. Higher usage rates in many countries in addition to the higher levels of seat belt reminders have assisted this development.

However, in many countries, higher belt usage rates only apply to the front seats. Rear seat usage rates are appallingly low on many markets. Both governments and manufacturers should increase their efforts to inform occupants on the importance of being belted in the rear seat.

As an example, the Swedish National Society for Road Safety (NTF) ran ads in the Swedish media a decade ago called "No elephants in the car please!" These ads clearly showed customers the risk for the front seat occupants of having an occupant unbelted in the rear seat. For example, it informed customers that for a crash at 50 km/h and an occupant whose weight is 75 kg, the corresponding weight considering the g-forces in the crash would be 3000 kg (3 tonnes)! This campaign was considered to be successful and has helped to significantly increase the belt usage rate in the rear seat.

The campaign was considered successful, and surveys afterwards showed a higher consciousness of car occupants to be belted while in the rear seat.

A recent development supporting the actions to prevent speeding is the introduction of the geofencing technology, an innovation forcing different kinds of restrictions to be applied to specific geographical areas. Examples of restrictions are maximum speed and only using electromobility within a city center area. This would be a very efficient means of, e.g., forcing compliance with speed restrictions outside of schools and shared spaces with vulnerable road users. Volvo Cars fully supports the deployment of this type of technology and believes that it will be an important contributor to reducing speeding and traffic casualties in critical city areas.

In conclusion, Volvo Cars believes that cars staying within the speed limit will be necessary in meeting the Vision Zero target, and measures for limiting the top speed and installing speed-limiting devices in motor vehicles will be an essential component in a strategy for preventing speeding violations.

## The Responsibilities of Car Manufacturers for Sharing Car Technology Developments Globally

The levels of traffic safety globally vary significantly. This is due to a fragmented picture of many factors, such as infrastructure status, the structure and development level of the transportation sector, how the road system is being used, levels of enforcements and traffic education, incentives and factors for improving safety, societal factors of age, gender distribution, general social status, and rural, urban, and infrastructure planning. An important factor is also the generic level of age and size distribution in the vehicle fleet as well as the technical level of advancements of the fleet.

Governments here have a major responsibility for both encouraging a renewal of the fleet at appropriate intervals as well as incentivizing technology advancements and setting minimum performance requirements for safety. However, there are a number of developing countries who have neither established any encouragements for adopting new technologies nor set any minimum legal safety performance requirements.

For Volvo, the level of safety needs to be the same regardless of any government mandates, third-party testing, or other outside requirements. Humans of all genders, sizes, and ages should be protected on an equal level. So, provided there are no unique circumstances dictating a special variant, no differentiation should be made on equipment and performance levels. Volvo Cars strongly advocates all manufacturers to adopt the same generic policy.

## Cooperation Between Different Traffic Stakeholders

Traditionally, the roads for the last 100 years have been designed based on fairly standard principles of offering a space where different road users could apply whatever means of transportation that was available and with rather basic standards for sharing this road space, staying safe, and reaching the goal for the journey.

Although the designs of the modern roads have indeed made significant advancements, the concept has still been to offer an open space for all vehicles, and then the vehicle manufacturers designed the vehicles assuming basic standard requirements for being able to carry the occupants safe and not to harm other road users.

However, with more advanced vehicles, higher speeds, more congestions and competition of the road space, and the need to significantly reduce the road casualties, the need for closer cooperation between vehicle manufacturers and the authorities has become clear during the last two decades.

Also, in order to get closer to the Vision Zero, a holistic view must be applied in order to balance both the vehicles' occupant protection in relation to the planning and design of the infrastructure. For instance, this is relevant when it comes to applying tougher requirements for road vehicles in different types of collisions. Applying tougher standards in order to meet very small numbers of collisions will automatically lead to less optimized levels of actions to improve all aspects of crash protection, e.g., restraint systems, passive crash protection, and other advanced occupant protection systems which add both costs and potentially weight. The consequences may potentially be new road vehicles being larger in size, being more expensive, and with lower levels of fuel economy, i.e., less attractive to both policymakers and customers, which in turn would reduce the pace towards reaching the desired level of traffic safety.

During the last decades, many efforts have been made in order to review the approaches to cooperations and to set the standards for both the design of roads and vehicles. Many of these cooperations have opened up for reaching clear views on how to most efficiently use the possible means for improving traffic safety and how to find a holistic view of how all stakeholders may be involved in reaching this.

However, in order to be able to efficiently explore the full possibilities of these cooperations, it requires the right mind-set of all stakeholders involved in reaching a Vision Zero target and the organizational and legal means for making real progress and setting standards that enable real progress. The stakeholders must be able to share a view of what would be the most optimized contributions of each one and how this would work together in a holistic and integrated approach.

In September 2007, the Swedish Road Administration and Volvo Car Corporation signed an agreement on cooperation for improving traffic safety in Sweden. This can be seen as extension and link up with both the Vision Zero target that was adopted by the Swedish Parliament in 1997 and Volvo Car's Safety Vision that was launched in 2007. The Swedish Vision Zero target did state the principles for how to approach the design of the transport system by stating that:

- The transportation system must be adapted to the human tolerances.
- "Normal" human mistakes should not have severe consequences. Instead, the transport system should be forgiving with respect to those mistakes.

The agreement of cooperating as signed by the parties included a number of areas of cooperation, including:

- A division of responsibilities for a whole set of conflict scenarios.

  These scenarios include, among others, frontal crashes, car-to-car side impacts, car-to-car rear impacts, car and VRU conflicts, car and wild animal conflicts, etc. Each scenario defines the speed of which the responsibility changes hands from the vehicle to the infrastructure. For example, for frontal crashes, a speed is defined for when the responsibility of keeping all occupants safe when a frontal crash occurs is transferred from the car and its occupant protection systems to the infrastructure, i.e., adding certain features to the infrastructure in order to avoid this type of scenario. For car-to-VRU conflicts, a maximum speed is defined for when the cars' active and passive protection systems should be able to jointly avoid serious injuries to the VRU and when instead the infrastructure should instead be designed in a way to avoid car and VRU conflict by separation. Please see attached figure below.

- Definitions of requirements for various interfaces between the advanced safety systems in the vehicles and certain features on the infrastructure.

  A number of advanced driver assistance systems, e.g., lane departure and lane keeping aid systems, need clear lane markings in order to define if the vehicle is rightly positioned and help the driver and the vehicle to correct the position if needed. For the case of the advanced systems enabling autonomous driving, lateral positioning will be guided through the assistance of lane markings.

  Thus, in order to be fully recognized by the detection systems in the vehicle, certain requirements are identified on the lane marking, e.g., size and contrast. The agreement also identified the requirements for the assurance of the existence of lane markings for all applicable roads.

  The agreements also covered other features needed in order to assure the compatibility between the vehicle's advanced systems and the infrastructure.
- Sharing of traffic and crash analyses in order to enable the best measures in infrastructure and vehicle design and avoiding traffic casualties.

The agreement of cooperation and dividing of responsibilities has become a role model for other similar approaches in sharing the view of how best to apply the capabilities of vehicles and infrastructures.

Cooperation between different stakeholders and sharing of data will be increasingly important when moving forward to improve traffic safety. This will be of even higher importance for the development of self-driving or autonomous vehicles.

The US government has announced the intentions of data sharing similar to what is done within the field of civil aviation. Here all stakeholders sit together and openly share critical data and agree on certain principles and standards. It should, however, be remarked that there are major differences in the foundation and principles of the transportation sector versus the civil aviation sector.

One of those major differences is that the industry is governed by antitrust laws which establish rules for the cooperation between manufacturers and how much of agreements limits the need for constant stretching of the boundaries of technical developments in occupant protection for motor vehicles. Agreeing on standards would limit the individual manufacturers' need for always looking for going beyond competitors and create a competitive edge. Also, there are many more actors in the road transportation sector that would significantly reduce the possibilities on agreeing on standards. In addition to this, motor vehicles are used in vastly different conditions and by largely different users and in totally different environments. All of

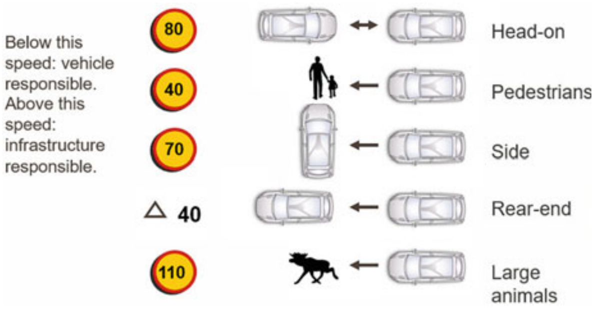


**Fig. 14** Division of responsibilities between vehicle manufacturers and authorities

these various factors make the opportunities for agreements on standards and principles a huge challenge, both legally and in practice.

## Manufacturers Sharing Research Data

In order to make motor vehicles safer, the knowledge gathered from real-world crashes is key and an invaluable asset. Since 1970, the Volvo Accident Research Team has compiled data from crashes involving Volvo vehicles. This data is and has been essential in understanding what happens during a collision.

With the EVA Initiative (Equal Vehicle safety for All), Volvo is sharing the results and knowledge of 50 years of research. By letting all other interesting parties download this, it will help to make cars safer. Volvo Cars is encouraging other OEMs and suppliers to join in on this effort.

EVA is assisting in identifying a number of data points that may be assembled and rejoined in order to get a more complete and comprehensible view of how to analyze the research data and help to use this data for improved and innovative safety systems.

What becomes clear from the research data is that women presently run a higher risk of getting injured in crashes than men. By using the research results available, it is possible to scale the data points in order to adapt them and be able to scale this to be able to accommodate for both the size and tolerance differences between men and women. This is part of a continuous effort in reaching the goal of having equal protection for all occupants, regardless of gender, size, age, and other tolerance level differences.

This strategy for reaching equal protection between the genders should be and must be the target of all OEMs in designing cars for the future.

One result showing the advantage of using this approach is the development of new technologies in the design of the Volvo Whiplash Protection System “WHIPS,” a system that is built into the front seats and is designed to reduce the loading on the neck of the occupants. When looking at the data of occupant injuries after this restraint had been on the market for a number of years, it was clear that there was a significant lower number of whiplash injuries, in particular for women.

## Further Improvements of the Infrastructure

As discussed in the earlier chapter, the design and basic structure of the infrastructure in most parts of the world have had the same outlook for the last century. Some parts are clearly not compatible neither with the present status of the modern vehicles nor with the level of intensity of modern traffic. Infrastructure improvements to reduce the risk for simple human mistakes having serious consequences should be the primary focus in making structural changes in combination with eliminating the types of crashes that will create the highest number of human casualties instead of focusing on transportation efficiency.

As examples of improvements with high potentials of reducing the risk of serious crashes are adding a median barrier on multi-lane highways and other roads or reshaping junctions with crossing high speed traffic with roundabouts or multi-layered viaducts.

Head-on collision is, by far, the most critical crash scenario and the most difficult one, when it comes to impact violence and possible measures to protect the occupants. Having median fences on higher-speed roads would efficiently remove this type of scenario from the radar and put other types of scenarios more in focus for further improving occupant protection, scenarios where measures would be more efficient in reducing fatalities and serious injuries.

A new type of median fence was created in the early 2000s, i.e., a wire fence that guides the car that is swerving towards the oncoming lane back into the ego lane. This type of fence has proven to be highly effective in eliminating head-in crashes (Vadeby 2016).

In-plane crossings and junctions, with high speed limits, share the basic flaw of requiring the full attention of the drivers at all times, and a mistake might lead to serious consequences. This flaw is equally valid for crossings with traffic lights. Human mistakes or drivers running a red light makes this type of scenario severely critical.

In line with one of the principles defined by the Swedish Vision Zero strategy, a human mistake should not lead to serious consequences, but the road structure should be forgiving and absorb this mistake without casualties.

By replacing in-plane crossings and junctions with roundabouts or multi-layered viaducts, the risk of driver mistakes leading to serious consequences will have the potential of being significantly reduced.

Roundabouts require the drivers to reduce the speed and look out for other vehicles in the roundabout which in turn increases the attention level. Although the number of low-speed crashes is likely to increase, the number of casualties goes down.

Measures for reducing the risk of cars injuring or killing pedestrian or other vulnerable road users could be separation of cars and VRUs. Another way practiced in many cities in Europe is to create chaos mixing the different types of road users, thus reducing the speed and creating a low-risk environment. The principle practiced for these examples is an allowed speed of approximately 7–10 kmh and that VRUs in these areas always have the right of way.

Most modern vehicles are or have the possibility of being connected. This opens up for introducing the concept of geofencing into the infrastructure. The technology linked to this may, by connecting up vehicles, restrict the usage of vehicles in a number of different ways. Forced reduced speed limits next to schools, hospitals, or residential areas, limiting driving using combustion engines in city centers, or only allowing pedestrian-friendly cars (e.g., equipped with automatic braking systems for pedestrians) are among those opportunities.

## Further Vehicle Development/Autonomous Vehicles

In parallel with the developments of motor vehicle safety, improving occupant crash protection, supporting drivers to avoid or mitigate crashes, and also activating autonomous systems, e.g., autonomous braking and steering, the development of autonomously driven vehicles offers a high level of opportunities for improving traffic safety.

In looking at the cause of motor vehicle crashes, it is estimated that around 90–94% of them involve human error. Autonomously driven vehicles, where the control of the driving is completely resting with the cars, have the potential of almost eliminating the risks associated with human error.

At the moment, there is an intense activity among the manufacturers to develop and test highly autonomous vehicles. The majority of these activities concern passenger cars or smaller vehicles, such as pod cars or smaller buses, but the heavy vehicle industry is also getting more into this important development.

Most national governments, states, or provinces worldwide have adopted rules for testing. Many vehicle manufacturers also have received permits to test self-driving vehicles on public roads.

An autonomous vehicle will have extensive capabilities both to drive safely and by being well prepared for any risks that may be encountered on the operational design domain (ODD) that it is operating on. By having very highly defined maps and extensive sensor and dual redundant computer capabilities, it will be able to deal with all the risks that can be somewhat likely on this ODD. The driving strategy that is pre-programmed into the vehicle and the downloaded map means that it will drive in a way that is exceedingly safe and it will make tactical and strategical decisions based on this.

A whole catalogue of risk situations will be pre-programmed into the vehicle's central computer. The basis for this is the data of crashes and incidents that have been collected for many years, both by the company through its accident investigation team and by governments and academia, and that forms a basis for covering both the most common incidents and crashes as well as rarer or edge cases. The basis for the AD vehicle design is that vehicles should be prepared for any crashes or risks that are somewhat likely to occur on the whole fleet, consisting of hundreds of thousands of vehicles during decades of driving and on similar ODDs globally.

This knowledge of what kinds of crashes or incidents cannot be gathered by purely road testing but needs to be based primarily on previous knowledge plus what can be added from purely AD-related causes (Lindman 2017).

RAND cooperation has estimated in its report (RAND Corporation 2016) that it would be necessary, by applying only public road testing, to drive hundreds of millions or billions of miles to verify the safety. Even with aggressive and ambitious testing programs, it would take tens or even hundreds of years to reach the levels of miles required. So, test driving alone cannot be used to demonstrate the safety level.

Therefore, the data bases with crashes and incidents are used to provide the knowledge needed. This data is used to simulate the situations that the vehicle's sensors need to register, and the vehicle's central computers then have to analyze and decide on the most appropriate actions. Any knowledge gathered from the road testing will, of course, also be added.

So, basically, the autonomous vehicles need to apply road driving strategies and tactics, preparing them for any reasonably scenarios that may occur on the ODDs. Primarily, this means that the vehicles should be able to handle situations without any drama and risk. If something unanticipated occurs, there should always be an exit strategy to handle the situation.

Within the public domain, both in media and within the academia, so-called ethical dilemmas are widely discussed. An ethical dilemma suggests that autonomous vehicles may end up in situations where they have to decide between undesirably scenarios. This is not recognized as a reality among vehicle manufacturers. With the principles for designing the safe handling of the driving, the autonomous vehicles will have a way of dealing with this safely by avoiding being faced with this kind of dilemma.

The technology is yet, however, only at the first initial stages of development, and it will take decades before it can make a serious impact on the number of traffic casualties. Normal cars of different ages and safety levels will also remain on the roads for still a long time in the future.

However, autonomous vehicles have the potential of making an impact by influencing the traffic flows and being a balance to the traffic. Autonomous car will have the built-in capabilities of planning the driving in a tactical and optimized way so that all aspects of comfort, safety, and fuel economy are balanced. The cars will, of course, also stay within the speed limits.

Volvo Cars believes that governments, authorities, manufacturers, suppliers, and other stakeholders should join forces in encouraging this promising development. In particular, the legal requirements' framework should be adapted to embrace and encourage this evolution.

## New Ways of Using Transportation

The transportation sector in the modern society faces many challenges, including congestion, health issues due to air pollutions from vehicle emissions and stressful lifestyles due to long commutes, valuable space lost in cities due to parking and spacious infrastructure, and unacceptable traffic casualties.

All of these point at an unavoidable transformation for how people will be mobile in the future. Individual mobility needs to be gradually expanded into different ways of using shared mobility. Different ways of being mobile are expected to be developed in the next decade, such as mobility as a service, peer-to-peer sharing, vehicle fleets and carpooling, etc.

This in turn is aimed to lead to a reduction in the density of vehicles and less risks of individual mistakes leading to crashes. The vehicles used for car sharing are also expected to have a higher standard of vehicle technology including the latest level of safety technology.

This shift in transportation is consequently offering a potential in reducing the number of traffic casualties at the same time delivering many other benefits.

For many cities in the world, among the challenges linked to modern transportation are living quality, the well-being, and the safety of the inhabitants. The mix of different road users of city streets, with vast differences in sizes and tolerances, from large trucks and buses to unprotected humans and speeds not compatible with the tolerances of the vulnerable road users, is causing huge numbers of killed and seriously injured humans on city streets globally.

With the shift in mobility, smaller units the size of passenger cars or vans, optimized to the size of the need of shared mobility for every journey and route, may replace larger outsized buses and other large-size vehicles occupying the major parts of streets and creating challenges for pedestrians, bicyclists, and smaller motorcycles to navigate safely. Thus, smaller units for shared mobility replacing the outsized public buses in many crowded urban areas may offer a benefit not just for occupying less city space but also for reducing the number of traffic casualties further assisting the efforts towards Vision Zero.

In line with the future focus on shared mobility, Volvo Cars has founded a whole new company, M, whose mission is to offer smart car sharing. This supports the shift from ownership to access to vehicles. Other manufacturers, such as BMW, Audi, and Mercedes, also have successfully formed and ran similar shared mobility companies.

With seamlessness and accessibility to mobility, this role model of car sharing offers the potential of reshaping and reclaiming cities that will offer people more space, more comfort, and improved habitat and living conditions.

Cars are parked more than 95% of their lifespan. With the trend of shifting from ownership to sharing, valuable space, now used for parking, and access to parking may be reclaimed and used as part of making moving around in cities safer. In particular, this also will offer a potential for improved safety for pedestrians by remodelling the vehicle and pedestrian interaction.

## Discussion

At the same time as the global situation with constantly increasing numbers of traffic casualties is deeply concerning, the success stories coming from systematic and structured systems safety design are remarkable and indeed promising. By combining the potential of modifying the infrastructure, prioritizing the reduction of human injuries instead of the number of accidents, with the technical developments of improved occupant protection and protection of other road users, the resulting reductions of traffic casualties are striking.

The ingredients in these efforts are proven and all necessary in being successful: firstly, an ambitious government vision broken down into goals and action plans; secondly, a motor vehicle industry with long-term targets of improved occupant safety and also the safety of other road users; thirdly, a cooperation between the governments and manufacturers in order to yield optimized benefits out of all the efforts of improving traffic safety.

The clearest shining success story exemplifying this is the Swedish Vision Zero. Reaching a reduction of traffic fatalities in Sweden from initially 16 per 100,000 inhabitants in the 1970s to 2.7 in 2019 is truly remarkable.

Focusing on minimizing the consequences of simple human mistakes, setting the tolerances in the road transport system at the human tolerance levels, inviting all stakeholders to participate, creating a shared view on the division of responsibilities, and sharing data and research knowledge all are ingredients that cannot be foregone in the strategic task of eliminating all traffic casualties.

Setting the safety of the road users as the number one priority and creating design standards for the infrastructure in line with human tolerances have revolutionized the thinking of the safety community. The examples mentioned earlier of replacing crossing with roundabouts and installing median fences on higher-speed roads in order to avoid head-on collisions have proven to be highly effective. These redesigns in turn have opened up for vehicle manufacturers to modify their safety strategies and reprioritize some of their own safety targets.

Significant progress on traffic safety has also been made in other places, particularly in Western Europe. A number of countries, such as the Netherlands, Denmark, and Great Britain, have achieved impressive low numbers of traffic casualties.

The same progress is, however, not seen within all of the countries within the industrial world. On some of the major markets, it appears that the progress of reducing the number of fatalities has more or less stalled and is not meeting the government targets.

The EU is trying to push its low-performing member countries in adopting ambitious targets for the traffic safety.

For the USA, the highest numbers of traffic fatalities were recorded in the early 1970s. These numbers were around 55,000, i.e., the same as the number of US soldiers killed throughout the Vietnam War!

However, during the first part of the 2000s, the USA made some significant progress in reducing the traffic casualties, unfortunately, during the last couple of years, this trend has changed and is now rising again. The number of fatalities in the USA was as low as 32,000 in 2014 but is now back up to 37,000 again. This is indeed a cause for concerns.

For the developing world, the numbers of traffic casualties continue to rise. In many countries in Africa and in the Middle and Far East, the numbers of fatalities reach as high as between 25 and 35 fatalities per 100,000 inhabitants.

The target of the UN Decade of Action 2011–2020 project was to save one million lives by suggesting a number of measures such as improving the safety of the road infrastructure, further improving the safety of road vehicles, and focusing more on road safety management and the leading killer of people aged 5–29 years. Most of the fatalities are pedestrians, cyclists, and motorcyclists. This is the case in particular for those living in developing countries. For the next Decade of Action, 2021–2030, road traffic safety is one of the goals: goal number 3, “Ensure healthy lives and promote well-being for all ages,” with target 3.6, “By 2020, halve the number of global deaths and injuries from road traffic accidents.”

Both from human suffering and a sustainability perspective, the global numbers for road fatalities and serious injuries are clearly not acceptable, and drastic measures are needed. In line with this, the targets for the next decade of action are dire and should be uncompromisable and require all stakeholders to be involved and contribute. As mentioned earlier, most fatalities are vulnerable road users, particularly in developing countries. Systematic planning of the safety improvements of the infrastructure focusing on VRUs and more efforts of the management of road safety in those parts of the world would potentially make a huge difference to the outcome for this category of road casualties. The major contribution of vehicle manufacturers, more pedestrian-friendly body structures, and benign exteriors are clearly beneficial and should be introduced for all new vehicles, and the legal requirements for the vehicle performance in the protection of VRUs and adopted by the UN ECE WP29 need to be adopted by all major markets globally.

The present trends among governments in developing countries, however, do not aim for this level of harmonization of vehicle safety requirements.

Vehicle manufacturers are also strongly encouraged to align their vehicle designs so as to meet the UN ECE requirements as a minimal level of vehicle performance even in countries who have not adopted any vehicle safety requirements.

Unfortunately, there is still a significant gap in the level of vehicle technology introduced in modern vehicles for developing countries as compared to industrialized countries.

This fact is something that is needed to be handled by both the governments and vehicle manufacturers. Governments may harmonize the vehicle requirements with those recommended by UN ECE, offer incentives for the introduction of new advanced vehicle technologies, and inform customers on the benefits of these systems, and vehicle manufacturers should voluntarily speed up the efforts of offering the safest vehicles on all markets.

However, even given the potential of further improvements to motor vehicle safety, the most significant challenges remain for improvements of the infrastructure, enhanced behavior of the road users, and road safety management, particularly in the developing countries.

## Conclusions

The Swedish example of safe traffic management in the form of the strategic work linked to the Swedish Vision Zero is a very striking example of how successful such an effort can and should be. The citizens’ safety cannot and must not be traded in for transport efficiency or for economic reasons. The safety of humans must always be paramount in these efforts.

The actions already taken in terms of improving motor vehicle safety and infrastructure changes and applying a safe systems approach to transportation are clearly in a positive direction and will, over time, give a significant reduction in traffic casualties, but with the seriousness in the present situation, stronger and more drastic measures need to be taken rather hastily. All road traffic stakeholders need to cooperate and bear the burden of responsibility for actions leading to progress in aiming for the Vision Zero target in the number of fatalities and serious injuries globally.

It is encouraging, however, when viewing the efforts to systematically approach this situation by involving all stakeholders and the different initiatives that are coming from major international bodies like the United Nations and the European Union.

In spite of the tremendous improvements in traffic safety during the last decades, the present global situation with approximately 1.3 million fatalities is deeply concerning. Since transportation is the backbone of modern society, many hesitations remain on behalf of some stakeholders on how measures for improved motor vehicle safety may affect the transportation flow and efficiency. However, by creating a collision-free traffic environment, with significant less friction in the system, this will create huge benefits by improving the flow of goods and the well-being of road users. Transportation research also clearly show that improved and efficient transportation goes hand in hand with improved vehicle safety.

Among those contributions are making safe and reliable products with the latest advancements in motor vehicle safety and knowledge that are distributed so as to benefit all markets and all road users globally, sharing important research data related to real-life traffic situations and sharing real-time data recorded by the vehicle and related to traffic safety, using safe and sustainable transportations related to all production and distribution activities, and cooperating with all stakeholders in moving safety forward.

Looking at all important players taking part in this effort and with their ambitions and the invested resources, together with the vastly increased knowledge from research gathered during the last decades and combined with the technological advancements and the future anticipated changes in the ways to use mobility in the future, the prospects to succeed with the Vision Zero target look promising and indeed inspiring. ***So, to us all within the global safety community, we are on a mission together, let's do it!***

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# What the Car Industry Can Do: Mercedes-Benz' View

# 24

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## Contents




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**Abstract**

The car industry faces some extreme challenges. Alongside the key task that we face of making individual transport climate-neutral, and alongside the new technological opportunities for communication and networking across our whole environment, it is clear that the user behavior of vehicle drivers and of all other road users is also going to change. Bearing all these aspects in mind, our overriding goal remains to make the traffic on our roads safer. Many of the activities in this context are summarized in the Mercedes-Benz “Vision of accident-free driving.” The current plateauing of road fatality statistics across the countries of the West is a clear signal that we need to intensify our efforts even further. And indeed, there are still plenty of levers that can be applied in order to optimize and improve these figures.

Following a review of the current situation from the perspective of Mercedes-Benz, the opportunities for further optimization of vehicle safety are now presented in the guise of the latest Experimental Safety Vehicle, ESF 2019, which above all addresses the new possibilities offered by increasing connectivity and automation. Many of the innovative concepts under consideration have a chance of reaching the market in future vehicles, either as they are or in a modified form; in other cases the discussion around them will lead to new ideas and proposed solutions.

The Integral Safety Strategy by Mercedes-Benz is a holistic approach that defines safety in four phases: (1) safe driving, (2) assisting in a critical driving situation with accident prevention systems and anticipatory protection elements such as PRE-SAFE® systems, (3) during a crash, for example, occupant and partner protection, and, finally, (4) after a crash, deploy systems for the rescue phase. All four phases must be high priorities during the development of the vehicle.

Even with an optimistic view of the vehicle-based opportunities, this chapter will demonstrate that vehicle measures alone will not be sufficient to solve all traffic safety issues, as road transportation is just too complex. All the factors that impact road safety, and which will need to play their part in delivering “Vision Zero,” must be addressed; in other words, infrastructural measures and people in traffic, too. As with the Mercedes-Benz strategy of Integral Safety, we shall only be able to make major advances toward “Vision Zero” if all influencing factors are properly investigated as part of an integrated examination of road safety.

**Keywords**

Vision of accident-free driving · Experimental safety vehicle · Pre-accident phase · PRE-SAFE® · Integral safety · Reversible protection measures · Crash brake · Traffic casualties · Stagnation · Speed differences · Different road users · Megatrends · CASE · High relative speed · Physical constraints · Accident risk · Infrastructure · Non-uniform traffic · Vulnerable road users · Preemptive or proactive protection systems · Situatively appropriate protection · Electric mobility · Pyrotechnically activated · Concept vehicles · ESF 2009 · ESF 2019 · Innovations · Cooperative behavior · Highly automated vehicles · Human centric lighting · Daylight+ · DIGITAL LIGHT · PRE-SAFE® Child belt · Slack in the belt · PRE-SAFE® Child side · Side impact protection elements · ISOFIX · Monitoring vital signs · Virtual crumple zone · Partner protection · PRE-SAFE® Impulse · PRE-SAFE® Impulse side · Dissipation of energy · Electric high-performance belt tensioner · Environment sensors · PRE-SAFE® Impulse front · Variability of the seating position · Protective principle "Flight" · Holistic safety concept · Steering wheel · Pedal cluster · Steer-by-wire · Integral sidebag · Rear seat passengers · Beltbag · Rear airbag · Tubular structure design · USB-C port · Heated seat belt · Securing the hazardous area · Warning triangle robot · Self-driving Cars · Roof warning triangle · PRE-SAFE® Side lighting · Emergency lighting

## Introduction

The concept and approach summarized as "Vision Zero" was initially developed as a strategy toward the end of the 1990s. It was a strong message, back then. Perhaps it was the steady reduction in the number of road fatalities in Europe around this time that stirred up hopes that this vision could be achieved within the foreseeable future. The idea of "Vision Zero" was adopted in many areas of the world, although at times with varying interpretations: "Zero road accident fatalities," "No serious injuries," or even "No more road accidents."

At Mercedes-Benz, too, the focus had long been on what might be the next stages in the development of vehicle and road safety. Following major advances in the areas of driving assistance systems and accident protection, the question was: What might come after ABS/BAS/ESP or after offset crash simulations, front and side airbags? Some industry experts were already then of the opinion that the future belonged to active safety alone and that there was little potential left to improve occupant protection.

This was not an opinion that was shared at Mercedes-Benz. Just how false the assumptions of such skeptics were has been proved by the next 20 years of development in this field, as I shall go on to show. In 1996, a specialist unit, "Strategies and concepts for vehicle safety," was established within the passenger car development unit at Sindelfingen, tasked with clarifying the questions swirling around at that time. Its aim: to outline two quite new, but closely related approaches to vehicle safety and to bring these to life.

The first of these was that particular consideration in vehicle safety terms should be given to the pre-accident phase of an accident. In this new, anticipatory phase, we even find an overlap between active and passive safety, something of a paradigm shift in safety development. Measures aimed at preventing an accident, or mitigating its severity, run in parallel with those readying the occupant protection systems for the expected impact, rather than consecutively. Innovations in this phase would later be clustered together by Mercedes-Benz under the term PRE-SAFE® systems.

And the second was a fundamentally new strategic approach that took as its premise that future-oriented vehicle safety would only be possible with a holistic understanding of this discipline:

- From the moment the risk of an accident arises
- Through the pre-accident phase
- The actual impact phase, in other words, the crash phase
- To the recovery of the occupants after an accident

Equal priority should be given to each of these phases, marking the birth of what would subsequently become known as the Mercedes-Benz strategy of "Integral Safety" (Fig. 1).

These two approaches were first incorporated into Mercedes-Benz's safety strategy in 1999 and influenced the way for a new era of vehicle safety. They led, step by step, to many innovative solutions as the strategy of Integral Safety was resolutely pursued over the ensuing years.

Making use of the time before the accident was the new direction taken in development work. It was already clear back then that major progress could be achieved with this new philosophy. However, the experts were engaged in long discussions about the right sensor systems that would allow the vehicle to decide to deploy restraint systems before the actual impact. The solution for a quick market introduction was that PRE-SAFE® initially concentrated on reversible measures that were triggered based on data of existing sensors.

The concept of Integral Safety was first introduced at the IAA in Frankfurt in 2000, followed in 2001 by the first demonstration of PRE-SAFE® at the ESV Conference in Amsterdam (Schoeneburg et al. 2001). The first series introduction was in 2002, in the facelifted S-Class of the day, with reversible seat belts and seat priming, as well as automatic closing of the side windows and sliding sunroof.

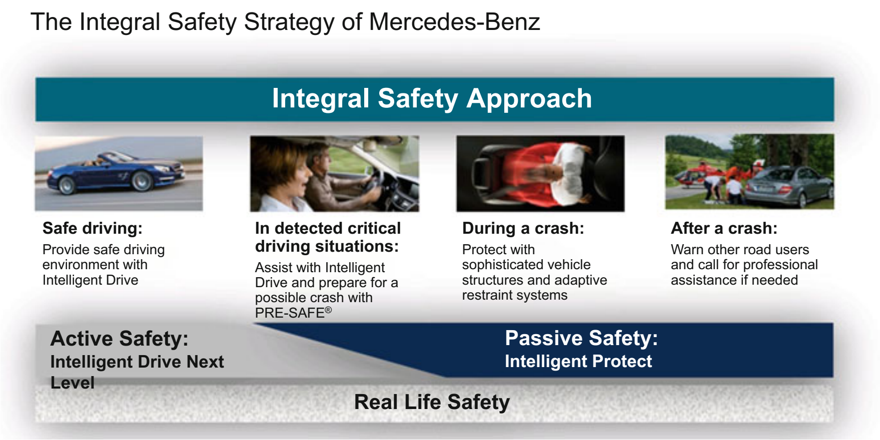


**Fig. 1** The Mercedes-Benz concept of "Integral Safety"

## The Vision of Accident-Free Driving

The holistic understanding of integral safety and the use of anticipatory measures released new impetus and led to a dynamic new development. While in the first instance, development work focused primarily on reversible protective measures to prepare the occupants for a possible accident, it quickly became clear that the new solutions could also include dynamic handling interventions. And so it was that, as early as 2001, the concept of automatic pre-crash short-term braking in the moment immediately before the impact came about, known internally as the "crash brake." The aim here was to dissipate energy as a preemptive measure, thereby reducing the severity of one's own accident and that of any other partner to the impact – a virtual or electronic "crumple zone," as it were, in front of the vehicle. This approach can be seen as the key innovation in accident avoidance, marking the inception of future accident-prevention safety measures. Even though controversially discussed at the beginning, the idea of being able to avoid the accident altogether in future began to take hold of the engineers' minds. And it was against this backdrop that the "Vision of accident-free driving" began to evolve in the research division at Mercedes-Benz. Accident avoidance can be regarded as the highest level of "vision zero," as it would not only address fatalities and injuries, but also the accident itself.

But at no point did the team surrender to the illusion that this beacon moment would be reached within the foreseeable future – and certainly not by means of vehicle-related measures alone. It was, however, a vision that was extremely important for all the safety experts at Mercedes-Benz, ensuring that projects and resources could all be focused in one direction.

## Traffic Involves Risks

Every form of mobility comes with its own specific risks. And that has not just been the case since the invention and wider availability of the automobile. In 1903, for example, there were already 215 fatalities on London's roads (Niemann 2002). The causes were, of course, different from today. Around the turn of the century, more than 90% of such accidents involved horses, horse-drawn vehicles, and carriages. Whenever people travel along a single plane at a finite speed, irrespective of how, there are risks involved. No surprise, then that in 1886 the first motor car also came under the spotlight with regard to safety. In 1888, Karl Benz touted his "Patent Motor Car" as being "comfortable and absolutely danger-free"! to operate, while its "steering, stopping and braking are lighter and safer than with conventional carriages" (Stolle 2004).

However, as we all now know, an increase in motorized traffic on the roads is likewise fraught with danger:

– Driving speeds increased.
– The infrastructure (roads) was not suitable for this type of traffic.
– The automobile, in its early days, was still unreliable and unsafe.
– Traffic levels continued to grow.

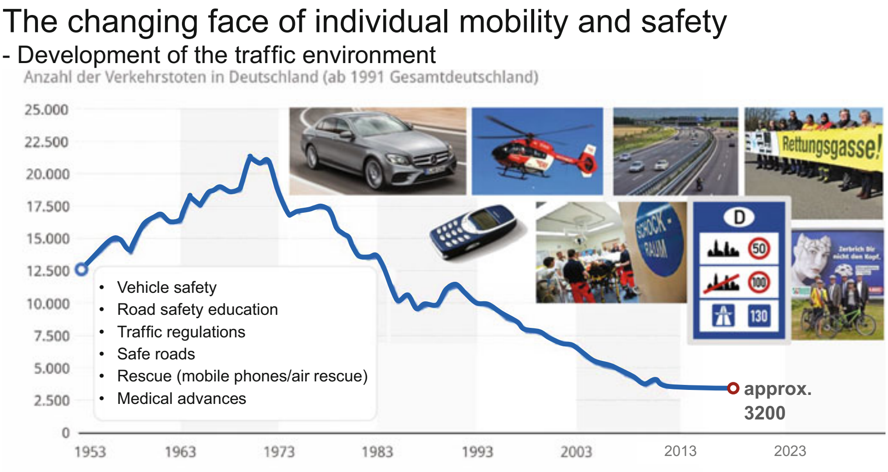


**Fig. 2** Road traffic fatalities in Germany since 1953 and the development of associated factors

Such risks had still not been overcome by the 1960s or 1970s. The accident figures continued to escalate; the number of road traffic casualties rose steadily. It was not until 1971 that a turning point in this development was reached in Germany and the accident statistics could be steered on a sustained basis in a new direction. A decade of declining accident casualties set in, despite an increase in the traffic on the roads.

It became evident to the authorities and to all car manufacturers that more vehicle safety was a key to reversing the trend and reducing the number of fatalities on the road. Many pioneering innovations, such as the airbag, ESP, or the configuration of the vehicle body structure to more realistic accident circumstances, brought about sustainable improvements in road safety. Legislators, too, began to put the right framework in place with regard to infrastructure and road traffic regulations.

In the 1970s, it was clearly understood that the automobile alone would not be able to resolve the problem of road safety and that the only way to deliver sustainable and lasting success would be through taking a holistic view of the traffic system. The success story since the 1970s, therefore, is not the result of just one factor but, as so often in life, of many factors (Fig. 2). Alongside vehicle safety, it has been road safety education, new traffic regulations, modernization of the traffic infrastructure, much faster and more effective emergency services and, not least, major advances in medicine that have contributed to the steady reduction in road fatalities over past decades.

## Current Developments in Road Safety

However, a look at the latest developments, particularly over the last 10 years since 2010, should give us in Germany, and in many other countries in the west, cause for concern. Looking at the positive trend in road fatality figures in Germany from the perspective of the 1990s, hope back then was perhaps justified that the number of traffic casualties would continue to fall steadily. For some it may possibly even have aroused hope that death on the roads would soon be a thing of the past. The realistic observer, though, would probably have realized that this downward trend would at some point level off. The only question was when, and at what level. And this is, indeed, what has happened. In 2010, this downward trend showed an unexpected significant change of direction, with the trajectory yielding to something resembling stagnation (Fig. 2). Whereas, in the past, road deaths in Germany had fallen by around 500 a year, it now took 10 years to achieve this. What had happened? Do the prevailing circumstances in vehicle and road safety mean that, as feared, we have now reached the end of the road? What new stimulus is now necessary if we are to make further progress and turn that dream of preventing the accident altogether into reality?

## Factors Influencing Safety on the Road

First of all, this stagnation in the accident statistics means that there is currently a balance between the factors reducing and those increasing risk. Along with many changes that have the potential to avoid an accident, reduce its severity or protect those involved, there are regrettably also those factors that, for their part, increase the risk of coming to harm and balance out the unquestionably positive factors (Fig. 3).

The risk of an accident is influenced significantly not only by the vehicle itself, but also by the form that road transport takes, both now and in the future. Compared with other extremely safe modes of transport, such as rail or air, road transport is considerably more complex and associated with far greater individual freedom.


**Fig. 3** Factors influencing road safety

– There is no separation, in terms of either space or time, between road users and the traffic flows within the same traffic environment.
– The differences in speed between different transport users within a very confined space are extremely high and all movements take place on the same plane.
– All types of different road users are separately under way within the same traffic space (from trucks and passenger cars to pedestrians and cyclists).
– The technological standards of the vehicles that come up against each other in traffic vary enormously.
– The individual skills and attitudes of the road users likewise vary significantly.
– And each road user acts independently.

The design of the transport infrastructure and the traffic environment, but also human influences and traffic regulations, play a significant part in determining the accident risk. Progress toward the achievement of "Vision Zero" will only happen if a holistic approach is taken to addressing all these parameters. The question for us as vehicle manufacturers, too, is to what extent the vehicle itself has an influence and which levers we can apply in relation to the vehicle, particularly in view of new developments in individual transport.

## The Automobile and Road Transport in a Time of Change

The automobile and traffic will continue to change in many ways. What is certain is that this process will move far more quickly as far as the actual vehicle is concerned than it will in relation to the constraints applicable to traffic in general. Despite many questions that remain open, the future "megatrends" are clear. These are clustered together at Mercedes-Benz under the acronym CASE. CASE stands for "Connected," "Autonomous," "Shared & Services," and "Electric." And when it comes to assisted driving and increasing automation, expectations are high as far as "Vision Zero" is concerned. But how closely is the automation of road transport linked to the elimination of accidents or "Vision Zero"?

Let us now take a closer look at the possibilities as well as at the limits of automation. Automation makes it possible to move the vehicle through traffic at an appropriate speed and in conformance with legislation. In an automated mode and within the limits defined by physics, the vehicle is able to accelerate, decelerate, undertake evasive maneuvers, or disobey driving commands (Fig. 4). The vehicle can also receive and act upon warnings, or warn other road users or the infrastructure. But all this is only possible if corresponding conditions exist, such as an adequate time window for the action, traction, space for the evasive measure, or the correct functionality of the vehicle.

In a real-life context and in normal traffic, there will always, though, be many dangerous situations in which these constraints, however perfect the level of automation, will mean that the accident cannot be completely avoided. The very fact that road users are moving at a finite speed in a nonuniform traffic environment makes it fundamentally possible that directions of movement will cross or

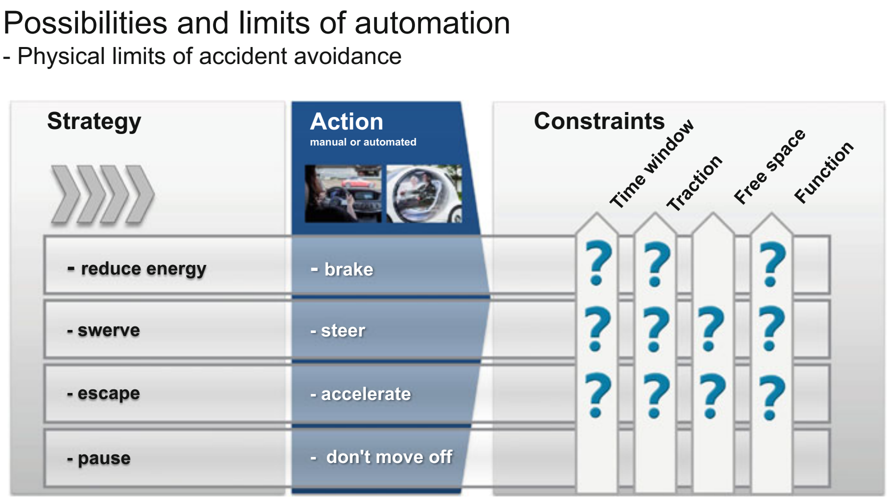


**Fig. 4** Physical limits of accident prevention

converge unexpectedly. With any two-way traffic on narrow roads without separation of the carriageways, for example, there is always the inherent risk of a collision with a high level of accident severity due to constricted passing and the high relative speed, to give just one example of a possible scenario. Furthermore, for decades to come, many road users will still not be using automated modes of transport, or can by their very nature not be automated (pedestrians, cyclists, and animals). Nor are the physical constraints necessarily there in terms of the road itself to allow driving commands to be correctly interpreted into reactions on the part of the vehicle. Defective infrastructure or weather-dependent limitations, such as aquaplaning or icy roads, will exist in the future too. And, ultimately, the possibility cannot be completely excluded that, even as automation becomes more prevalent, there will be a residual risk as a consequence of technical defects or functional limitations of the vehicle. And as long as automation, in certain situations, requires the intervention of human beings, or as long as there is an option for the driver to overrule regulated, automated driving, that human influence and thus the potential for misuse will continue to represent a latent danger with a risk of accident.

The shared, general traffic environment – still largely with today's infrastructure and with continuing individual influences from human beings – is therefore likely to remain the prevailing traffic scenario for a long time to come. There is no doubt that increasing automation offers tremendous potential for improving road safety. But it will continue to be necessary, even in the future, to design vehicles with accidents in mind – regardless of whether they are driven by automated means or not. Given today's infrastructure and a nonuniform traffic – a mixture of automated/conventional driving –, the vehicle on its own will not be able to prevent accidents for many years to come.

## Implications for the Vehicle

So, going forward, the vehicle must continue to reflect the concept of Integral Safety (Fig. 1). In terms of accident prevention, the mitigation of accident severity, the protection of external road users and of the vehicle occupants themselves, as well as the post-accident phase, major efforts will continue to be required if we are to get closer to "Vision Zero." However, to anticipate the potential for preventing accidents attributable to the increasing automation of road traffic by reducing the priority given to accident prevention is something to be avoided at all costs.

In order to **drive safely**, the vehicle in manual mode must be in a position to "forgive" and compensate as much as possible for errors made by its driver. It is designed to assist and to intervene automatically in the event of danger. There is no question that this is an issue that needs to be discussed in considerable depth and with great sensitivity. When driving in automated mode, the connected vehicle must be in a position, as it communicates with its surroundings, to move safely through traffic and to use intelligent algorithms to recognize the potential for danger well in advance and take corresponding action. The vehicle can thus generate advantages for other road users as well as for its own occupants. The more vulnerable road users in particular, such as pedestrians, cyclists, and motorcyclists, who are subject to inherent limitations in terms of accident protection measures, can benefit in this respect. The vehicle of the future must leverage its anticipatory, safe, and cooperative style of driving to win the trust of its occupants and of those partners with whom it shares the road.

The **PRE-SAFE® phase** will become more and more important as time goes by. Innovative solutions that move vehicle occupants into the best position to provide protection in the event of an accident will become more and more important as the level of automation increases. Preemptive or proactive protection systems, as already seen with the Mercedes-Benz PRE-SAFE® Impulse safety systems, will continue to improve and enhance the possibilities for protecting occupants. In line with this idea of preventive action, it is also important, in situations where an accident appears imminent, to warn anyone else near the vehicle and thereby to mitigate the potential danger for other road users.

There will also be plenty of scope for action, going forward, in the third pillar of the Integral Safety concept, **situatively appropriate protection in the event of an accident**. Automating the actual task of driving will change the behavior and habits of the occupants in the vehicle. We can expect to find that people who are no longer permanently tied to the controls of their vehicle will want to position themselves differently within the vehicle. This idea poses major challenges in terms of occupant protection and of the vehicle interior, which until now has always been configured to ensure the correct position of the occupants in the vehicle. Electric mobility, too, presents new challenges in terms of protection in the event of an accident. The current range of Mercedes-Benz vehicles with electric drive system, for example the EQC, demonstrates that there is no need to compromise when it comes to matters of safety. The vehicle structure and all electric components, such as the high-voltage battery, for instance, are configured to cope with the many ramifications of real-life accidents. With electrically powered vehicles, it is even possible to exploit quite new potential for protecting both occupants and any other parties involved. The powerful onboard electrical system, for example, offers the possibility of using electric means to trigger protection systems that until now were pyrotechnically activated, thus making them reversible, or in other words reusable.

For the last pillar of "Integral Safety," the **post-accident phase**, there are also lots of new ideas for the future. Modern communication tools make it far easier to activate the chain of rescue. There will also be solutions that no longer make it necessary for anyone involved in an accident to secure critical traffic situations manually themselves.

As a means of addressing all the issues that we have been talking about and to create a platform where Mercedes-Benz's possible approaches can be discussed with safety experts, the press, and customers, the decision was reached within our company to create a so-called Experimental Safety Vehicle known as the "ESF," for the German words for this term. "Learning by doing" has always been the motto behind the development of concept vehicles of this nature.

## The ESF Experimental Safety Vehicles as Technology Platforms

Experimental Safety Vehicles were used as far back as the 1970s in the context of the "International Technical Conferences on the Enhanced Safety of Vehicles" (ESV) as a basis for the design, practical demonstration, and discussion of safety concepts for future vehicles (Weishaupt 1999). It became evident that these concept vehicles had a particularly valuable role to play as tools for learning and as opinion formers in professional circles as well as among the wider interested public. They provided a means of testing and ensuring the feasibility and acceptance of such future solutions for accident prevention.

That earlier idea of demonstrating futuristic technologies as part of an experimental vehicle was picked up again in 2009. The ESF 2009, based on the S-Class of the time (Fig. 5), proved just as successful. The key features of the more than 20 innovations incorporated into this concept vehicle demonstrated new PRE-SAFE® solutions or improved occupant protection in the rear of the vehicle. Today's current Mercedes vehicles, meanwhile actually incorporate many of the ideas shown back then.

The positive experiences made in relation to new safety-related technologies on the basis of the ESF vehicles provided the impetus for once again adopting this promising approach when it came to the latest investigations into the implications for vehicle safety of increasing vehicle automation and electric mobility.

## The Mercedes-Benz ESF 2019 Experimental Safety Vehicle

In 2016 it was agreed that, to mark 50 years of accident research at Mercedes-Benz, a new ESF 2019 would be built as a way to demonstrate innovations and ideas in line with the following requirements:

**Fig. 5** The ESF 2009 with the most important earlier ESFs from Mercedes-Benz

– Opportunities and potential solutions stemming from increasing connectivity and communication
– Occupant protection systems that need to adapt as a consequence of the increasing automation of road transport.
– Safety and electrical mobility
– The safety potential of new technologies

The search for solutions across the full spectrum of Integral Safety brought together an ever-widening consortium of different specialist units. This spurred on the creativity of the concept team, releasing a powerful and motivating dynamic impetus. The absence of pressure, when an ESF is being designed, to make something immediately series-ready, furthermore allowed the team to introduce various avant-garde and very futuristic solutions (Schoeneburg et al. 2019).

The ESF 2019 on the basis of the GLE saw many of the topics listed above addressed and solutions mooted (Fig. 6). The development and planning of this research field represented a whole new ball game for everyone involved as they worked through the concept and implementation phases. As far as the innovations that it incorporates are concerned, it marks a new milestone in vehicle safety. The following chapters will now examine the most important innovations of this concept vehicle in detail (Niemann 2019).

## Informed Confidence – Cooperative Behavior and Intuitive Communication

Informed, rather than "blind," confidence is a key factor determining the successful integration of a highly automated vehicle into the future traffic environment. This assumes, first and foremost, that the algorithm is configured for cooperative behavior – comparable with a considerate driver. Typical examples include stopping at a pedestrian crossing, allowing a gap so that other traffic can filter in, or moving to one


**Fig. 6** The ESF 2019 on the basis of the Mercedes-Benz GLE

side to create an emergency lane. And secondly, particularly with respect to highly automated vehicles, the concern is to find ways to provide information about the vehicle's intentions that will be immediately and intuitively understood by other road users. Researchers at Mercedes-Benz are looking, for example, at the use of turquoise-colored light signals to indicate that the vehicle is in a highly automated mode. The ESF 2019 also demonstrates how the vehicle might communicate with its surroundings, thereby mimicking the gestures and facial expressions of a driver. In addition, highly automated vehicles can help other road users to avoid accidents, by sharing their awareness of potential dangers with their immediate surroundings. By using their extensive environment sensors and their connection to a backend server, they can provide warning of wrong-way drivers or localized hazards, for example. Any warning of a hazard is given via visual and acoustic signals. Even when parked, a vehicle like this can warn other road users if they appear to be heading for a collision (Fig. 7).

## Biologically Effective Light – Daylight+

For some years now, scientists around the world have been investigating the trending topic of "Human Centric Lighting." What is meant here, primarily, is the psychological as well as physiological impact of light on a person. Light can have either a calming or stimulating effect, thereby reinforcing attention levels during the day or supporting the winding-down phase in the evening. In recent years, a series of scientific studies have been undertaken at Daimler AG to investigate the psychological and physiological impact of daylight, as well as of "biologically effective light," on vehicle drivers and passengers. The focus of this work was on those aspects with implications for driver-fitness, as well as on improving the occupants' overall sense of wellbeing. In the ESF 2019, the adaptive Daylight+ system ensures the provision

**Fig. 7** Informed confidence/cooperative communication with the environment

of biologically effective light to the driver at the wheel. The light helps to counteract the driver's tiredness and, by doing so, can ensure that the driver remains alert for longer. Ultimately this leads to improved driver behavior and increases vehicle safety noticeably. In addition, it is possible to revitalize oneself during a break in driving with a "light-shower," as a quick way of freshening up. A light-shower might therefore, for example, be used at the end of a power nap (a short period of sleep outside the main night-time sleeping phase), as a means of getting into a physiologically beneficial condition. The system thus gives the driver the opportunity to ensure that they are fit enough to continue their journey safely. This function could also easily be integrated into a highly automated vehicle; the vehicle can detect in advance when the driver is ready to drive again themselves (e.g., once a tailback has dissipated or as soon as the vehicle leaves the city and reaches the open road). In plenty of time before this happens (perhaps a quarter of an hour), the light-shower starts, revitalizing the driver for the imminent task of driving. Alertness improves, making the journey altogether safer. In highly automated driving mode it is also possible to lean back and enjoy a light-shower as preparation for the busy day ahead (business meeting, sports event, or similar).

## Seeing and Being Seen

Many hazardous situations and accidents arise at night. The revolutionary DIGITAL LIGHT headlamp technology facilitates pioneering driving assistance and communication with the driver and can create almost perfect light conditions in any driving situation. The new headlamps of the ESF feature chips with a multitude of micro-reflectors. The advanced functionality here means that this adds up to several million micro-reflectors per vehicle. Cameras and sensor systems also detect other road users, while powerful computers evaluate the data plus digital navigation maps in milliseconds to give the headlamps the necessary commands to allow them to adapt the light distribution in the ideal way in any situation. With the innovative software-


**Fig. 8** DIGITAL LIGHT – projection of symbols onto the road in HD quality

controlled DIGITAL LIGHT technology, symbols can also be projected onto the road in HD quality (Fig. 8). This not only provides the driver with information in their direct field of vision but, in the ESF 2019, also allows them to communicate with their surroundings.

## Child Safety

The basis for this innovation in the ESF 2019 is a standard child's seat, suitable for children from 0 to 4 years of age (Fig. 9). The seat has a rotation function, which means that it can be used facing either toward the front or toward the rear. This feature also offers the option of turning the seat in the stationary vehicle to a 90° position to make it easier to lift the child in or out. This standard process is used for the mechanical pretensioning of the PRE-SAFE® Child Belt System. The special feature here, which provides the basis for all other features, is that the seat is wirelessly connected and thus able to exchange information with the vehicle. As a result, it is possible to introduce some important safety features and, on the other hand, to offer certain hitherto unknown comfort and convenience features.

### PRE-SAFE® Child Belt

The preventive tensioning of the seat belt integrated into the child's seat can, for example, take up any slack in the belt and thus also reduce the peak loads in a crash,

**Fig. 9** Networked child seat with PRE-SAFE® functions

thanks to the way the vehicle electronics are networked with the seat. A PRE-SAFE® system sends a radio signal to the child seat which will then, in the event of an impending front, rear, or side impact, activate the belt pretensioner. This process does not depend on an external power supply and is furthermore reversible.

### PRE-SAFE® Child Side

Side impact protection elements are designed to further enhance the protection of the child in the child seat. They are triggered as a preventive measure in a detected critical situation that can lead to an accident. This happens whichever way the seat is positioned to face, but always only on the door side. The side impact protection system extends over a length of 100 millimeters and is designed to reduce peak acceleration in a crash. The PRE-SAFE® signal is a radio signal transmitted by the car to the seat with the effect that, if a side impact threatens, the side impact protection elements will be extended and belt pretensioning activated. The system is mechanically pretensioned by manually pressing the side impact protection elements into the seat. It does not depend on an external power supply and is furthermore reversible.

### Installation Monitoring

LED status lights mounted on the seat itself provide direct feedback about the installation, monitoring the following parameters: ISOFIX connectors, supporting leg, seat buckle, belt tensioning, PRE-SAFE® readiness, seat base rotation function locked into position, radio connection with the vehicle, and external power supply. These parameters are likewise sent to the vehicle, providing the driver with clear information about the child seat in the vehicle display. In the event of incorrect installation of the child seat, an animation in the display helps the driver find a solution to the issue.

### Monitoring of Vital Signs

In addition to the installation data, the seat monitors the child's vital signs and presents them in an easily understandable way. The temperature around the seat, as well as the child's pulse, breathing, and state of wakefulness are monitored. During a journey, the driver is furthermore kept informed by helpful animations of the state of the child's wellbeing, without being at all distracted. This information relates to the time spent sleeping, waking, or sitting and can be retrieved live on a mobile phone via the Mercedes me App.

### Baby Live Video

When the vehicle is stationary or travelling at low speed (<5 km/h), an HD camera integrated into the child's seat can be used to transmit a live video to the vehicle display or to a mobile phone (Mercedes me App).

## The Virtual Crumple Zone:

Besides understanding how road crashes happen and how the safety systems perform, the ultimate goal of accident research is to find ways to mitigate or even prevent accidents all together. The stiff passenger cell, combined with a physical "crumple zone" specifically designed to absorb the energy of an impact by deforming, will always remain a vital concept but should be viewed increasingly as the last resort. New mechanisms must be able to trigger well before the actual moment of impact in order to replace the effect of a physical crumple zone. To do this, the vehicle needs to have at its disposal the necessary information that will allow it to react of its own accord at as early a stage as possible. To react, in this context, means that, if there is an impending risk, the vehicle will automatically slow down, take evasive maneuvers, or possibly even accelerate. The information needed in order to realize this is comparable to that needed for the implementation of highly automated driving. It includes performant sensors (e.g., for the measurement of distance, proximity, and location), together with comprehensive networking capability between the systems in the vehicle and with the vehicle's environment.

The ability to monitor the full surroundings of the vehicle visually, but also to become aware of them before they become visible, for example, through car-to-car communication, will be an indispensable skill in the future. No less important is the accurate evaluation of these countless pieces of information and the ability to use them to identify the correct course of action. Intelligent information received via sensor systems and communication tools will expand enormously the "field of view" and the "field of the not-yet-visible." If the spontaneous occurrence of a hazardous situation means that the accident-prevention measures outlined here are not sufficient to avoid a collision completely, the vehicle will actually initiate measures before the collision, in other words before the moment of impact with the other party involved that will help reduce the consequences of the accident. We call this concept the "virtual crumple zone" (Fig. 10). This covers the time from the moment

**Fig. 10** The virtual "crumple zone"

when the vehicle first reacts to the information from its sensors during the pre-accident phase to the moment the deceleration of the vehicle instigated by its physical crumple zone begins. Examples of such reactions include braking or the forward acceleration of the occupants. The virtual crumple zone is not spatially defined but will depend on the specific circumstances. It comes into particular effect in cases where it recognizes that the collision is already unavoidable. In order to provide the best possible protection for the vehicle's occupants as well as for other parties to the collision, all available (surroundings-related) information will be used to trigger all measures, such as the reduction of speed, as soon as possible. By the time an object penetrates the virtual crumple zone, the information from the system about the impending crash is already available. The vehicle now has just a few milliseconds in which to deploy practical measures to protect the occupants and the other party involved as best possible.

With respect to partner protection, the virtual crumple zone also permits cooperative crash configurations whereby, for example, the height of the vehicle can be adjusted to the opposing party.

## The Fundamental Premise Behind PRE-SAFE® Impulse and PRE-SAFE® Impulse Side

Further components that are also activated as soon as the other party to the accident penetrates the virtual crumple zone are the PRE-SAFE® Impulse systems. Deliberate forward acceleration of the occupants can reduce their relative velocity within the vehicle and thus the extent of the forces acting on them in a crash (Fig. 11). In an impact from the side, this safety system propels the driver or front-seat passenger, for example, toward the middle of the vehicle by means of small air cushions in the seat backrest. The occupants thus move in a direction that takes them away from the intruding side wall, thereby creating additional space. The other restraint systems, such as the sidebag, are configured to accommodate this forward momentum and will use the now enlarged deformation space for the dissipation of energy.

It may also be necessary – particularly with new interior concepts designed to allow a position of comfort for the driver during highly automated driving – to

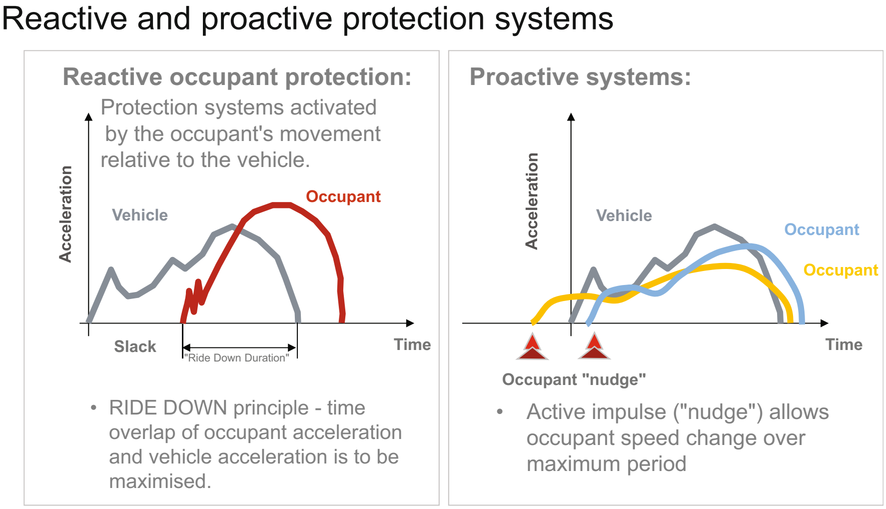


**Fig. 11** The concept of "proactive" protection systems – PRE-SAFE® Impulse

preposition the occupants in readiness for the impact. This idea in turn influences the design of the seats and seat belt system, since the primarily longitudinal direction of the forward impetus (front/rear) means that the electric high-performance belt tensioner cannot be used with this positioning.

PRE-SAFE® Impulse for a frontal impact has been available since the S-Class generation launched in 2013. The PRE-SAFE® Impulse Side system that was demonstrated in the ESF 2009 has been available as an option in the E-Class since 2016. As the performance capability of the environment sensors in the vehicles grows, so too does the number of predictable scenarios, thereby raising a whole raft of new possibilities for the further development and deployment of PRE-SAFE® Impulse systems.

## PRE-SAFE® Impulse Front: Electric Belt Tensioners Instead of Pyrotechnics

If the algorithm responsible predicts a frontal collision and the accident appears imminent, the PRE-SAFE® Impulse Front system can move the occupant back as far as possible and out of the danger zone. To achieve this, the system in the ESF 2019 is fitted with seat belt units that feature very powerful electric motors. In just a few milliseconds an impulse is sent through the seat belt that allows the front-seat occupants to become part of the deceleration process from a very early stage and, in some situations, can move them out of the danger zone. The tensioning force of the belt can also in this case be adjusted to the situation predicted by the sensor systems. It is therefore also possible to suggest various possible stages of escalation for the current PRE-SAFE® belt tensioning device. The further development of the system means that a pyrotechnical belt tensioning device is no longer needed in the belt unit of the ESF 2019. This brings benefits in terms of the space required for installation and thus of the options for integration. Particularly in cases, as here, where the belt unit has to be integrated into a seat, since the variability of the seating position makes a seat with integrated seat belt a vital requirement in the ESF 2019.

## PRE-SAFE® Impulse Rear

This new system attempts to prevent collisions at the end of a line of tailbacked traffic, or at least to mitigate the severity of the accident. As soon as the ESF 2019 comes to a standstill in traffic, numerous sensors work to monitor and interpret everything around it. If the vehicle behind appears to be approaching too fast, its driver will be alerted to the situation by hazard warning lights and a tailback warning projected onto the rear window of the ESF 2019. If the system recognizes that a rear-end collision is nevertheless imminent, and assuming there is sufficient space between the ESF 2019 and the vehicle in front, the system will briefly take advantage of this gap to undertake a calculated evasive maneuver in a longitudinal direction. Maximum acceleration is applied very briefly, followed by hard braking. In an ideal situation, the accident can be avoided this way. Certainly, in most cases the severity of the accident will be reduced by this targeted and time-controlled motion; the impulse is synchronized precisely in such a way that the impact takes place at the end of the acceleration phase. There are two advantages to this: first of all the relative speed of the crash is noticeably lower; secondly, by this time the occupant's head is already braced against the head restraint, thus significantly reducing the risk of neck injury (whiplash).

This system is able to exploit the benefits of electric mobility, since the low latency required in the sudden demand for acceleration is more easily achieved with an electric motor than with a combustion engine, due to the speed at which the rated torque is reached. With PRE-SAFE® Impulse Rear, for the first time, the protective principle of "flight," in other words acceleration rather than deceleration of the vehicle is applied for the protection of occupants and other parties involved.

## Occupant Protection Systems for the Driver, New Interior Layout

Automated cars such as the ESF 2019 bring the vision of accident-free driving that little bit closer. However, in an era of automated and autonomous driving, what is needed is a holistic safety concept with many innovative solutions, as passengers may enjoy more flexible seating options in the interior than they do today. The ESF 2019 adapts itself to the situation: when it is driving in fully automated mode, the steering wheel and pedal cluster are retracted (Fig. 12). Together with the level, padded floor, this is not only able to reduce the risk of injury in a crash, but also clearly indicates that the vehicle is in automated mode.

**Fig. 12** New steering wheel and pedal cluster concept

**Fig. 13** Seat-integrated seat belt and electric high-performance belt tensioner

Coordinated interaction between the seat belts, belt tensioners, belt force limiters, and airbags is a standard feature of Mercedes-Benz restraint systems. As the passengers in automated vehicles might not always be in the best possible seating position in relation to present restraint systems, new ideas are necessary. For example, the belt system has been integrated into the front seats (Fig. 13), so that even when the occupant is in a more relaxed position, the belt fits as closely as possible. The belt system also features an electrically powered high-performance belt tensioner, as previously mentioned. This not only tensions in PRE-SAFE® situations, but is also able to react immediately before the moment of impact to tension the occupant's seat belt to an extent adequate to ensure that even when projected forward, he/she is pulled back into a more favorable, upright position.

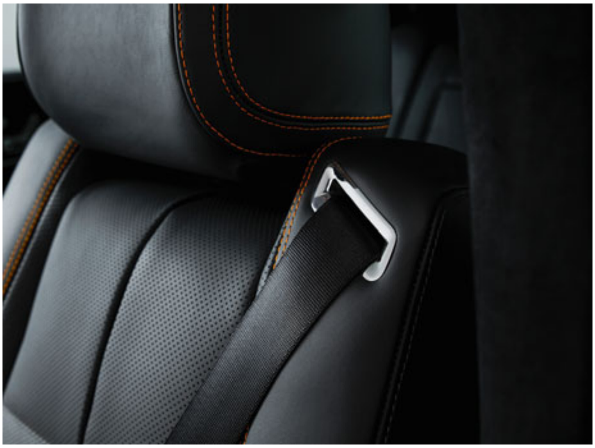

**Fig. 14** New driver airbag for highly automated vehicles

The new flexibility in the interior requires new airbag systems with alternative installation spaces. In the ESF 2019, for example, the driver airbag is located in the dashboard, not the steering wheel (Fig. 14). This deployment concept, already familiar from the front-passenger airbag, plus the three-dimensional airbag shape it makes possible, allows greater coverage. For a better view of the instruments and displays, and to position the airbag where it is least obstructed, the steering wheel has a flattened upper section. The Steer-By-Wire technology in the ESF 2019 – in which steering commands are transmitted electrically and not mechanically – supports the new, somewhat rectangular steering wheel geometry (Fig. 12). As the steering ratio is now variably controllable, it is no longer necessary to use both hands to grip the steering wheel when steering. Maneuvering, for example, requires significantly less movement of the steering wheel, even for a large turning angle.

Another completely new development is also due to the greater seating flexibility: the integral sidebag (Fig. 15), which deploys from the side bolsters of the seat backrest on both sides. The wing-shaped airbag wraps itself around the shoulders, arms, and head of the seat occupant. What is so special about it is that it not only protects the passenger on the side facing the impact. As a so-called center airbag, it can also cushion the passenger on the side away from the impact (known as a far-side impact) and prevent him/her from moving too far toward the middle of the vehicle and a possible passenger alongside.

## Safety of Rear Seat Passengers

The attention paid to the safety of rear seat passengers at Mercedes-Benz has always far exceeded the legal requirements. Examples here include the rear belt tensioners and belt force limiters, sidebags, and Windowbag that have already been available for several generations of the vehicle. An inflatable rear seat belt was offered for the

**Fig. 15** Integral sidebag for any seat position

**Fig. 16** Rear bag within the seat backrest for a particularly gentle deployment

first time in the Mercedes-Benz S-Class. This beltbag, as it is known, can reduce the risk of injury to rear seat passengers in a frontal collision by reducing the load on the ribcage. The larger surface area of the belt strap created in this way results in better distribution of the forces acting on the seat occupant, thus lowering the risk of injury.

In the ESF 2019, the beltbag is further complemented by a new-style airbag for the rear seat passengers. This improves protection of the head and neck area in particular and leads to a further reduction of the risk of injury (Fig. 16). This new type of airbag deploys out of the front seat backrests and, by gently cushioning the head, lessens the forces acting on the seat occupant. The functionality of these rear airbags differs, however, from that of a conventional airbag. They use a unique concept that is deployed here for the first time anywhere in the world. Only the actual structure of the air cushion that gives the airbags their shape is actively inflated. The remaining capacity of the airbag is filled by drawing in the ambient air. This new-style tubular structure design allows the air cushion to deploy without any risk to either adults or children.

Safety and comfort are core values for automotive customers. Innovations will continue to reinforce these core values in future, too. A seat belt extender simplifies the buckling-up process for passengers in the rear and helps to improve seat belt wearing rates. An invitation to the passenger to fasten the seat belt is also conveyed in the form of a light integrated into the seat buckle. It is even conceivable that, in future, the fastening of the seat belt could be rewarded by making it possible to charge a mobile phone via a USB-C port in the belt buckle once the buckle is fastened. Components could thus play their part in enhancing not only comfort, but also the effectiveness of the safety systems. A heated seat belt creates a warming effect close to the body, which is actually very pleasant and, indeed, efficient, negating the need for the occupants to keep their coats on in winter. This also brings clear benefits in terms of safety in the event of an accident: without a jacket or coat there is less slack in the belt, thereby improving the starting position for the occupant in the event of a crash.

## Securing the Hazardous Area (Accident or Breakdown)

Anyone experiencing a breakdown or perhaps an accident is going to be exposed to a high level of stress. You have to get yourself and potentially other vehicle occupants to a place of safety and the emergency services and/or recovery services need to be alerted. It's also essential to secure the scene of the incident, which in certain circumstances can mean walking 200 m or so up the road against the traffic to put the warning triangle in place. In the ESF 2019, all this is the responsibility of the warning triangle robot. This is activated either automatically or by the driver and will then drive of its own accord to the prescribed position in order to secure the scene (Fig. 17).

As soon as the robot has emerged from its box underneath the vehicle, the illuminated warning triangle that is integrated into the roof opens up to warn

**Fig. 17** Securing the scene of an accident – warning triangle robot and roof warning triangle

approaching traffic of the danger with a flashing light signal. Once the danger has passed, the warning triangle robot automatically returns to its box. This way no warning triangle gets left by the side of the road, and the driver is not exposed to a dangerous situation once again. Self-driving cars, such as app-based or automated ride-sharing services, represent another potential area of use. In the event of a need to secure a hazardous situation arising during a driverless journey, or even during a completely unmanned journey, this action can be undertaken automatically – a clear safety advantage. Although of course self-driving cars of this nature are more likely to be used in big cities. The ability to secure the scene of an incident in a tailback situation will here gain corresponding importance. In a situation like this, the putting up of a warning triangle by the warning triangle robot, as indeed the erection of a conventional warning triangle, could not only be dangerous but also have no significant effect. The visibility of a warning triangle on the ground is severely restricted by the very limited gaps between the vehicles. The consequence here is that the other road users might only become aware of the hazardous situation when it is already too late, which could lead to further accidents. As a way of compensating for this, the ESF 2019 includes an additional fold-out warning triangle integrated into a roof-mounted module. Complex accidents in which a vehicle suffers several impacts or even in some cases rolls over multiple times can also occur. In a scenario like this, however much it goes against the grain to picture it, there is no guarantee that either the warning triangle robot or the roof warning triangle could be deployed.

### PRE-SAFE® Side Lighting

The level of damage may also be such that we cannot be sure that the hazard lights will even still function. An incident like this can have dramatic consequences. The unlit vehicle involved in the accident could remain unseen by other road users, with the risk that they then fail to brake and run into the unlit obstruction. For cases like these, the ESF 2019 includes an electroluminescent lighting system, known as PRE-SAFE® Side lighting. PRE-SAFE®, since this lighting can also be activated preventively if the vehicle's sensors detect the potentially critical approach of other road users at a junction (Fig. 18).

The emergency lighting is made up of several layers of thin foil, with the electroluminescent material lying between two conductive layers (electrodes), where it is electrically insulated. One electrode is translucent, while the second foil reflects the light. The total thickness of the foil is less than 1 mm. This foil has the advantage that, even if is partially destroyed, the function will remain effective in the undamaged sections. As a result, even after an accident involving a very high level of damage, the vehicle remains visible to other road users, even in the dark.

## Summary

The ESF 2019 from Mercedes-Benz shows that there is still plenty of leverage in the vehicle itself to draw closer to that major goal of "Vision Zero." Topics such as highly automated driving, electric mobility, and connectivity are all addressed here.


**Fig. 18** PRE-SAFE® Side lighting in critical situations

It marks the latest step in a tradition of Experimental Safety Vehicles that dates back to 1971 and uses precisely defined concepts to suggest potential solutions, which are characterized by their growing networking and communication capabilities, new forms of drive systems and complex patterns of user behavior as a consequence of significant changes in individual mobility (Fig. 19).

This research vehicle, with all the innovations it presents, serves as a learning object for engineers, while also being a valuable opinion-forming tool when it comes to devising future measures to enhance vehicle safety. However, it is just as clear that much still needs to be done if we are to prevent serious road accidents altogether.

“Vision Zero,” in other words – in an ideal world – a vision of accident-free driving, remains our guiding principle and not a target that we want to have reached by day X. Perpetual, ongoing effort is going to be needed in order for us to get closer to achieving this vision. The approach of Integral Safety that has been thus shaped by Mercedes-Benz will therefore continue to form the basis of our activities in the interests of robust vehicle safety for many years to come. Accident avoidance and the mitigation of accident severity remain major priorities in this respect, not least because in many accidents, particularly those involving unprotected road users, the “classic” concept of passive safety can only ever offer limited leverage. Exploitation of the pre-accident phase too, however, offers tremendous potential and will in future deliver many crucial

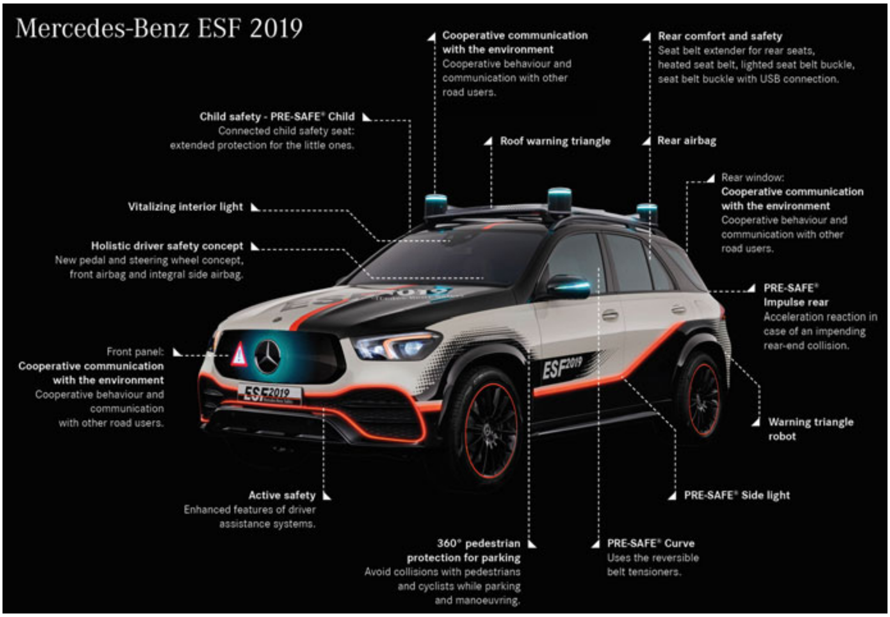


**Fig. 19** Overview of the innovations found in the ESF 2019

contributions to the prevention of accident casualties. Preemptive, proactive PRE-SAFE® systems open up completely new perspectives on this discipline.

Having said that, superlative safety engineering in the vehicles themselves must also win through to prevail in the traffic environment. History shows us that it can sometimes take a very long time before life-saving safety systems, for example ESP or the Windowbag, become widely available. In many cases, an impetus from the legislators is needed to accelerate this process.

Regrettably, as I said at the beginning, not all accidents can be avoided through the possibilities offered by the vehicle alone. Human beings and infrastructure are very often the determining factors. "Vision Zero" will therefore only succeed if all parties involved who have any influence at all on the road traffic accident situation commit themselves to this vision and focus all their efforts on its realization.

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# 25 Consumer Ratings and Their Role in Improving Vehicle Safety

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## Contents



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**Abstract**

Safety ratings for cars, published by New Car Assessment Programmes (NCAPs) around the world, have mobilized consumers and enabled them to make a more intelligent, better-informed buying decision based on a car's crash test performance. Consumer ratings involve comprehensive, objective, and realistic crash testing of cars, and the application of best-practice, consumer-oriented criteria and thresholds to promote safety enhancements beyond the legal requirements. Over time, the New Car Assessment Programmes have tailored their crash tests to focus on real-world priorities in the protection of car occupants and vulnerable road users. They have also successfully incorporated the assessment of new crash avoidance technologies, such as autonomous braking systems, in the ratings. All of this has made NCAP a driving force behind many improvements in the safety of vehicles throughout the world and a key instrument in reaching vision zero.

**Keywords**

NCAP · Consumer ratings · Vehicle safety · Crashworthiness · Crash avoidance · ADAS · Assisted driving

## Introduction

Over the last decades, the improvement of vehicle safety has emerged as one of the most cost-effective and leading strategies to reduce road casualties. Vehicle safety technology accommodates everyday human mistakes: by actively encouraging the driver to adopt safe driving habits; by maintaining control of the vehicle in critical situations; and, in the event of a crash, by reducing injury to occupants and the consequences of those injuries. According to the European Road Safety Observatory report on Vehicle Safety (2018), safety technology "... is fundamental to a Safe System approach which requires safe interaction between users, vehicles, the road environment and prompt access to the emergency medical system. Vehicle design, which takes account of the behavioural and physical limitations of road users and other system risks, can address a range of risk factors and help to reduce accident involvement, accident injury severity and accident injury consequences" (Fig. 1).

By now, safety systems have demonstrated their effectiveness in substantially mitigating injuries from crashes (Broughton 2003) and in preventing crashes. What makes the promotion of safer cars such a compelling proposition for society is that, year in, year out, new safety-enhanced vehicles are coming to the market, substituting older, less safe vehicles on our roads. As best practice activity, and following the recommendations of the Decade of Action's Global Plan for Road Safety 2011–2020 (World Health Organization 2001), many countries have successfully stimulated improvements in vehicle safety, mandating the use of safety systems like seatbelts and child restraints, and actively encouraging the uptake of new technologies.

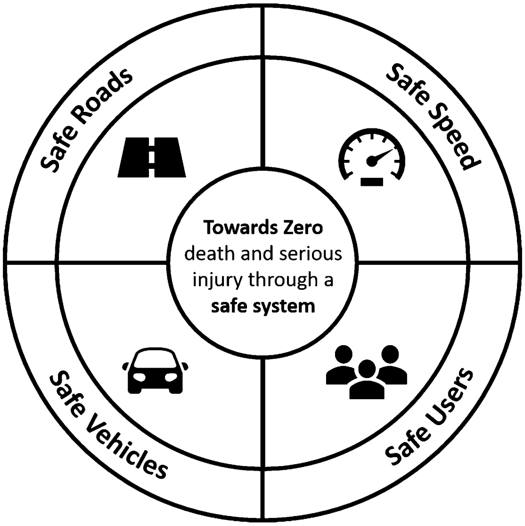


**Fig. 1** Vehicle design contributes to the safety system approach by helping to reduce accident involvement, accident injury severity, and accident injury

Ever since the car became the most popular mode of transport in more developed countries, safety has been a top concern for car buyers and fleet operators. In many nations, regulations have been put in place to establish minimum levels of vehicle safety. Furthermore, consumer information regarding automotive safety has educated the public about safe vehicle design and the differences that exist between specific makes and models and thus influenced the level of safety provided by vehicle manufacturers. Therefore, consumer demand for safer cars has become a catalyst to car manufacturers and governments to improve vehicle safety standards throughout the world.

In 1979, the National Highway Traffic Safety Administration (NHTSA) launched the first New Car Assessment Program (US NCAP) to provide information to consumers on the relative crashworthiness of automobiles (Hershman 2001). The outcome, the first public prospective safety ratings for cars, mobilized consumers and allowed them to make better-informed buying decisions. This in turn incentivized local vehicle manufacturers to innovate and provide safer vehicles at lower prices to attract more customers (Fig. 2).

The success of NHTSA's first safety ratings has since inspired other regions and organizations to develop their own consumer safety rating programs based on the same principle. Over the last 25 years, several official programs have emerged around the world, covering high-income markets such as Japan (Wani et al. 2001), the Republic of Korea (Korea Ministry of Land, Infrastructure and Transport 2014), Australia and New Zealand (Haley and Case 2001), Europe (Hobbs and McDonough 1998), and upper and lower middle-income markets like China, Latin America (Furas and Sandner 2013), and South-East Asia (Anwar Abu Kassim et al. 2013). The insurance industry has also launched its own safety ratings, with the Insurance Institute for Highway Safety (IIHS) (1995) in the USA as its main proponent. More


**Fig. 2** US NCAP safety rating information published by NHTSA is required to be part of the Monroney (automobile price sticker) label

recently, Global NCAP (2015) has introduced the concept to emerging markets, such as India and South Africa, calling for minimum vehicle safety standards across the regions and holding the industry accountable for not adhering to the same ethics everywhere. The level of engagement worldwide and the NCAP activity that is still visible today underlines the importance of consumer vehicle safety ratings to many regional road safety policies and demonstrates that the NCAP approach can be successfully applied to countries with very diverse market conditions and vehicle fleets.

The European New Car Assessment Program (Euro NCAP) was established in 1997 with the aim of providing motoring consumers with a realistic and objective assessment of the safety performance of the most popular cars sold in the European Union (Fig. 3). Euro NCAP is a public-private partnership which operates independently from the European type approval system. At present, the organization has 12 members including the member state governments of the United Kingdom, Germany, France, Sweden, the Netherlands, Luxemburg, and the regional government of Catalonia; the International Automobile Federation FIA; motoring clubs ADAC and ACI; Consumers International; and Thatcham Research, primarily focused on the needs of the motor insurance industry (Van Ratingen et al. 2016). Among all NCAPs, Euro NCAP is considered one of the more established programs and its test and assessment protocols are often referenced by newer programs. The European Commission believes that Euro NCAP has become the single most important mechanism for achieving advances in vehicle safety in the European market (European Road Safety Observatory 2018).


**Fig. 3** Euro NCAP's first launch included safety ratings for seven popular supermini's and raised major concerns about their crashworthiness

## Consumer Safety Ratings as Policy Mechanism

Fortunately, today's modern cars offer more occupant protection and accident avoidance technologies than a typical model from a decade ago. Still, not all cars are equal; clearly some models are better equipped and may perform better in real life than others. The principle behind consumer testing is to reveal the "hidden" differences between cars, so that the potential buyer can take this knowledge into account when purchasing a new car.

Consumer ratings involve comprehensive, objective, and realistic comparative testing of cars and components which have been proven to be important in crashes, applying best-practice, consumer-oriented criteria and thresholds that allow discrimination between models. The results are shared with the public in an easy-to-understand way, often using "stars" to classify levels of performance. In order to stay relevant to the public, NCAPs must evolve over time and focus on new areas of safety and new life-saving technologies entering the market.

Consumer rating programs are essentially a form of "self-regulation." It is important to note that the power of consumer testing comes from its accessibility to non-experts, in its use of open and transparent test methods and simple presentation of results, allowing easy comparison of vehicles' performance. This active dissemination of their findings – online, on social media, in printed magazines, etc. – distinguishes NCAPs from legislative compliance testing, where tests are conducted in secret and results remain undisclosed to the general public. The influence of rating programs comes from their ability to provide the public with an enhanced understanding of the car's performance and bring a competitive advantage to those that perform best in safety testing. Ultimately, the availability and value of vehicle safety in society is determined by a combination of international and national regulation, consumer information, car industry policies, and product liability considerations.

## The Development of NCAP

The roots of many consumer rating programs can be found in regional vehicle crash test legislation. This means that a compliance crash test has been adopted but altered in order to motivate manufacturers to optimize safety performance beyond the minimum legal requirements. To this extent, most NCAP programs have begun crashworthiness testing in frontal impact conditions using Hybrid-III adult crash test dummies (Backaitis 1994) to assess the injury risk.

As vehicles became increasingly better in frontal crash protection, new opportunities for improving safety further were considered. The different objectives, markets, and priorities of various consumer rating programs led to a smorgasbord of new tests that have found their way into consumer rating programs over the last decades. The following will provide you with an overview of the most popular rating tests.

### Vehicle Frontal Crashworthiness

US NCAP's first full-width front barrier test was derived from Federal Motor Vehicle Safety Standard (FMVSS) No. 208 but executed at higher severity compared to the compliance test, in order to raise intrusion and acceleration levels in the occupant compartment (Hershman 2001). Similarly, IIHS, Australasia NCAP, Euro NCAP, and others adopted the moderate offset deformable barrier test (UN/ECE 1995) at a higher impact speed than regulation, alone or in addition to the full-width test. In most instances, the biomechanical injury criteria (HIC, chest accelerations, etc.) are not unlike those applied for regulation testing, but more demanding limits or additional requirements are often set. As a result, a car which barely meets legal requirements is likely to be limited to a one- or zero-star rating by NCAP.

The above approach of basing consumer ratings on compliance testing has allowed standards in occupant protection to evolve at a fast pace. In Europe, the start of Euro NCAP testing coincided with the full implementation date of directives for frontal and side vehicle impact (96/79/EC and 96/27/EC, respectively). From 1997 onwards, new batches of test results were launched about twice each year, sometimes during public car exhibition events (Fig. 4).

Soon car manufacturers, setting aside their initial reservations, started to sponsor the testing of their own cars. As new car models replaced those already tested, the improvements in occupant protection over and beyond the legal requirements, such as reinforced cabin structurers, driver and passenger airbags, and seat belt load limiters and seat belt retractors, could be clearly observed (Hobbs and McDonough 1998).

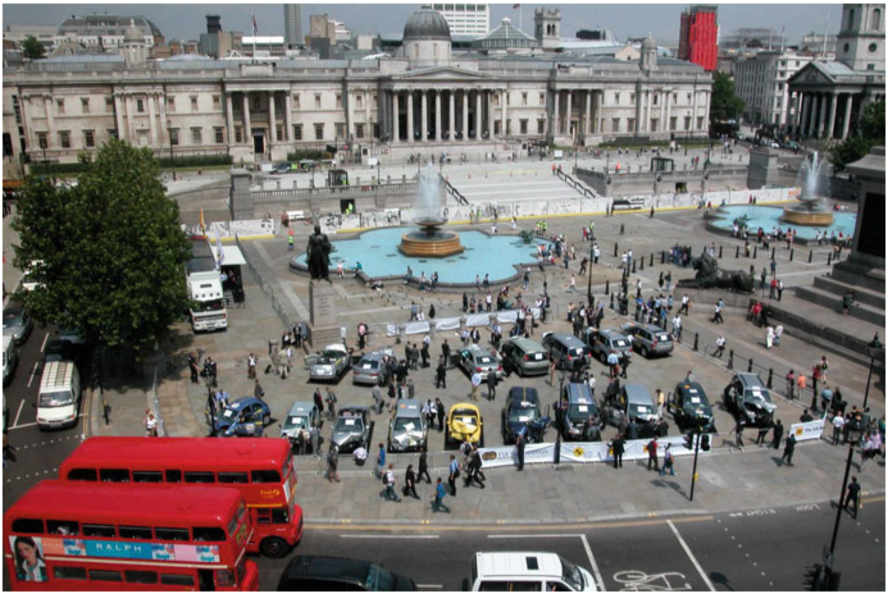


**Fig. 4** Between 2000 and 2005, Euro NCAP exhibited crashed cars at public squares across several cities in Europe to raise awareness about vehicle safety among consumers

Following the success of the first five-star rating for the Renault Laguna in 2001, manufacturers increasingly saw this as the goal for all their new models for the European market.

However, success does not always come easy. Latin America is one of the world's worst performing regions with an annual road fatality rate of 17 deaths per 100,000 individuals, almost double the average rate registered for high-income countries (World Health Organization 2013). When Latin NCAP was first launched in South America in 2010, many models failed to meet the frontal impact test requirements, despite being produced by manufacturers who were routinely achieving five-star ratings in Europe and elsewhere. Cars which were ostensibly the same, often carrying the same name, were made to very different standards and were very differently equipped, in different parts of the world. Since then, visible progress has been made yet zero-star results are no exception. The program is still searching for the broad industry engagement that is needed to improve vehicle safety as the governments responsible have so far been unable to agree on realistic minimum safety requirements for the region. This reminds us of an important lesson: that consumer information works best when complementing regulation but cannot, and should not, replace it.

Since the early 1980s, improvements in frontal crashworthiness claim to have reduced the risk of death and serious injury for car occupants by half or more. For instance, IIHS reported a 46% lower risk in death and injury in head on crashes for good versus poor rated cars (HLDI 2019). Frampton et al. (2002) analyzed real-world collisions and medical records from injured drivers and identified significant reductions for serious and fatal injuries in new cars in frontal impacts. They attributed the observed improvement in injury levels to improvements in crashworthiness and the introduction of vehicles with airbags and more effective restraints. Comparing the fatality risk for car passenger in collisions with other cars, Folksam (Kullgren 2017) estimated that cars introduced in the period 1996–2004 had a 43% less risk than those launched in period 1985–1995. This risk has further reduced to 86% for the latest generation of cars, introduced between 2005 and 2014.

Even after many years of testing, the full-width and moderate offset frontal crash tests speak to the imagination of consumers and for this reason remain important tests for many NCAPs today. Despite this, frontal impacts are still the most common type of crash resulting in fatalities and this has driven an obvious interest in further improving frontal crash protection among NCAPs. Small overlap frontal crashes primarily affect a vehicle's outer edges, which are not well protected by the traditional crush-zone structures. The IIHS small overlap (SO) frontal crash test (Sherwood et al. 2013) is primarily a test that drives structural countermeasures although it may also be a challenge for some belt restraint and airbag designs because of the higher oblique loading component. Vehicle manufactures have responded by strengthening the occupant compartment, adding new structures to engage the barrier and creating an additional load path for crash forces (Fig. 5).

Other notable upgrade to frontal crash testing is the adoption of the advanced Test Device for Human Occupant Restraint THOR-M mid-sized male crash test dummy (Ridella and Parent 2011; Parent et al. 2013) and biomechanical injury criteria in two new test procedures: the moving deformable barrier (OMDB) test procedure for evaluating small overlap and oblique crashes (Saunders et al. 2011), announced by NHTSA (National Highway Traffic Safety Administration 2015) and Euro NCAP's

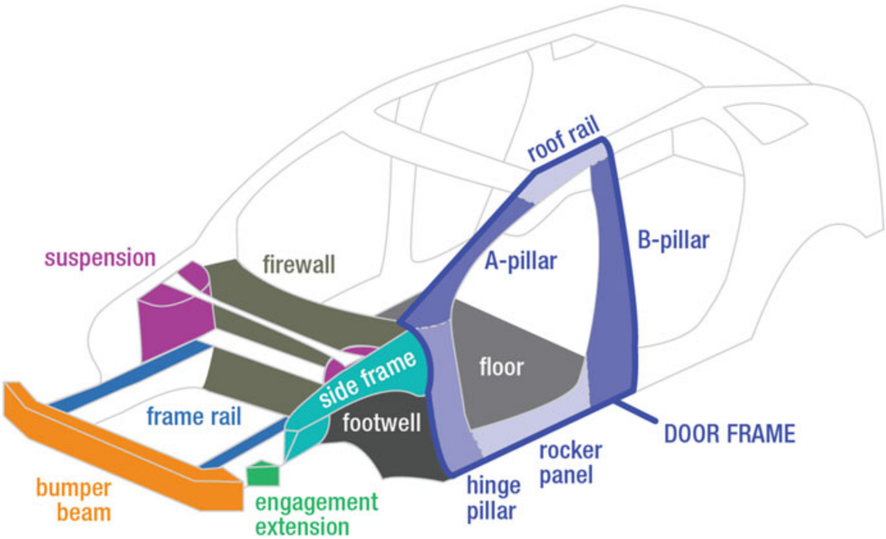


**Fig. 5** Areas modified for small overlap performance. Not pictured: door beam, seat mount, wheel, steering column. From: Insurance Institute for Highway Safety. Status Report, Vol. 49, No. 11

mobile progressive deformable barrier (MPDB) test for vehicle compatibility evaluation introduced in 2020 (Sandner and Ratzek 2015; Sandner et al. 2019).

## Encouraging Side Impact Protection

In most developed markets, side crashes account for about a quarter of passenger vehicle occupant fatalities and a more sizeable 40% of serious injury crashes. In the mid-1990s, vehicle makers started to install side airbags and strengthen the structures of vehicles to prevent ejection and provide a survivable occupant environment. Around the same time, moving deformable barrier and side pole crash tests were introduced in consumer rating programs to verify the effectiveness of these measures, to drive market installation rates, and promote further innovation.

NHTSA began testing passenger cars in side impact in NCAP in 1997 (Hershman 2001). The US NCAP side impact – a 90-degree side impact in which a moving deformable barrier, crabbed at 27 degrees, strikes a stationary vehicle - is taken from FMVSS No. 214 but run at approximately 62 km/h, 8 km/h higher speed than in the compliance test. In Europe, Australia, and Asia, side impact barrier tests are also performed but follow the perpendicular (non-crabbed) test configuration of the UN/ECE standard (UN/ECE 1995) at speeds ranging from 50 to 55 km/h. However, as head impact does not regularly occur in the barrier test, some have adopted an additional pole test to assess the benefit of head protecting airbags for side impact. In the USA, IIHS was concerned that these tests still did not completely capture the types of crashes likely to occur in the real world with SUVs and pickups. In 2003 the Institute initiated its own test with a different barrier – one with the height and shape of the front end of a typical SUV – and a new small female dummy, SID-IIs (Insurance Institute for Highway Safety 2017).

Since then, the various tests underpinning the side impact crash ratings around the world have continued to evolve. More recent developments include the application of an oblique pole test by US NCAP and Euro NCAP, among others; the adoption of the advanced WorldSID mid-sized male dummy (Scherer and Cesari 2001); the Advanced European Mobile Deformable Barrier (AE-MDB) (Ellway et al. 2013); an assessment of the head protection device extended to rear seats by JNCAP and Euro NCAP, and the application of far-side impact testing (Ellway et al. 2019).

The focus on improving side impact protection has delivered real benefits. IIHS estimated that the overall effectiveness of side impact protection measures, particularly side airbags and curtains, was a 45% fatality reduction for drivers of cars with head-protecting side airbags, and 11% reduction with torso-only side airbags (Insurance Institute for Highway Safety 2003). NHTSA showed statistically significant fatality reductions between 8% and 31% for four types of curtain and side airbags in near-side impacts for drivers and right-front passengers of cars and LTV (National Highway Traffic Safety Administration 2014). Folksam and Chalmers also reported a significant reduction in the injury risk in side impact for near-side occupants based on an analysis of STRADA (Swedish Traffic Accident Data Acquisition) data (Stigson and Kullgren 2011).

## Forgiving Vehicle Front-End Designs for Pedestrians and Cyclists

According to the World Health Organization, over a third of road traffic deaths in low- and middle-income countries are among vulnerable road users (World Health Organization 2013). In high-income countries, pedestrian motor vehicle crash fatalities have decreased over the last decades but still account for 15–20% of crash deaths. The pedestrian protection subsystem tests, developed and validated by the European Enhanced Vehicle safety Committee (EEVC 2003), have been the basis for testing and assessment protocols by Euro NCAP, Australasian NCAP, Japan NCAP, as well as UN regulation. These tests, which evaluate the aggressiveness of vehicle front-ends in car-to-pedestrian impacts, comprise the legform to hood test, the upper legform to bonnet leading edge test, and the headform to bonnet top test, each with its own impactor, impact conditions, and criteria.

Car front-end structures initially improved only gradually as the vehicle industry resisted expensive engineering solutions and requirements that could compromise vehicle styling. The test method was also criticized for a lack of reproducibility, resulting from test point selection and poor test tool repeatability. In 2009, Euro NCAP addressed the lack of progress by introducing a new rating system that required minimum performance in pedestrian testing in order to achieve an acceptable star rating. It also solved the main concerns about the test procedures by various updates (Zander et al. 2015) and the adoption of improved impactor devices, such as ACEA head forms and the JARI Flex Pedestrian Leg Impactor (Konosu and Tanahashi 2005). The proportion of vehicles offering good pedestrian protection has since noticeably improved.

The inclusion of pedestrian subsystem testing in consumer ratings has brought about more pedestrian-friendly designs and has triggered new innovations such as “pop-up” or deployable bonnet technology. In the latter case, an extension to the subsystem test procedure was needed to evaluate the robustness and effectiveness of the deployable device itself. The method features sensor activation tests carried out with a special PDI2 legform (Concept® Technologie 2015) to check system responsiveness to pedestrians of various sizes, and numerical simulations using “certified” human models (Klug et al. 2017) to verify that deployment occurs before the head contacts the bonnet. This experimental-numerical method is the first of its kind in consumer testing.

A significant correlation between pedestrian subsystem scores and injury outcome was reported by Pastor using German National Accident Records from 2009 to 2011 (Pastor 2013). Comparing a vehicle scoring 5 points and a vehicle scoring 22 points, pedestrians’ conditional probability of getting fatally injured was reduced by 35% (from 0.58% to 0.37%) for the latter. Strandroth et al. (2013) also showed a significant reduction of injury severity for cars with better pedestrian scoring. The reduction of Risk of Serious Consequences (RSC) for medium-performing cars in comparison with low-performing cars was 17, 26, and 38% for 1, 5, and 10% of medical impairment, respectively. These results applied only to urban areas with speed limits up to 50 km/h, suggesting that in order to reduce injuries at higher impact speeds, other types of countermeasures should be considered.

## Mitigating Rollover and Loss of Control Crashes

The 1990s and early-2000s saw the sales of Sport Utility Vehicles (SUV) and pickup trucks surge in the North America and Australia. These vehicles, with high centers of gravity, have an inherently greater risk of rolling over and, with such crashes causing some 10,000 fatalities annually in the USA by the start of the new millennium, it was not long before this accident type became a key priority. In 2001, NHTSA added a new test for rollover resistance assessment to their rating system using a "Static Stability Factor" (SSF), based on a vehicle's measured static properties. The US NCAP rollover resistance rating was later amended to include the results of a dynamic vehicle test in addition to the SSF (Hershman 2001). In 2009, the IIHS began testing the roof strength of vehicles, to ensure that the roof can maintain the occupant survival space when it hits the ground during a rollover (Insurance Institute for Highway Safety 2012). Today, consumer information on rollover resistance remains largely a North American phenomenon. A notable exception is Korean NCAP which adopted the dynamic rollover assessment in 2004 and since published a Driving Stability Rating based on rollover and braking tests (Korea Ministry of Land, Infrastructure and Transport 2014).

Another effective countermeasure to avoid the cause of many rollovers, especially fatal single-vehicle ones, is Electronic Stability Control (ESC), an electronic system that improves a vehicle's stability by detecting and reducing loss of traction. When ESC detects loss of steering control, it automatically applies the brakes to help "steer" the vehicle where the driver intends to go. ESC, or Electronic Stability Program (ESP) as it was better known at the time, made its breakthrough after the "flip over" crisis of the Mercedes-Benz A-Class in 1997, that generated widespread consumer interest. In the years that followed, several studies confirmed that ESC is highly effective in reducing single-vehicle crashes (Lie et al. 2004; Thomas 2006; Farmer 2010) bringing the anti-skid technology further into the focus. Installation of ESC equipment was successfully promoted by the international Choose ESC! campaign (Fig. 6), supported by the FIA Foundation, the European Commission, and others (2007). The technology was adopted in several rating programs, such as Australasian NCAP, US NCAP, and Euro NCAP, before it became mandatory for all passenger cars and light trucks in their respective markets. ESC remains an important condition for five stars in Latin and ASEAN NCAP and for other emerging markets, where this technology is still not mandated.

## Promoting Seat Belt Usage

As protection for belt wearers improved, accident data increasingly showed that a higher proportion of seriously and fatally injured casualties were not wearing their seat belts (Frampton et al. 2006). To improve this situation, Euro NCAP (2003) first developed a protocol to encourage the fitment of Intelligent Seat Belt Reminders (SBR). Research had shown that most non-wearers could be persuaded to use their seat belt if they were given a suitable reminder. Although simple reminders have


**Fig. 6** Left: The Choose ESC! campaign organized test drives and demonstration events around to world to promote ESC. Right: Euro NCAP added an ESC test in 2011

been available for many years, intelligent systems can be much more effective: almost unnoticed by belt wearers but increasingly aggressive and demanding for those who do not “buckle up.”

For front seats, Euro NCAP requires a “final (reminder) signal,” which must be audio-visual and must be presented at the latest 60 s after the engine start, after 500 m of vehicle travel or speeds above 25 km/h. The final signal must last for a minimum of 90 s and consist of a “loud and clear” audible signal and a visual indicator. For rear seats, Euro NCAP requires a “start signal,” which may be visual only. For all seats, if a change in belt status occurs at speeds above 25 km/h, i.e., a belt gets unbuckled, an immediate audible signal must be given. The Euro NCAP protocol recommends occupant detection on the rear seats but does not require it.

Since 2003, Euro NCAP and Australasian NCAP rating systems have encouraged front and rear SBR by awarding points that count towards the overall score or, more recently, the Safety Assist component of the rating system. Thanks to this incentive, most light vehicles in these regions offered SBR for all seats ahead of regulation. From September 2019, UN/ECE regulation UN R16.07 requires seatbelt reminder systems in all front and rear seats on new cars.

When Japan NCAP introduced an overall rating scheme in 2011, SBR points became part of the evaluation. It also includes a reward for advanced seat belt reminders on the rear seats: additional points can be scored if the rear SBR alert includes an audible warning of at least 30 s. Such a warning, however, can only be triggered if passenger presence information is available (Mousel et al. 2015). Several other NCAPs, such as Korean, China, ASEAN, and Latin NCAP have included incentives for the SBR systems into their rating. From September 2019, the United Nations Economic Commission for Europe (UN ECE) Regulation No. 16 on safety belts and restraint systems requires mandatory fitment of safety belt reminder systems to the driver’s seat and to any other seating positions in the same row as the driver’s seat for all M and N category vehicles.

Lie et al. (2008) conducted an extensive study into the effect of enhanced SBR in six European countries. This study concludes that seat belt reminders fulfilling Euro NCAP's SBR protocol significantly increase seat belt use in daily traffic: around 80% of drivers who do not wear a seat belt in cars with no reminder do so in cars equipped with a system that has a visual signal and an associated loud and clear sound signal.

## Safe Transport of Children

Many high- and middle-income countries require the use of approved child restraint systems (CRS) for infants and children, meeting specific criteria for certain age or size groups, even though the exact requirements in each country, region, or state may vary considerably. Especially in developed nations, child fatalities in motor vehicle crashes have steadily declined over the last decades, thanks to these laws and greater consumer awareness. However, vehicle crashes remain a leading cause of death and disability for children and young adults in many parts of the world today.

Safe transport of children in cars is the joint responsibility of parents, child restraint suppliers, and vehicle manufacturers. Responsible parents and caregivers must ensure that children are properly restrained in a correctly installed child restraint system that is appropriate for the size and weight of the child. Child restraint suppliers make certain their products meet (or go beyond) local regulations, offer adequate protection, and can be fitted easily and correctly in all cars. Finally, it is the vehicle manufacturers' obligation to guarantee that children are as well protected as adults in the event of crash and that special any provisions needed for children are offered as standard.

In practice, this joint responsibility leads to a set of complex interactions and a patchwork of solutions that make it difficult for average consumers to know how their child is carried in the best and most safe way. There exist several child seat consumer rating programs worldwide aiming to guide consumers into buying the best seat for their child. Organizations such as Consumer Reports in the USA (2019), China Automotive Technology Research Centre (2019) and collaborative programs, like the European Testing Consortium (Van Ratingen et al. 2019) (Fig. 7), Australian Child Restraint Evaluation Program (Suratno et al. 2007), and the Latin American Child Restraint Systems Evaluation Programme PESRI (2017), are regularly testing new child restraints for crash performance, ease of use, and how they fit into vehicles. These benchmarking tests have become powerful means to drive improvements in CRS design, as a good consumer rating is a must for child seat manufacturers to be successful in the market.

There are also many aspects of child protection which cannot be influenced by the child restraint manufacturer alone, but which require action on the part of the car manufacturer as well. In 2003, Euro NCAP introduced a child occupant star rating, specifically addressing the vehicle design and equipment for safe transport of children. The rating was based on the protection offered in the front and side crash

**Fig. 7** Side impact test setup used a.o. by the European Testing Consortium to evaluate the protection offered by Child Restraint Systems

tests to a 3-year-old and 18-month-old child seated on the rear seat in a restraint of the type recommended by the car manufacturer. The assessment was complemented with other incentives with regards to communication (handbook instructions, information at dealerships, warning labels, etc.), an assessment of the ease of child seat installation, and availability of easy-to-use ISOFIX attachments and other relevant equipment, such as a front passenger airbag deactivation switch. Between 2013 and 2016, Euro NCAP introduced several updates to the child occupant assessment rating including a Child Restraint System Installation check, new incentives for iSize compliant seating positions, and the use of Q6 and Q10 child dummies in crash tests (Van Ratingen et al. 2019).

Among all NCAP programs, a similar assessment of child safety, based on different child dummies seated in child restraint systems in the rear, has been adopted by Australasian NCAP, ASEAN, and Latin NCAP. China NCAP introduced child safety assessment in full frontal 50 km/h rigid barrier test from 2010 (Hu et al. 2011). For the China NCAP 50 km/h full-width test, a P3 child dummy is positioned in the vehicle outboard rear seat, but in the opposite side, a Hybrid III small female dummy is positioned. The IIHS does not use child dummies in their front and side crash testing – a small adult female dummy, comparable in size to a 10-year-old child, is placed on the rear seat for the side impact test – but its LATCH ease-of-use ratings (Insurance Institute for Highway Safety 2015) are an indicator of how easy it is to achieve a correct, tight installation of a child restraint in a given vehicle when using the dedicated child restraint attachment hardware.

The use of child safety seats and improved car measures have been shown to reduce infant deaths in cars by approximately 71% and deaths to small children by 54% (National Highway Traffic Safety Administration 2002). Especially rearward-facing systems have demonstrated to reduce injuries between 90% and 95%, while forward-facing systems have been shown to have an injury reducing effect of approximately 60% (Tingvall 1987). Therefore, in countries where the usage rate is low, are to increase the use of child restraint systems and to provide adequate information about how they are correctly used in the vehicle in order to avoid misuse.

## Whiplash Prevention

Whiplash-associated disorder remains the most frequently reported injury in insurance claims across many high-income countries. As whiplash injury to the neck often leads to long-term impairment, with 10% of people suffering long-term discomfort and 1% permanent disability, addressing "whiplash" neck injuries, understanding the cause and how to prevent the injury has been an important priority for the auto insurance industry and governmental bodies.

Whiplash may occur in all impact directions, but the injury is most frequently observed, and its risk most effectively addressed, in rear-end impacts. For this injury type, no biomechanically based vehicle safety regulations exist, mainly because of the limited (or inconclusive) knowledge available about the exact injury mechanism. However, research has demonstrated that, in the event of a rear-end collision, the vehicle seat and head restraint are the principal means of reducing neck injury (Farmer et al. 2003).

Starting from the assumption that lowering loads on the neck lessens the likelihood of whiplash injury, the first stand-alone consumer tests for seats and head restraints were developed by Folksam and the Swedish Road Administration (SRA) (Krafft et al. 2004) and the International Insurance Whiplash Prevention Group (IIWPG) of the Research Council for Automobile Repairs (RCAR 2006). Both initiatives used car seats mounted on a sled to evaluate and rate the ability of seats and head restraints to prevent neck injury in moderate- and low-speed rear-end crashes. Measurements were taken from the BioRID II dummy, an anthropomorphic test device with a flexible spine (Davidsson et al. 1998), which, in the case of IIWPG, were combined with an evaluation of the head restraint geometry. However, the tests adopted different philosophies with regards to relevant seat performance parameters, one putting heavy emphasis on real-world validation (IIWPG), the other using plausible hypotheses regarding the causes of whiplash injury (SRA).

IIHS has been publishing ratings of head restraint geometry since 1995 and has been rating head restraint systems since 2004 using a combination of their static measurement procedure and the IIWPG developed "single-pulse" dynamic sled test procedure. Between 2003 and 2008, the German Automobile club also published whiplash ratings. The ADAC test procedure was similar to the IIWPG test procedure but with an additional sled test and seat stability test (Lorenz and Sferco 2004).


**Fig. 8** Typical whiplash seat sled test setup with the BioRID-II dummy, used by many NCAPs around the world including IIHS, Euro NCAP, JNCAP, and China NCAP

Australasian NCAP began publishing head restraint geometry ratings to the IIWPG protocol in 1997 and added the dynamic test in 2012. Also, Korean NCAP and China NCAP adopted a dynamic test based on the IIPWG pulse during the late 2000s (Fig. 8).

In 2008, Euro NCAP launched its first series of results of (front) seat testing based on its own geometric and “three pulses” dynamic sled test procedure, which combined aspects of the IIWPG, Folksam/SRA, and ADAC methods (Van Ratingen et al. 2009). In 2014, the Euro NCAP’s geometric assessment procedure was extended to include rear seats. Japan NCAP has conducted similar assessments of seats in Japan using different injury criteria and pulses starting from 2010 onwards (JNCAP 2014).

Kullgren et al. (2015) carried out an evaluation of the effectiveness of Euro NCAP, Japan NCAP, and IIHS whiplash protocols, respectively, using real-world crash data. Three analyses were undertaken comprising an analysis of test outcome data, a logistic regression analysis, a receiver operating characteristic (ROC) analysis, and a correlation analysis comparing crash and injury outcome. Correlations between the test scenarios of each of the three protocols – as well as the outcome associations with crash outcomes – suggested consistent improvements in the risk of permanent medical impairment. Encouraged by the positive impact of whiplash seat testing around the world, amendments to Global Technical Regulation on Head Restraints No. 7 to address minor whiplash injuries were finally agreed in 2019.

## The Advent of Crash Avoidance

By the mid-2000s, crashworthiness ratings had been in common use around the world for a decade or more and the industry's efforts to deliver increasingly safer cars had resulted in many five stars successes. But while this represented a significant step forwards for consumer protection, concerns started to rise over the future direction and the message that the programs continued to deliver.

The key reason behind these concerns was the emergence on the market of a new category of safety technologies designed to automatically intervene in critical, near-crash situations and assist the driver in driving safely, the so-called Advanced Driver Assistance Systems (ADAS). Several car manufacturers have made their commitment to active safety clear, among them Daimler, but also Volvo, which was among the first to offer a collision mitigation system as a standard installation in a consumer vehicle. Yet, crash avoidance and ADAS technology was largely overlooked by consumer rating programs at this time (with the notable exception of Electronic Stability Control, which was encouraged by several NCAPs in the late 2000s).

The industry's shift from passive to active safety initially put the NCAPs on the backfoot as they grappled with the wide variety of new systems and functionalities entering the market and the lack of suitable, "regulation-quality" performance tests for these new systems. To make matters worse, only a few systems were offered as standard and the uptake of optional systems in the fleet was generally low. This seriously challenged the ability of NCAPs to quickly identify and confirm (based on real-world evidence) those technologies that delivered a true benefit to the consumer and to society. Consequently, the risk grew that the consumer ratings were becoming less relevant in the eyes of the public and the industry.

From 2012 onwards, NCAP's and the regulator's focus on ADAS has accelerated, and spearheaded by NHTSA, IIHS, and Euro NCAP, vehicles have been increasingly credited for offering certain recommended advanced technologies. This has educated drivers about how these systems operate and helped change the consumer's perspective on ADAS from "great gadgets" to "must have" technology.

## Autonomous Emergency Braking

Autonomous Emergency Braking (AEB) is without doubt the most important active safety technology that has emerged since ESC. Using sensors such as radar, lasers, and cameras to identify other vehicles or other road users, AEB automatically applies the brakes if the driver does not respond in time, to avoid or mitigate a collision, saving countless lives, injuries, and inconvenience. Systems are most effective at lower speeds (<40 km/h) where more than 75% of rear-end crashes occur, but they are also valuable in mitigating the devastating effects of higher speed crashes by reducing impact speeds, if a crash cannot be avoided.

AEB, or Crash Imminent Braking (CIB), was one of the technologies covered under the Crash Avoidance Metrics Partnership (CAMP) (National Highway Traffic Safety Administration 2002) between NHTSA and the American auto industry.

CAMP was established in the mid-1990s to accelerate the implementation of crash avoidance countermeasures in passenger cars. Based on the groundwork by CAMP and their own research activities, NHTSA began recommending Forward collision warning (FCW) systems to consumers starting with the 2011 model year. NHTSA recently announced that it would include AEB systems (crash imminent braking and dynamic brake support) as a recommended technology and test such systems starting with model year 2018 vehicles (National Highway Traffic Safety Administration 2015).

Within Europe, four main initiatives have actively contributed to development of test procedures for assessing AEB and forward collision warning systems for car-to-car crashes. ADAC, with support from automotive suppliers Continental and Bosch, developed a standardized inflatable vehicle test target (Sandner 2013) in order to perform a comparative test of AEB systems on high-end vehicles. The RCAR Autonomous Emergency Braking group (Hulshof et al. 2013), led by Thatcham Research, designed a testing and (insurance) rating approach for AEB systems. The European Commission sponsored research project ASSESS (Assessment of Integrated Vehicle Safety Systems for improved vehicle safety) (European Commission 2009) and the German initiative led by DEKRA, called Advanced Forward-Looking Safety Systems (vFSS) (Berg et al. 2011), had similar project goals: to develop harmonized and standardized assessment procedures and related tools for selected integrated safety systems. Based on the outcome of these research projects, Euro NCAP adopted both low-speed and high-speed AEB systems in the rating scheme in 2014. In 2016, the first AEB pedestrian test was added to provide an incentive for systems with advanced detection capabilities (Grover et al. 2015), followed by AEB cyclist test in 2018 (Euro NCAP 2018), see Fig. 9.

The low-speed "AEB City" test also became an RCAR standard and is similar to the Insurance Institute for Highway Safety Autonomous Emergency Braking Test. Forward collision warning systems (FCWS) have been tested by KNCAP from 2016 onwards. China NCAP has adopted an AEB test protocol in its suite of tests beginning from 2018 and Australasian NCAP aligned with Euro NCAP for AEB and other active safety tests in the same year. Finally, Latin NCAP has announced its plan to evaluate AEB systems from 2020 onwards.

The IIHS states that (low speed) "AEB systems can reduce auto insurance injury claims by as much as 35 percent" (Insurance Institute for Highway Safety 2015). Euro NCAP, with support of the Australasian NCAP, studied the effectiveness of the low-speed AEB systems promoted through the rating scheme since 2014, and showed that low-speed AEB technology leads to a 38% reduction in real-world rear-end crashes, with no significant difference between urban and rural crash benefits (Fildes et al. 2015).

## Lane Support Systems

Lane support technologies, such as Lane Departure Warning (LDW) and Lane Keep Assist (LKA), are designed to address single-vehicle run-off-road and head-on crashes. The IIHS (Farmer 2008), NHTSA (Barickman et al. 2007), and others (Scanlon et al.

**Fig. 9** Autonomous Emergency Braking tests for vulnerable road users were first introduced in 2016 for pedestrians and in 2018 for cyclists

2015) have studied the potential of these crash avoidance technologies and have estimated big fatal crash reductions. However, current lane support systems often are still not well accepted by consumers, mainly because warning systems are perceived as annoying and unreliable. Perhaps for this reason, clear evidence that lane support technology is delivering on its promise has been slow to emerge. A positive indication has recently come out from field data in Sweden (Sternlund et al. 2016), suggesting LDW/LKA systems are reducing head-on and single-vehicle injury by up to 53%. Also, IIHS has lately found positive, albeit more modest, benefits (Cicchino 2018).

To improve the performance of these systems, US NCAP and Euro NCAP have introduced incentives as part of their respective consumer rating programs. The technology is tested in a straightforward manner by steering the LDW or LKA equipped vehicle slowly towards a solid or dashed line, thus triggering a warning or intervention. While NHTSA's test can be performed by a driver, Euro NCAP's test protocol requires path accuracy that can only be performed by driving robots that can also be used for AEB testing.

Recently, more intuitive, intelligent, and integrated systems are entering to the market that can avoid unintended road departures and critical overtaking lane change maneuvers, based on an assessment of threat (Emergency Lane Keeping). The latest Euro NCAP protocols have taken this development into account (Grover and Avery 2017). Besides NHTSA, Euro NCAP, and Australian NCAP, KNCAP has included LKA systems in the rating, while Latin NCAP has announced lane support system testing from 2020 onwards. ASEAN NCAP instead has given priority to Blind Spot Detection, which it sees as key enabler to reduce crashes between cars and powered-two-wheelers (Malaysian Institute of Road Safety Research 2018).

## Speed Assistance Systems

Excessive speed is a factor in the causation and severity of many road crashes. In fact, it has a greater effect on the number of accidents and injury severity than almost all other known risk factors. Speed restrictions are intended to promote safe operation of the road network by keeping traffic speeds below the maximum that is appropriate for a given traffic environment. Voluntary speed assistance systems (SAS) are a means to assist drivers to adhere to speed limits, by warning and/or effectively limiting the speed of the vehicle. The only technical requirements for such devices are laid down in United Nations Regulation No. 89 “Speed Limitation Devices,” which is not mandatory in Europe and does not specifically apply to M1 passenger cars.

Starting from 2009, Euro NCAP has rewarded manually set and driver advised speed limitation devices which meet the basic requirements of United Nations Regulation No. 89 but have additional functionality with regards to the warnings given and the ability to be set-at-speed. By doing so, Euro NCAP has created a first incentive to manufacturers to promote such speed-limitation devices, to make them available on more models and to fit them as standard equipment (Schram et al. 2013). Around 90% of vehicles achieving a five-star rating from Euro NCAP in recent years have a speed-limitation device, usually in combination with a cruise control system.

Recently, more advanced speed assistance systems have been introduced onto the market which are able to inform the driver of the speed limit at the vehicle’s current position, based on digital speed maps and/or traffic sign recognition. The Euro NCAP rating system also encourages these speed limit information functions (SLIF). Although there are still limitations to these technologies, intelligent speed assistance systems that combine speed limit information and (over-rideable) speed-limitation, have much greater potential and will be more readily acceptable to the public. As a result, Euro NCAP extended the speed assistance protocol in 2013 to include the latest generation of Intelligent Speed Assistance (ISA) systems.

In 2019, the European Parliament has given the green light to new minimum EU vehicle safety requirements that will come into force from 2022, including over-ridable Intelligent Speed Assistance for passenger cars, vans, and buses (European Parliament 2019). The availability and popularity of Speed Assistance systems in other regions is still lagging, despite excess speed being one of the leading causes for crashes worldwide. Australian NCAP, KNCAP, C-NCAP, and Latin NCAP are promoting the technology as part of the safety rating to improve update in the market.

## Combining Passive and Active Safety

NCAPs have been successfully promoting many different vehicle safety technologies as part of their programs but as more tests have been included, it also has become more difficult for consumers to understand and digest the ratings. Several approaches were adopted to deal with the situation of emerging advanced technology in the respective rating systems. In US NCAP, vehicles earn ratings of 1–5 stars in frontal crash and side crash performance, as well as in rollover resistance. Since 2011, vehicles also earn an Overall Vehicle Score rating, which indicates how the individual 5-Star Safety Ratings combine to reflect a vehicle's overall safety. NHTSA has utilized NCAP to encourage automakers to add advanced safety features on a voluntary basis and recently began evaluating which ADAS technologies might potentially be included in the near future. Today, the US NCAP checklist includes forward collision warning, lane departure warning, and backup cameras (followed by Autonomous Emergency Braking technology as of MY 2018 models). The checklist gives consumers a quick and easy way to compare the availability of safety features across models although fitment does not affect the star rating.

In 2009, Euro NCAP changed from three individual crash ratings to a single overall safety rating with a maximum of five stars. This overall rating combined the results of assessments in four areas: adult protection, child protection, pedestrian protection, and the new area of safety assist technology. The underlying tests included the full-scale frontal offset, side-impact barrier and pole tests carried over from the previous adult and child protection ratings, the seat tests for whiplash prevention in rear-end crashes and front-end component tests for pedestrian protection. The assessment of Intelligent Seat Belt Reminders was complemented with that of Speed Assistance Systems and Electronic Stability Control as part of Safety Assist. In each area of assessment, scores were calculated as a percentage of the maximum points available and a weighted sum of these scores indicated the car's overall all-round performance. The testing of low and higher speed Autonomous Emergency Braking as well as Lane Support systems was added in 2014. The latest update of the Euro NCAP rating is the addition of Autonomous Emergency Braking technology for pedestrians and pedal cyclists.

Other NCAPs responded with changes to the rating systems, which sit in between the "encompass all" approach of Euro NCAP and the advisory approach of US NCAP. For example, to qualify for IIHS's Top Safety Pick, a vehicle must earn good ratings in five crashworthiness tests – small overlap front, moderate overlap front, side, roof strength, and head restraints – as well as a basic rating for front crash prevention, its low-speed Autonomous Emergency Braking technology test. To qualify for Top Safety Pick+, a vehicle must earn good ratings in the five crashworthiness tests, an advanced or superior rating for front crash prevention and a good headlight rating.

Until recently, the Australasian NCAP star rating was based on the vehicle's performance in frontal offset, side barrier, and pole crash tests, as well as pedestrian and whiplash tests. To earn five stars, it also required key features such as SBR on front and rear fixed seats, head protecting technology (curtain bags) for front and rear seat, three-point seat belts for all forward-facing seats and ESC. This scheme was extended with a "tick-box" approach, based on a menu of Safety Assist Technologies (referred to as "additional SAT"), that included many potential technologies. In 2018, Australasian NCAP aligned their tests, criteria, and rating scheme with Euro NCAP, apart from minor differences due to local regulations.

Almost all major NCAP programs have recently introduced rating changes to accommodate the testing of avoidance systems. China NCAP has begun AEB testing as part of their star rating. Other NCAPs like Korean, Japan NCAP, Latin and ASEAN NCAP have moved to an overall rating system and/or are in the process of making changes to accommodate more crash avoidance technologies. Finally, NHTSA is considering a new approach to determining a vehicle's overall five-star rating that may, for the first time, incorporate advanced crash avoidance technology features, along with ratings for crashworthiness and pedestrian protection.

## Consumer Information in the Era of Automation

The idea of assisted driving, automated driving, and self-driving cars has been widely aired in technical discussions and in media coverage over the last years. The rapid development of electronic safety systems and communication over the air has made the concept possible and the first cars have come onto the market, which are able, with driver oversight, to "drive" themselves in controlled situations. The established vehicle industry is active in this field but also new players, such as Waymo, Zoox, UBER, Lyft, etc., are trialling self-driving cars. There is no doubt that greater automation will lead to a revolution in safety, putting it above all other requirements and characteristics of a car. Not only will the self-driving car have the technology to sense, avoid, and mitigate in potential crash scenarios, it will also drive in a safer manner. Besides that, the vehicle must always carry the safety elements and technologies to intervene and protect the occupants when necessary (the "backup safety").

However, as Volvo, Mercedes, Tesla, GM, and others are launching their first "auto-pilot," Highway Driving Assistant systems, it is not easy to see to what extent safety on the roads may be affected in the short term. Cars with increasing levels of automation will allow drivers to delegate control, taking their eyes of the road and engage in activities unrelated to driving. Drivers, however, must resume control in conditions not yet supported, such as adverse weather or complex traffic conditions. Drivers need enough time to regain situation awareness in order to effectively take back control, a challenge that may become more critical the longer the driver has been "out of the loop." So far, this means that drivers must always continue to monitor the vehicle drive itself and the systems can only be used safely in restricted traffic situations that represent a relatively low crash risk in the first place.

Unfortunately, the automated driving media hype is confusing consumers, as many drivers believe they can purchase a self-driving car right now. According to a study, commissioned by Thatcham Research, Euro NCAP, and Global NCAP (Thatcham Research 2019), 71% of motorists believe that they can buy a self-driving car today, while 11% would be tempted to have a brief nap while using current "Highway Assist" systems. The research was conducted throughout October 2018 and included 1567 car owners from China, France, Germany, Italy, Spain, the UK, and the USA.

Tests of cooperative driving systems such as “Highway Assist systems” by IIHS (Insurance Institute for Highway Safety 2018), Euro NCAP (Euro NCAP 2018), and others clearly demonstrate that cars on the market today can provide driver assistance, but this should not be confused with automated driving. The driver remains fully responsible for safe driving. Used correctly, this technology can help the driver to maintain a safe distance, speed, and to stay within the lane, but these systems should not be used in situations they are not designed for and should not be relied upon as an alternative to safe and controlled driving. The lack of driver training and standardized controls, symbols and names for these features, is further complicating matters for consumers. For the time being, NCAPs can play an important role in promoting realistic expectation among consumers and highlighting the need for constant driver vigilance.

The industry is working towards a safer system by adding Vehicle-to-Everything (V2X) communication, improved 360 degrees sensing capabilities, driver state monitoring, and smarter algorithms, which will further reduce driver engagement risks. Hands-free driving will open the door to completely new concepts that are offering a high degree of flexibility in design, layout, and seating arrangements. From an occupant crash protection perspective, this means that restraint systems will probably become more seat-centric and that the classic approach where belt and bags systems are validated against a limited number of load cases and occupant seating positions will need to be revisited. The continuous situation-awareness of the vehicle itself, facilitated by surround sensors and communication, and that of the occupants inside, will allow for more integrated safety functions across sensors and actuators. This, in turn, can improve pre-crash interventions and enhance the efficiency of passive safety systems.

With over 1.2 billion vehicles on the world’s roads and the average age of vehicles on the road rising to over 10 years, it is a given that automated and self-driving vehicles will have to operate in a mixed traffic environment with manually driven cars for many years to come. The accident distribution of automated cars will be notably different from today’s cars as, although they are expected to cause fewer crashes, they will still be involved in accidents with older, manually driven vehicles and other road users. Improving the level of safety of all vehicles on the road, regardless of level of automation, therefore deserves our continued attention. This remains particularly true for the vehicles sold in the most low-income countries, which do not meet minimum safety standards and trail behind the advancements made in high-income markets over the last decades.

## NCAP Challenges for the Next Decade

Over the years, NCAP has offered a mechanism by which improved insight or technology can be introduced into the design of new vehicles much faster than would otherwise be possible. Gradually, the vehicle industry has come to terms with consumer ratings and has learned to use the system to its advantage in each market. This has greatly helped to democratize car safety and has improved consumer awareness around the world, important steps in achieving the Vision Zero goal to eliminate traffic casualties.

As the automotive industry is rapidly changing and new forms of mobility become available, the formal role that NCAPs traditionally had in influencing the market through consumer information will no doubt become more difficult to play in the future. One of the challenges for NCAPs will be who actually will be the consumer in the future – will private individuals still be buying cars as they do now 10 years from today? Will safety continue to sell, now that that most cars offer many systems as standard and our focus has radically shifted towards the promotion of sustainable mobility and reducing the impacts of climate change? And will consumers, even if it is just as service users, be allowed to have a say in setting minimum levels of safety for automated vehicles?

The answers to these and many other questions will need to be found the coming years. Even so, in the era of false information and differing opinions, there remains a need for truthful and transparent information, and so there will be plenty of opportunities for NCAPs to continue to make a difference.

## Correlation with Real-Life Injury Risks?

For NCAP to maintain its credibility, the overall indication of the safety level that is provided by a safety rating must be a valid prediction when considering severe or fatal injuries or injurious crash involvement. On a technology level, a positive correlation between improved safety performance and the reduction of real-life injuries can often be determined, as shown by the numerous examples mentioned before, but in most cases, consistent field data only emerges several years after countermeasures have penetrated the market. An important challenge for NCAPs worldwide therefore continues to lie in the early identification of live-saving technologies, such that these organizations can effectively play their role as catalysts.

For this, a robust system for the collection, management, and analysis of regional road accident data is essential. Accurate information from before, during, and after an accident, including on the driver state, helps to determine accident causation and allows accident researchers to assess the effectiveness of countermeasures.

Furthermore, as most new safety technology is fitted as optional and, in the case of ADAS not always default on, it is important that researchers can independently verify which technology was fitted and in use on when a vehicle was involved in a crash?

On a more general level, it is more challenging to determine whether there is a correlation between star ratings and benefits in real-life impacts. Lie and Tingvall (2002) found that in car-to-car collisions, cars with three or four stars were found to be approximately 30% safer when compared with two-star cars or cars without a Euro NCAP score. The results indicated a 12% per star risk reduction for severe and fatal injuries. A few years later, these conclusions were supported by more broad international study, SARAC II (European Commission 2006); however, it was noted that significant variation remained in the measures of injury outcome in real crashes for specific vehicles within each Euro NCAP score category. Kullgren et al. (2010) again showed Euro NCAP crash tests to be highly correlated with serious crash performance, confirming their relevance for evaluating real-world crash performance. Good concordance was also found between Euro NCAP and Folksam (insurance claims based) crash and injury ratings. More recently, Kullgren et al. (2019) reviewed the developments in car crash safety in cars launched since the 1980s based on real-world data and reexamined how Euro NCAP crash test results predict the outcome in real-world crashes. It was found that Euro NCAP crash test ratings mirror real-world injury outcomes for all injury severities studied. Comparing five-star with two-star rated cars, the proportion of AIS 3+ injuries was 34% lower.

Note that the above studies focused on crashworthiness improvements and excluded active safety or driver assist technologies. To further develop rating systems that reward the overall safety of a vehicle from a self and partner protection point of view, the real-life impact of the combination of passive and active safety measures still needs to be better understood.

## Vehicle Safety in Low- and Middle-Income Countries

As the Academic Expert Group for the third Global Ministerial Conference on Road Safety (Global Ministerial Conference on Road Safety 2019) points out, only 40 countries have implemented 7 or 8 of the critical safety standards identified in the 2018 Global Status Report on Road Safety, whereas 124 countries, many of them low- and middle-income nations, have implemented none or just one of these standards. Especially in developing markets, that are showing extraordinary growth in the number of vehicles in use, this is a major challenge as without such standards, manufacturers can easily cut back on safety to boost profitability.

To bring safer cars to these regions, a combined approach of legislative action and raising consumer awareness is most efficient, as has been illustrated in India recently by the efforts of Global NCAP and the Indian government (Ministry of Road Transport and Highways 2019).

## Harmonization of Standards

But whereas NCAP's strength is its ability to follow closely the technology development by industry and take account of local market circumstances, it is also true that this has led to a wide variety of test conditions and inherently different rating schemes applied around the world. The criticism about the lack of harmonization is certainly justified in some instances, when different test speeds, barriers and crash dummies are used to evaluate a car's performance in what is essentially the same real-world crash scenario. On the other hand, there are many good reasons too to be different, not in the least because the cars built around the world are so diverse and must often meet local regulations.

Global NCAP provides a cooperation platform for NCAPs and similar organizations around the world to share best practice, to further exchange information, and to promote the use of consumer information to encourage the manufacture of safer cars across the global automotive market facilitates the dialog between NCAPs. Recently, more efforts have gone into cooperation between NCAP programs at the development phase as well, for instance, on the definition of a common 3D "soft" vehicle target for AEB testing (Grover et al. 2017).

## Population Diversity

In most markets, new cars today are safer than they were a decade ago thanks to improved test standards, crumple zones, seatbelts, and airbags, which all help to protect occupants in a crash. While most occupant safety measures can be considered mature, more could and should be done to improve their robustness and effectiveness for the general diversity of vehicle occupants and crash scenarios.

Standard crash tests focus primarily on a limited number of sizes of occupants, namely the mid-sized male, small female, and large male. The effect of variation in age, gender, race, and corpulence must be better understood so that vehicle safety systems can work to the benefit of all. Test methods and injury criteria, especially those applied in regulation and by NCAPs, must drive more robust performance for the population of car occupants and vulnerable road users.

## Encouraging ADAS

Crash avoidance systems can help prevent accidents from happening in the first place. Considering the time any new technology needs to penetrate the vehicle fleet, it is important that they are effectively deployed to address the above key accident scenarios, including those that involve other road users and commercial vehicles.

Today, the global uptake of crash avoidance technology is still developing: a large variety of systems is available, some are standard in developed markets, but only offered as optional elsewhere. As most ADAS are not mandated, the uptake of optional systems is still low and depends greatly on market incentives. The situation is likely to improve as the need for more on-board technologies to support (partial) automated driving will make crash avoidance systems cheaper and more cost-effective across the car fleet. Voluntary agreements to make equipment standard across the fleet – like those announced by US.DOT and IIHS on AEB systems in the USA (Insurance Institute for Highway Safety 2015) – help generate the momentum in the marketplace. In Europe, Euro NCAP's five-star system has helped boost the availability of ADAS across the Member States, as is shown from the share of the total cars rated with standard ADAS between 2012 and 2019 (Fig. 10). The situation is about to improve even more from 2022 onwards as the General Safety Regulation (European Parliament 2019) will come into effect, mandating, for the first time, systems like AEB, lane support, and speed assistance for passenger cars and LCVs.

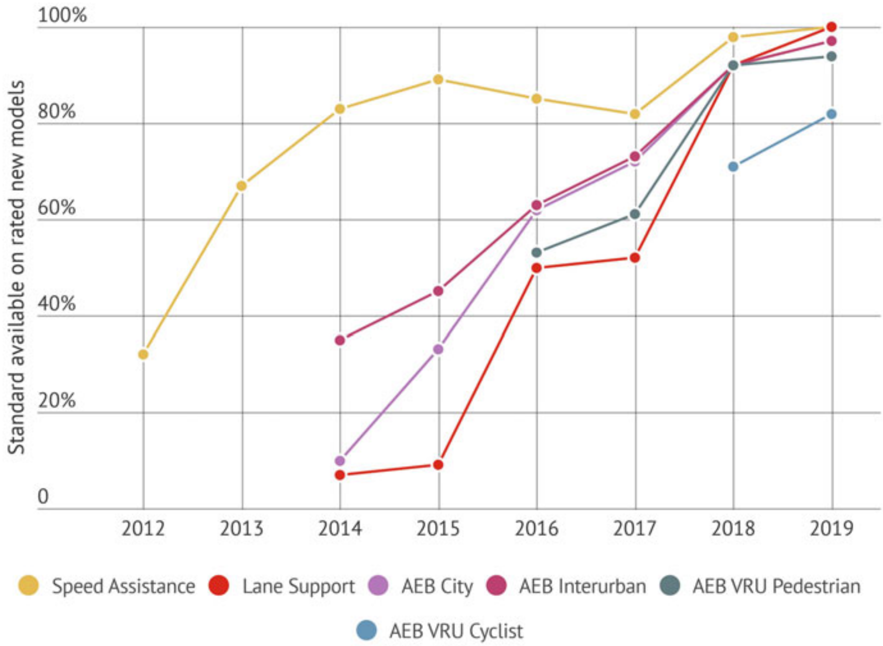


**Fig. 10** Percentage of cars tested per year that is equipped with standard ADAS across the European market. Euro NCAP 2012–2019

Besides price, the acceptance and volume of advanced technologies are driven largely by how well consumers understand these features and value them. Today, when they are placed on the market, ADAS are often not yet fully mature. Together with the lack of knowledge among drivers, situations in which drivers fail to understand why the vehicle responds or indeed fails to respond in a certain way, can quickly arise. To counter this, consumer ratings must adequately evaluate the complex role of driver behavior and address inconsistencies in information, warning, and intervention strategies across the industry.

## From Assisted to Autonomous and Connected Driving

As automation in cars becomes more mainstream, new crash scenarios and priorities may emerge and surveillance systems should be in place to ensure high quality data will be collected on the circumstances of a crash and the role of man and machine. There is a high expectation that vehicle automation will lead to innovations in the in-vehicle environment. This will lead to a potentially more complex loading environment for future restraint systems and will present a major challenge to NCAPs and regulators that must evaluate them.

As long as there are clear categories of crash avoidance systems that address typical accident scenarios and where the contribution of the driver is limited, the "spot testing" approach currently followed by NCAPs will remain beneficial. Verifying the performance on a system level in idealized conditions has the advantage of being able to set clear engineering targets, raise consumer awareness and effectively drive best practice and higher equipment fitment in the market. However, as safety functions become further integrated and vehicles begin to rely on connectivity with infrastructure and other road users – in other words become truly connected – it is unlikely that track testing alone will be sufficiently meaningful or conclusive to steer improvements in industry or to inform the consumer.

## Conclusions

Vehicle safety has played an important role in reaching Vision Zero. Whereas regulations set minimum safety standards for motor vehicles in each region and give authorities the power to restrict sales of unfit vehicles, consumer ratings are an effective mechanism to influence the consumer preference and promote new technology entering the market.

Most consumers will have no personal experience by which to judge the crash safety of their car. Are they happy with the level of safety offered? Can they specify what level they want? Can they assess whether this objective has been met? Clearly, without objective and transparent safety information, these questions would be impossible to answer. This underlines the importance of public safety ratings and justifies why NCAPs around the world continue to develop their comparative safety tests. Moreover, it explains why consumer ratings continue to have an impact, not only with consumers but also more and more with public and private fleet managers to help them ensure that their vehicle fleet provides acceptable levels of protection to their employees.

A consumer rating system that is rooted firmly on real life experiences, but which closely follows the technological innovations in the marketplace, can deliver the most benefit for society. For this reason, links to road safety and biomechanical research as well as to the automotive industry are essential. The NCAPs together have achieved much to be proud of, but there is still important work to be done: in low- and middle-income markets to ensure that zero-star cars will be a thing of the past and, in developed markets, to ensure safety remains a priority for car manufacturers, in order to reduce road fatalities and injuries even further.

The NCAP community plans to engage in the roll out of vehicle automation as a way to dramatically improve vehicle safety and safe driving. It will continue to promote best safety practice when vehicles start to have elements fitted which support automated driving and to ensure that the vehicle manufacturer remains responsible for safe operation of the system. Consumer acceptance of these systems and objective, independent reassurance of their performance will play a key part in the transition that is ahead of us.

NCAP has shown that increasing consumer demand for safer cars, combined with exerting pressure on car manufacturers to incorporate better safety features into their vehicles, can make significant improvements to the safety of cars and bring Vision Zero one step closer.

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# Saving Lives Beyond 2020: The Next Steps 26

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## Foreword

Road safety has come a long way in our lifetimes, and there are steps in this progress that mark their place in history. Many of these were technical innovations, such as seat belts, electronic stability control, and geofencing for vehicle speed control. Also important, though perhaps fewer in number, were innovations in strategies to achieve change. These include the public health model of Dr. William Haddon, the introduction of Vision Zero, the World Report on Road Traffic Injury Prevention from WHO and the World Bank, and more recently, the Decade of Action 2011–2020. I am sure that the work and recommendations presented in this report will deserve their place in a "Hall of Fame" for strategic innovation in saving lives across the globe.

Our report and recommendations are based on the introduction of 2030 Agenda, often referred to as the Sustainable Development Goals (SDGs). With the establishment of these Goals in 2015, road safety was explicitly included for the first time as part of the global development agenda, and this heightened recognition gives us a new and unique opportunity to accelerate progress. This recognition puts road traffic safety on the same level of global criticality as climate, health, and equity issues and means that road safety can no longer be traded off in order to promote other needs. Inclusion among the SDGs also means that road safety is the responsibility of a wide range of stakeholders, both public and private. While some might see this as an imposition, I see it as hope and an opportunity to use our knowledge to achieve a vision of mobility without fear for our lives.

In this report, we point out that road safety is a necessity for health, climate, equity, and prosperity. If children cannot walk or bicycle to school without risking their lives, we limit their access to education, good health, and freedom and consequently our hope for the future. If we cannot transport goods across a nation or around the world in a safe and sustainable way, we limit the possibility of trade, economic development, and elimination of poverty. If our workplaces are not safe, we threaten earnings and the sustainability of families. Elimination of deaths and serious injuries in road traffic is essential to many other sustainability goals in very direct and clear ways. Road traffic safety can no longer develop in isolation.

The SDGs have been widely endorsed, and their achievement is now accepted as a central responsibility by governments, corporations, and civil society. Expectations for meaningful contributions by these organizations are driving public attitudes and even affecting investment decisions. Sustainability reporting has become a means for organizations to demonstrate their societal value, and new tools are needed to help them communicate their contributions in an accurate and transparent way. Cities and corporations can do fantastic things to protect the public and create a more livable environment with improved security, better health, and cleaner air.

I am proud to have led a group of internationally recognized road safety thought leaders to formulate the vision, strategy, and rationale underlying these recommendations. Capturing the wisdom of these leaders was among the most challenging tasks I have undertaken, but also the most rewarding. The ideas in the report were developed by consensus. Each member of the group made concessions in our personal viewpoints, but gained insight and knowledge from the others. All of us are proud to stand behind the product of our collaboration, and that is in the end what counts!

## Executive Summary

The Academic Expert Group convened by the Swedish Transport Administration lent its combined experience, expertise, and understanding of global road safety issues, problems, and solutions to create a set of recommendations for a decade of activity by the public and private sectors that would lead to a reduction of worldwide road deaths by one-half by 2030. The recommendations are made in the context of a Third High-Level Conference on Global Road Safety to be held in Stockholm in February 2020 and are offered for consideration by conference participants and leaders from businesses, corporations, governments, and civil society worldwide.

The report reflects on the Decade of Action for Road Safety 2011–2020, addressing both its accomplishments and limitations. The targeted reductions in global road deaths were not achieved, and in fact the number of global road traffic deaths increased over the decade. Available data are insufficient to assess progress on serious injuries. However, there were many foundational accomplishments during the decade, including increased awareness of road safety problems and solutions among governments, corporations, businesses, and civil society; measurable and effective safety improvements in many locations; new funding; and new partnerships. Road safety needs were expressed in a new structure using five pillars, and evidence-based interventions were identified for each pillar, along with measures and targets. A significant achievement of the Decade of Action 2011–2020 was the inclusion of road safety among the Sustainable Development Goals (SDGs). Integrating a road safety target into SDG 3.6 and 11.2 was a remarkable accomplishment with far-reaching potential.

The report proposes a vision for the evolution of road safety and recommends a new target of 50% reduction in road deaths and serious injuries by 2030 based on expanded application of the five pillars, adoption of Safe System principles, and integration of road safety among the Sustainable Development Goals. The vision describes an evolution of road safety, building from the foundation of the pillars, incorporating adoption of the Safe System approach, and leading to a future comprehensive integration of road safety activity in policy-making and the daily operations of governments, businesses, and corporations through their entire value chains. The vision also stresses the need for further engagement of the public and private sectors and civil society in road safety activities and capacity-building among road safety professionals worldwide.

A set of nine recommendations are proposed to realize the vision over the coming decade:

| | |
|---|---|
| *Sustainable Practices and Reporting*: including road safety interventions across sectors as part of SDG contributions | *Safe Vehicles Across the Globe*: adopting a minimum set of safety standards for motor vehicles |

(continued)

| | |
|---|---|
| *Procurement*: utilizing the buying power of public and private organizations across their value chains | *Zero Speeding*: protecting road users from crash forces beyond the limits of human injury tolerance |
| *Modal Shift*: moving from personal motor vehicles toward safer and more active forms of mobility | *30 km/h*: mandating a 30 km/h speed limit in urban areas to prevent serious injuries and deaths to vulnerable road users when human errors occur |
| *Child and Youth Health*: encouraging active mobility by building safer roads and walkways | *Technology*: bringing the benefits of safer vehicles and infrastructure to low- and middle-income countries |
| *Infrastructure*: realizing the value of Safe System design as quickly as possible | |

## Preamble

In 2018, as the Decade of Action for Road Safety 2011–2020 was nearing its conclusion, the Government of Sweden made an offer to host the Third Global Ministerial Conference on Road Safety, an event that will gather road safety experts and national delegates from around the world to reflect on the purpose, progress, and future of this global road safety movement. As a leader in both road safety theory and practice, Sweden is well-positioned to host this important gathering and provide a structure and forum where stakeholders look back at how the global effort started, take stock in how far we have come, and consider our path forward.

Recognizing the pivotal role that this conference will serve in global road safety and the range of stakeholders engaged in the movement, the Government of Sweden worked closely with UN colleagues to create an inclusive conference planning structure that engaged leaders from governments, non-government and civic organizations, academia, and businesses. Work groups were formed, research was reviewed, and perspectives on the past and future of road safety were compared in order to formulate a framework for the Third Ministerial Conference.

The work of these groups was further motivated by the Political Declaration from the Sustainable Development Goals Summit taking place on September 24–25, 2019 which reaffirmed commitment to implementing the 2030 Agenda on Sustainable Development and called for accelerated action by all stakeholders at all levels to fulfill this vision (United Nations 2019).

Among the work groups engaged in conference planning was the Academic Expert Group consisting of experienced road safety researchers, practitioners, and thought leaders from around the world. The Academic Expert Group was charged with these primary tasks:

- What are the results of the Decade of Action, and what experiences can we draw from the efforts made during the past 10 years?
- What is a challenging and usable target (or targets) for the next 10 years up to 2030 that can be integrated in the 2030 Agenda, in particular Goal 3.6?

- What processes and tools could be further developed or added to make actions even more effective, and which sectors of the society could be further stimulated to contribute to the overall results?
- How can trade, occupational safety, standards, corporate behavior, and other aspects of the modern society be linked with road safety?
- How can nations, local authorities, and governments as well as public and private enterprises, in particular major enterprises, be stimulated to contribute to road safety through their own operations?
- How can other important challenges, in particular those targeted in Agenda 2030, contribute to improved road safety, and vice versa?

This report documents the recommendations of the Academic Expert Group and provides an indication of the rationale behind their views. A list of the members of the Group is included in the appendix.

## Reflections on the Decade of Action 2011–2020

### Origins of the Decade

General Assembly Resolution 58/289 of April 2004 recognized the need for the UN System to support efforts to address the global road safety crisis. The Resolution invited the World Health Organization to coordinate road safety issues within the UN System, working in close cooperation with the UN Regional Commissions. The UN Road Safety Collaboration was established, bringing together international organizations, governments, non-government organizations, foundations, and private sector entities to coordinate effective responses to road safety.

The Commission for Global Road Safety formed by the FIA Foundation in 2006 issued a call for a Decade of Action for Road Safety in its 2009 report which was widely endorsed. The UN Secretary-General, in his 2009 report to the General Assembly, encouraged Member States to support efforts to establish a Decade as a means to coordinate activities in support of regional, national, and local road safety, accelerate investment in low- and middle-income nations, and rethink the relationship between roads and people.

In March 2010 the UN General Assembly proclaimed the Decade of Action for Road Safety 2011–2020 with a goal of stabilizing and then reducing the forecasted level of road fatalities and injuries around the world. The resolution requested that the World Health Organization and the UN Regional Commissions, in cooperation with partners in the UN Road Safety Collaboration and other stakeholders, prepare a global plan with the Decade as a guiding document to support the implementation of its objectives.

### Major Milestones and Accomplishments

The Decade of Action raised global awareness of road safety among governments, businesses, and civil society. It brought measurable and effective safety improvements. It attracted new funding and new partnerships and brought road safety closer to the global arena of public health issues.

Target setting is now common practice across sectors of society as a means for managing progress toward ambitious goals, and in some cases the practice has developed from simple targets to complex sets of sub-targets, indicators, and action plans. However, there is room for improvement in road safety indicators to ensure an adequate link to outcomes so they can be useful in guiding policy decisions.

A significant achievement of the Decade of Action with regard to the long-term course of road safety is the inclusion of road safety among the Sustainable Development Goals (SDGs). Integrating road safety targets 3.6 and 11.2 in the SDGs was a remarkable accomplishment with far-reaching implications. The 2030 Agenda states clearly that the "17 Sustainable Development Goals with 169 associated targets are integrated and indivisible." This recognition places road safety at the same level of criticality as other global sustainability needs and clearly indicates that sustainable health and well-being cannot be achieved without substantial reductions in road deaths and serious injuries. While this integration with other SDGs has yet to be realized on a global level, the opportunity for new partnerships is now available, and the potential benefits that could come from such integration are compelling.

According to the projections for road deaths and the ambition set by the Decade of Action in 2011, deaths were expected to reach 1.9 million by 2020 if no actions were taken. The ambition was to "stabilize and then reduce deaths" by about 50% of the forecast level, or approximately 900,000 deaths, by 2020. The road safety target included in the SDGs uses different definitions and data sources and calls for an ambitious 50% reduction in the absolute number of global deaths and injuries between 2015 and 2020, or about 650,000 deaths.

The 2018 Global Status Report estimates a current level of about 1.35 million road deaths, indicating that the ambition of stabilizing the trend of global deaths has not been met. Data on injuries are insufficient to measure progress. The targeted numbers of annual deaths – neither the 900,000 proposed by the original Decade nor the 650,000 included in the later SDG – are likely to be reached by 2020 (Fig. 1).

A significant achievement was the establishment of the UN Special Envoy for Road Safety. This position, created by the UN Secretary-General in April 2015, signifies the importance of road safety among global needs and provides a focal point for promoting and coordinating road safety activities among government and non-government organizations worldwide.

A particularly visible element of the Decade are the road safety pillars. This pillar structure illustrates the scope of activities needed to achieve lasting road safety progress and has proven to be useful for identifying gaps in national programs and allocating local resources to the most critical areas for improvements. The individual interventions included under each of the five pillars have been tested and evaluated and provide an evidence-based pathway to sustainable road safety. Evaluations of these interventions has been collected in systematic reviews and meta-analyses, and their application has been facilitated by the development of calculator tools that can

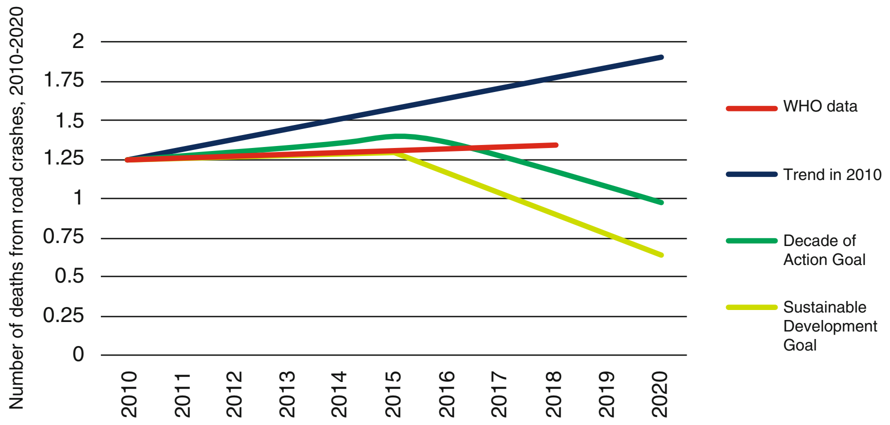


**Fig. 1** Number of deaths from road crashes. (Adapted from OECD, International Transport Forum)

estimate impacts of changes and assist implementers in making strategy and investment decisions (Elvik et al. 2009; Wismans et al. 2019).

The road safety pillars are expected to remain the primary tools for improving road safety in the coming decade. The challenge is in expanding their adoption and application, building upon this achievement with the Safe System approach and integrating safety across sectors. The Sustainable Development Goals offer an opportunity to achieve these objectives.

## Vision for the Second Decade

Road safety is integral to nearly every aspect of daily life around the globe. We step from our homes into a road system that leads us to work, to get our food, and to many of our daily family, health, and social needs.

The influence of the road transportation system is so pervasive that its safety – or lack of safety – affects a wide range of social needs. Road safety – mobility without risk of death or injury – affects health, poverty, equity, the environment, employment, education, gender equality, and the sustainability of communities. In fact, road safety directly or indirectly influences many of the UN Sustainable Development Goals.

Unlike other modes of transportation such as aviation, railways, or maritime, road transport has lacked an integrated and comprehensive approach towards safety. The Academic Expert Group proposes a global road safety vision that describes how existing accomplishments combined with progressive techniques can lead to a new era in which road safety is integrated in a range of other social development movements and pursued in a comprehensive manner.

The vision proposes an evolution of road safety beginning with the road safety pillars as a foundation. Nations at every level of road safety development rely on fundamental tools included among the pillars as the operational elements to achieve and maintain high levels of road safety.

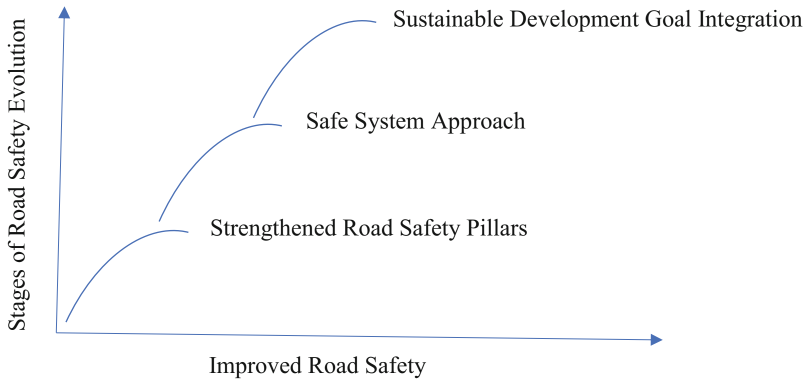


**Fig. 2** The evolution of road safety

Many nations around the world have enhanced the effect of pillar interventions by applying them selectively and strategically according to Safe System principles. The Safe System approach addresses problems closer to their root cause and on a broader scale than conventional methods.

The highest level of road safety evolution has yet to be reached by any nation but promises exponential benefits. At this level, road safety is no longer an independent public health and safety initiative, but rather an integral part of a broad range of societal endeavors from commercial enterprise to humanitarian initiatives (Fig. 2).

## Strengthened Road Safety Pillars

While there is still much to learn, we have the tools to vastly improve road safety around the globe. The five road safety pillars identified in the Global Plan for the Decade of Action for Road Safety 2011–2020 include a set of evidence-based interventions that can measurably improve the safety of road traffic, especially if they are applied with the Safe System approach. These road safety pillars include tools for improving road safety management and enhancing the safety of roads and mobility, vehicles, road users, and emergency response.

We have made progress in getting these tools into practice. What we need is much more progress, the sort of progress that will require a larger and more effective army of implementers. The Sustainable Development Goals – and the army of advocates who are advancing these goals around the world – can make a substantial contribution to this need.

## Safe System Approach

The vision for the next decade multiplies the reach and impact of the tools within the five pillars and also extends the value of another critical component of the first decade, the Safe System approach. The vision recognizes that the tools of the five pillars will have the greatest effect on safety when they are applied alongside new tools in a strategic and pervasive manner following the proven principles of the Safe System approach. The Safe System approach – also referred to as Vision Zero – recognizes that road transport is a complex system and that humans, vehicles, and the road infrastructure must interact in a way that ensures a high level of safety. The Safe System approach (Welle et al. 2018):

1. Seeks a transportation system that anticipates and accommodates human errors and prevents consequent death or serious injury
2. Incorporates road and vehicle designs that limit crash forces to levels that are within human tolerance
3. Motivates those who design and maintain the roads, manufacture vehicles, and administer safety programs to share responsibility for safety with road users, so that when a crash occurs, remedies are sought throughout the system, rather than solely blaming the driver or other road users
4. Pursues a commitment to proactive improvement of roads and vehicles so that the entire system is made safe rather than just locations or situations where crashes last occurred
5. Adheres to the underlying premise that the transportation system should produce zero deaths or serious injuries and that safety should not be compromised for the sake of other factors such as cost or the desire for shorter transportation times

## Integration of Road Safety in Sustainable Development Goals

As an independent endeavor, the road safety movement is limited in potential reach and influence. Positioned as a special interest, road safety is often subordinate to other social needs and can gain progress only where it can achieve attention by road users or those who make decisions about roads and vehicles. But if recognized as a basic necessity that can facilitate progress in meeting social needs ranging from gender equity to environmental sustainability, the potential of road safety can be greatly expanded.

Among the key achievements of the Decade of Action 2011–2020 was the inclusion of road safety in the Sustainable Development Goals. Because these Goals are defined as indivisible and mutually dependent (United Nations 2015), the explicit citation of road safety in the *Health and Well-Being* and *Sustainable Cities* goals is accompanied by implicit integration across the goals and especially in those addressing climate, equity, education, and employment.

Integrating road safety among the Sustainable Development Goals is an important step toward embedding road safety expectations and activities in the far-ranging daily processes of governments and in the operations of corporations, businesses, and civic organizations globally. Substantial levels of such widespread integration have yet to be achieved but have the potential to expand interventions to a scale where road deaths and serious injuries would be reduced to near zero.

## Importance of the Vision for Low- and Middle-Income Nations

The focus of global road safety efforts needs to remain on low- and middle-income nations, the location of the great majority of the problem – 93% worldwide road traffic deaths in 2016.

The Academic Expert Group believes that the value of the road safety pillars is universal.

That is, the scope of action described by the pillars – Road Safety Management, Infrastructure, Safe Vehicles, Road User Behavior, and Post-Crash Care – is essential in any environment, and the activities outlined in the Global Plan of Action (World Health Organization 2010) for each pillar can be effective in nearly every national context.

However, the Group recognizes that implementation of these activities from the Safe System perspective in some environments can face formidable barriers. Competing priorities, the capacity of local governments to take action, and differences in geographic, geopolitical, and geodemographic situations can present serious challenges to implementing changes necessary to initiate or sustain road safety improvements. These challenges have likely contributed to the lack of reductions in road deaths over the past several years in many nations.

Despite these challenges, many nations have made progress with key road safety activities. Since 2014, 22 nations with a combined population of over 1 billion people – 14% of the world population – have amended laws on one or more key risk factors, bringing their legislation in line with best practice (World Health Organization 2018a). Credit for this progress likely goes to a range of influencers, including motivated local government or non-government leaders, actions by national or international NGOs with interest in road safety, and leadership through the UN system.

Change in low- and middle-income nations has been slower, and governments in these nations need to take a deeper look at their situation and address this issue, with help from external partners as the situation requires. While the Agenda 2030 looks to governments for lead responsibility, strong and sustained efforts from the private sector are important for the achievement of the goals and targets. Business underlies 84% of the GDP and 90% of the jobs in developing countries and, by utilizing their full value chains, can make a substantial contribution to the safety of those who are at greatest risk for a range of threats including motor vehicle crashes.

The Safe System approach is of critical importance not only for developed areas but also for developing nations and cities. The global trend toward urbanization will cause widespread expansion of cities and create new urban areas in coming decades. The UN Department of Economic and Social Affairs predicts that urban areas will grow by more than 50% over the coming 30 years, with the great majority of this expansion occurring in Africa and Asia (World Urbanization Prospects 2018). New roads and infrastructure will be necessary to accommodate the urban expansion, and this creates an opportunity to incorporate Safe System design features from the beginning.

Technological development will continue to accelerate making existing safety devices more affordable and introducing new safety potential for vehicles and the road infrastructure. Public and private sector organizations will be increasingly compelled to contribute to sustainability goals, including road safety. The vision presented here by the Academic Expert Group provides an opportunity to guide these changes in ways that can improve road safety and contribute to global sustainability.

## Sustainable Development Goals

The UN 2030 Agenda for Sustainable Development, adopted by all Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. The Agenda is based on 17 Sustainable Development Goals (SDGs) and presented as an urgent call to action for both the public and private sectors in a global partnership.

The SDGs cover a range of necessities for improving and stabilizing both the human condition and the condition of our planet, recognizing the interdependence of these two objectives (Fig. 3).

The SDGs build on decades of research, deliberation, and negotiation. Transportation issues have been part of the sustainability discussion for at least 30 years, initially with a focus on reducing congestion and improving energy efficiency. However, road safety was not explicitly included among the development goals and targets until adoption of the 2030 Agenda for Sustainable Development in 2015.


**Fig. 3** UN Sustainable Development Goals (World Health Organization)

## Sustainable Development Goals: Integrated and Indivisible

The UN General Assembly Resolution 70/1, Transforming our World: The 2030 Agenda for Sustainable Development, defines a global vision of unprecedented scope, far beyond the previous Millennium Development Goals. It maintains a focus on priorities such as poverty eradication, health, education, and food security and nutrition, while adding critical economic, social, and environmental objectives.

The specific inclusion of road safety targets in Agenda 2030 reflects universal recognition that death and injury from road crashes are now among the most serious threats to the future of our people and planet. Article 55 of the Resolution states that the 17 Goals are "integrated and indivisible, global in nature and universally applicable." This means that road safety is no longer a need that can be compromised or traded off in order to achieve other social needs. It implies, for example, that the safety risks inherent in raising speed limits should not be tolerated in order to realize economic benefits of faster traffic and that investments necessary to improve road safety should not be diverted for other needs.

The 2030 Agenda also points out the deep interconnections among the goals and targets, beginning with the fundamental interconnection of the health of people and the health of the planet and extending to many other interdependencies (Fig. 4).

An analysis of SDG interactions at the Goal level by the International Council for Science (2017) points out the connections between Goal 3: Good Health and Well-Being, the location of the primary road safety target, and many of the other Goals.

Together, these qualities of indivisibility and connectedness among the goals and targets present an opportunity to advance road safety in new context, but they need to be pursued and acted upon by the road safety community and others. They need to be translated into actions and solutions to contribute to improving road safety and other human development issues worldwide.

Agenda 2030 compels public and private organizations of all sizes to apply their resources and influence to the widest extent possible toward achievement of SDGs. Many organizations, government and corporate, have a health or safety mandate that will lead them to apply resources directly to targets 3.6 and 11.2. A far greater range of entities have mandates that point them directly at one or more other Goals and – because of the interconnectedness and indivisibility of the Goals – will also recognize the relevance of applying their influence to advance road safety. Examples of these connections include:

- Environmental organizations contributing to efforts to reduce vehicle speeds and lower emissions and noise
- Gender equity organizations contributing to safe pedestrian, bicycle, and motor vehicle travel as a means to open opportunities for women of all ages
- Workplace safety organizations contributing to road safety as a leading cause of workplace death and injury
- Organizations pursuing eradication of poverty advancing road safety as a means for improving access to employment opportunities
- Education organizations promoting road safety to facilitate travel to local schools

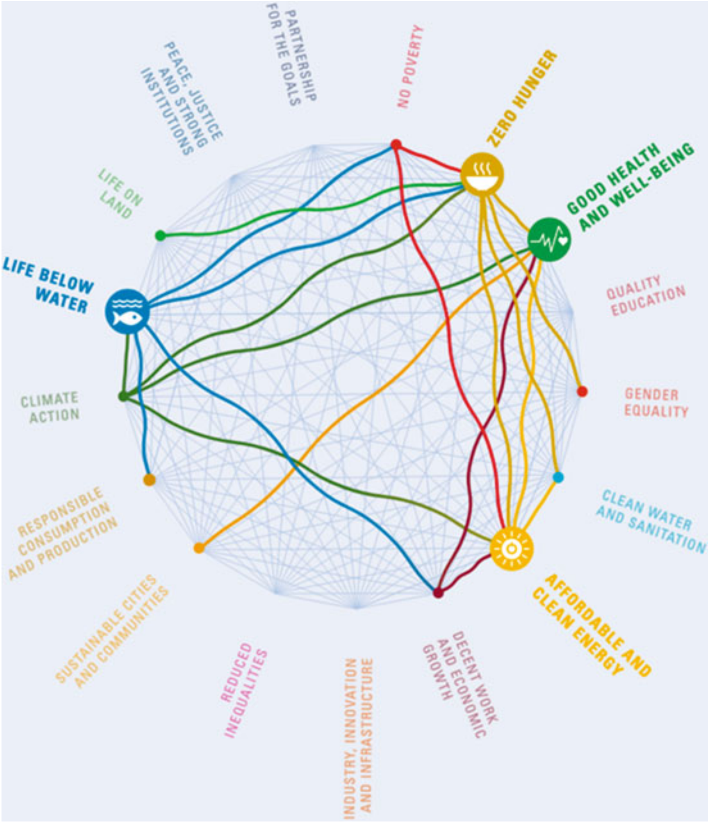


**Fig. 4** Goal interactions (International Council for Science)

- Organizations seeking elimination of inequalities supporting road safety to encourage access to essential needs for individuals and under-served communities

## Strategies and Tools for Achieving Sustainable Development Goals

Government and corporate organizations need guidance and direction to make meaningful contributions to a range of SDGs. Following are examples of tools and guidance available to assist organizations in focusing their efforts to make efficient and effective contributions.

In their Sustainable Development Report: 2019, Bertelsmann Stiftung and Sustainable Development Solutions Network propose a set of six transformation strategies that can be used by governments and corporations to organize their SDG contributions. These transformation strategies are structured to take advantage of synergies among the SDGs and to align with typical methods of government and corporate operations (Bertelsmann Stiftung and Sustainable Development Solutions Network 2019).

Sustainable Mobility for All is advancing sustainable mobility as a prerequisite for achieving a range of SDGs. The organization is engaging stakeholders to develop a Global Roadmap for Action to promote four mobility policy goals, Universal Access, Efficiency, Safety, and Green Mobility, and offers tools such as Mobility Data by Country, a Global Mobility Tracking Framework, and Global Transport Stakeholder Mapping (Sustainable Mobility for All 2019).

The World Business Council for Sustainable Development (WBCSD) works with cities and corporations to facilitate their effective and efficient contribution to the SDGs. WBCSD is a CEO-led global membership organization representing nearly 200 leading businesses. WBCSD enhances the business case for sustainability with tools, models, services, and experiences (World Business Council for Sustainable Development 2019).

The Sustainable Development Compass provides practical guidance for companies to align their strategies and measure their contributions to the SDGs. Developed through a partnership among GRI, the UN Global Compact, and WBCSD, the Sustainable Development Compass assists companies in understanding the SDGs, defining priorities, settings goals, integrating activities, and reporting and communicating progress (Sustainable Development Compass 2015).

Finally, while sources of guidance and tools such as those described above can help engage businesses, governments, and civil organizations in effective contributions to the SDGs, and assist them in focusing, coordinating, monitoring, and measuring their work, there are currently few such tools available to guide road safety contributions. This type of road safety guidance is urgently needed.

This guidance for corporate and government organizations needs to address where contributions can be made to road safety as well as how such actions can be taken. The ground-level activities needed to contribute to the road safety targets 3.6 and 11.2 are well understood and documented. The five pillars described in the Global Plan for the Decade of Action for Road Safety 2011–2020 include a comprehensive set of evidence-based interventions that have proven effective in some circumstances and will provide a useful basis for new road safety contributions by governments, corporations, and civil society, especially if applied according to Safe System principles (Global Plan for the Decade of Action for Road Safety 2010).

## Prerequisites for Change

### Expanded Engagement of Public and Private Sectors

In the coming decade, we have the potential to use the linkages between road safety and the Sustainable Development Goals to expand the reach of our tools well beyond the traditional scope of transportation, public safety, and public health. Integrating road safety among a range of Sustainable Development Goals will engage non-traditional public and private stakeholders and lead to road safety activities taking place across entire governmental and corporate value chains.

Governments, corporations, and civil society will be encouraged to use their resources and influence to contribute to the achievement of Sustainable Development Goals wherever possible. The collective power of public and private organizations around the world adopting road safety practices as part of their contributions to the Sustainable Development goals, together with their endorsement, leadership, and purchase power, is substantial. This potential multiplies the value of the road safety pillars, placing these tools in the hands of a far wider group of motivated implementers than has previously been possible.

Corporations from every sector and public authorities with a wide range of direct responsibilities can be engaged in road safety activities. These organizations will be motivated to look beyond their core tasks for efficient and effective strategies to contribute to the SDGs. If these organizations are educated concerning the need and opportunities, road safety actions could be a widespread priority.

The means for contributing to road safety by these new partners could include policies regarding vehicle fleet purchase and the manner in which these vehicles are scheduled, routed, and driven. In addition, these organizations can use their contractual and procurement power to affect road safety policies and practices of all those upstream organizations from which they purchase services and supplies and all those downstream to whom they distribute their services.

Methods to realize the full potential of corporate and government engagement in road safety have yet to be fully explored. Combinations of traditional government-corporate regulatory roles may be effective alongside government incentives and voluntary SDG-driven roles. Exploration and evaluation of such alternative combinations of governmental and corporate initiatives is a high priority.

## Capacity-Building

Research shows that a strong road safety management system is correlated with good road safety performance. The World Report on the Prevention of Road Traffic Injuries (2004) points out two key elements of a strong road safety management system, an effective lead road safety agency and committed road safety leadership.

The World Report defines a lead agency as an organization with the authority and responsibility to make decisions, control resources, and coordinate efforts by all sectors of government, including those of health, transport, education, and the police. The Report describes road safety leadership as including the capacity for commitment and informed decision-making at all levels of government, the private sector, civil society, and international agencies to support the actions necessary to achieve reductions in road risks, deaths, and serious injuries.

While a top-down approach to road safety management incorporating a lead agency and good safety leadership is an important ingredient, examinations of high-performing national road safety programs also point out the need for committed and knowledgeable road safety professionals. High-performing professionals are not only good practitioners (able to design and implement effective interventions) but also are able to link themselves with top-level decision-making in order to create a positive political environment and scale up effective road safety interventions. In some countries, road safety professionals are able to influence public and political discourse on road safety, and this has paved the way for effective policies (Bliss and Breen 2009).

However, many road safety professionals lack the skills necessary to be good practitioners, and an even greater number lack the insights needed to recognize opportunities to influence top-level road safety decision-making in the public and private sectors.

This lack of capacity among road safety professionals is a major barrier to progress in many countries. These countries do not have professionals with the specialized knowledge necessary to be effective in making roads and vehicles safer, to achieve safer road user behavior, and to design and operate a well-functioning post-crash system. Further, many countries and cities do not have the expertise required to adapt Safe System principles to their own conditions, effectively collect and analyze road safety data, or carry out quality road safety research. While less information is available to generalize the adequacy of such road safety professional expertise in the private sector, it is very likely that similar deficiencies exist.

Capacity-building for road safety professionals working for the government, the private sector, civil society, and research institutions should be given top priority, not only to make them better practitioners but also to prepare them to act more effectively within their organizational and national structures. Such capacity-building could go a long way toward moving road safety higher on the political agenda and advancing the evolution of road safety programs in jurisdictions and corporations. Study of road safety capacity-building approaches should be conducted to identify effective techniques and strategies.

## Recommendations

The following recommendations are offered by the Academic Expert Group for inclusion in the Stockholm Declaration and for use by political, corporate, and civil society leaders and practitioners worldwide. The recommendations are directed towards 2030 and are intended to build upon those previously established in the Moscow Declaration of 2009 and the Brasilia Declaration of 2015 as well as prior UN General Assembly and World Health Assembly resolutions. The Academic Expert Group considers these additional recommendations to be essential for achieving the goal of reducing global road fatalities and serious injuries by half by 2030. The recommendations are interrelated and intended to be considered as a set rather than as individual options. The recommendations are based on the Safe System Approach.

These recommendations are necessarily far-reaching in both scope and ambition. The Group believes that the best strategy for reaching the goal for 2030 is to maintain commitment to prior recommendations and immediately initiate action on each of these new recommendations with sufficient intensity to achieve substantial progress by the middle of the coming decade. The Group further recommends that a rigorous evaluation be conducted 5 years into their adoption to measure progress and that the findings be used subsequently to refine and adjust the strategy.

## Recommended Target for 2030

The Academic Expert Group discussed the importance of target setting and recognized the action taken by the High-Level Political Forum on Sustainable Development to “maintain the integrity of the 2030 Agenda, including by ensuring ambitious and continuous action on the targets of the Sustainable Development Goals with a 2020 timeline (United Nations 2019).”

The Group recommends the following points:

> It is crucial that a specific road safety target is maintained and kept up to date within the Sustainable Development Goals.

Proposed wording for Sustainable Development Goal 3, Target 3.6:

> Between 2020 and 2030, halve the number of global deaths and serious injuries from road traffic crashes, achieving continuous progress through the application of the Safe System approach.

The Academic Expert Group further recommends that:

> Operational targets should be set by individual global regions (consistent with the ambition of 3.6, but taking into account local developments, conditions, and resources).
>
> Targets should include fatalities and serious injuries. Identifying appropriate rates of deaths and serious injuries is also desirable. However, the optimal measure of fatal and non-fatal injury rates has yet to be determined.
>
> Linkages and collaborations should be established among the constituencies associated with the range of other SDGs that are affected by and associated with road safety. These include Quality Education, Decent Work and Economic Growth, Reduced Inequalities, Sustainable Cities and Communities, Climate Action, and others. Actions should involve both the public and private sectors.

## Criteria Considered in Formulating Recommendations

To identify areas of focus and specific content of the recommendations, the Academic Expert Group agreed on a number of inclusion criteria:

1. Recommendations that extend beyond Sustainable Development Goal 3.6 and establish synergies with other Goals will be prioritized.

2. Recommendations that engage non-traditional partners with potential for leadership or constituencies that could reach widespread participation will be prioritized.
3. Recommendations must reach beyond those previously established in Declarations from the First and Second Ministerial conferences and Resolutions from intervening UN General Assemblies.
4. Recommendations must have compelling evidence of potential impact in terms of intervention effectiveness, scale of the problem addressed, and efficiency of the proposed solution.
5. Recommendations must adhere to the SMART principle:
   *Specific*: identifiable responsibilities and actions
   *Measurable*: tangible and observable with objective units of scale
   *Attainable*: possible considering known obstacles
   *Relevant*: consistent with the Safe System approach
   *Timebound*: achievable (or capable of substantial progress) by 2030

The Academic Expert Group recommends that additional consideration be given to monitoring progress toward achievement of the recommendations. While useful measurement tools are available, such as the UN Voluntary Global Performance Targets (United Nations 2018a) and their associated indicators (United Nations 2018b), these measures do not adequately reflect implementation of the Safe System approach. More work is needed to develop targets and indicators that reflect Safe System implementation (European Commission 2019).

## Recommendation #1: Sustainable Practices and Reporting

### Summary

In order to ensure the sustainability of businesses and enterprises of all sizes, and contribute to the achievement of a range of Sustainable Development Goals including those concerning climate, health, and equity, we recommend that these organizations provide annual public sustainability reports including road safety disclosures and that these organizations require the highest level of road safety according to Safe System principles in their internal practices, in policies concerning the health and safety of their employees, and in the processes and policies of the full range of suppliers, distributors, and partners throughout their value chain or production and distribution system.

### Rationale

The traditional assumption that road safety is solely the responsibility of governments is being challenged by several factors. First, while some governments have led substantial improvements in road safety in prior decades, relying on government leadership and regulation has not resulted in sufficient progress in recent years in most countries. This shortcoming is despite the launch and growth of a worldwide road safety movement stimulated by the UN Decade for Action for Road Safety 2011–2020 that was largely targeted at engaging and directing government action.

Second, governmental strategies to improve road safety have largely targeted the regulation of individual road user behaviors, missing the opportunity to engage organizations such corporations, businesses, civil society, and other authorities in road safety commitments.

Third, the scale and potential road safety impact of large multinational corporations is larger than that of many governments. Supply chains associated with multinational corporations account for over 80% of global trade and employ one of five workers (Thorlakson et al. 2018).

The World Economic Forum points out that a number of multinational corporations have grown to such a scale that they eclipse most national governments in gross annual revenue (World Economic Forum 2016). Other authors point out that the scope of multinational companies allows far-reaching influence. More than 30 financial institutions have consolidated revenues of more than $50 billion each – more than the gross domestic product of 2/3 of the world's countries. Beyond their economic power, multinational companies shape social conditions. In developing nations, large corporations may spend more on education than the government (Khanna 2016) (Fig. 5).

Clearly, corporations and businesses have the power and global reach to effectively contribute to the achievement of the SDGs. A number of frameworks, principles, and guidelines have been developed over the past decades to establish expectations concerning their contributions, including:

- International Labour Organization Tripartite Declaration of Principles Concerning Multinational Enterprises and Social Policy
- UN Global Compact Principles
- UN Guiding Principles on Business and Human Rights

These principles address responsibilities such as universal rights, environmental concerns, and anti-corruption standards, defining minimum expectations for

**The world's biggest economic entities**

Based on a ranking from Global Justice Now. Data from the Fortune 500 and CIA World Factbook. Compares government and corporate revenues

| |
|---|
| 1. United States |
| 2. China |
| 3. Germany |
| 4. Japan |
| 5. France |
| 6. United Kingdom |
| 7. Italy |
| 8. Brazil |
| 9. Canada |
| 10. Walmart |

Source: Global Justice Now, CIA World Factbook and Fortune

**How the 10 biggest corporations compare to economies**

Based on a ranking from Global Justice Now. Compares government and corporate revenues. Overall ranking in brackets

| |
|---|
| 1. Walmart (10) |
| 2. State Grid (14) |
| 3. China National Petroleum (15) |
| 4. Sinopec Group (16) |
| 5. Royal Dutch Shell (18) |
| 6. Exxon Mobil (21) |
| 7. Volkswagen (22) |
| 8. Toyota Motor (23) |
| 9. Apple (25) |
| 10. BP (27) |

Source: Global Justice Now, CIA World Factbook and Fortune

**Fig. 5** World's largest economic entities (World Economic Forum) companies engaging in sustainable development activities. Other guidelines include the ISO 26000 Guidance on Social Responsibility and regional guidance such as the OECD Guidelines for Multinational Enterprises (Sustainable Development Compass 2015).

Businesses recognize the value of corporate virtue, and the SDGs provide a timely and widely endorsed opportunity for corporate engagement in sustainability. A review of business trends in the book *The Market for Virtue* concludes that corporate social responsibility has been a global phenomenon since the 1990s and that the business case for such practices is widely understood and applied. However, the author explores the extent of corporate sustainability practices and suggests that they could go much further (Vogel 2005).

An analysis performed by Oxfam in 2018 (Mhlanga et al. 2018) found mixed evidence of corporate action in responding to the SDG opportunity. An important positive finding is that more companies – especially multinational organizations – are making commitments to the SDGs in their corporate communications. This is an essential step forward; however, evidence concerning increases in corporate action were more difficult to identify.

A large body of evidence supports the benefits of sustainable practices. A review over 200 academic papers on sustainability and corporate performance found that:

- Ninety percent of the studies find that sound sustainability standards lower the cost of capital of companies,
- Eighty-eight percent of studies conclude that solid environmental, social and governance practices result in better operational performance, and
- Eighty percent of studies show that stock price performance is positively correlated with sustainability practices (Clark et al. 2015).

Increasingly, investors are looking beyond solely economic indicators before purchasing a firm's stock or providing capital. One in four dollars now invested in the USA – a total of $23 trillion/year globally – is now directed to firms after considering their environmental, social, and governance performance (Scott 2019).

Sustainability reporting is key to stimulating corporate change. Reporting that is relevant, reliable, and accessible will help businesses organize and prioritize their efforts, actuate the business case for corporate virtue by enabling meaningful external review, and stimulate the application of stakeholder pressure, both positive and negative.

### Actions and Responsibilities

Sustainability reporting standards and models are available from a number of sources, including those developed by Global Reporting Initiative (GRI) who report widespread use of their standards among the world's largest corporations (GRI and Sustainability Reporting 2019).

Existing literature provides little detail on how to report on road safety in the context of the Sustainable Development Goals. Further work is needed to facilitate this reporting task. Because organizations differ in the ways they can affect sustainability, including their opportunities to improve road safety, reporting standards should be specific to the functions of the organization. For example, opportunities for sustainability contributions by a manufacturing firm that uses trucks to bring in raw materials and distribute products will be far different than a banking organization that performs its transactions electronically. Specific standards for several industrial sectors are now being developed by GRI. To fully reflect road safety sustainability actions across the range of public and private sector organizations, many more such targeted reporting standards – including standards for road safety reporting – are needed.

With regard to road safety targets 3.6 and 11.2, reporting should be internal and external and extend across the full range of the corporate value chain. A value chain is the full scope of activities – including design, production, marketing, and distribution – businesses conduct to bring a product or service from conception to delivery. For companies that produce goods, the value chain starts with accessing raw materials used to make their products and includes every other step including distribution and use by purchasers (Harrison 2018).

Author Michael Porter from Harvard Business School was the first to discuss the concept of a value chain and how it can be used to identify opportunities and focus energy to increase corporate value. Porter points out five primary activities in a corporate value chain (Porter 1998):

- ***Inbound logistics*** are the receiving, storing, and distributing of raw materials used in the production process.
- ***Operations*** is the stage at which the raw materials are turned into the final product.
- ***Outbound logistics*** are the distribution of the final product to consumers.
- ***Marketing and sales*** include advertising, promotions, sales-force organization, distribution channels, pricing, and managing the final product to ensure it is targeted to the appropriate consumer groups.
- ***Service*** refers to the activities needed to maintain the product's performance after it has been produced, including installation, training, maintenance, repair, warranty, and after-sale services.

While specific opportunities will vary, nearly every business, corporation, or government organization could contribute and report on road safety across their value chain. Using Porter's model, the following table illustrates a number of possibilities:

| | Inbound logistics | Operations | Outbound logistics | Marketing and sales | Service |
|---|---|---|---|---|---|
| **Vehicle manufacturer** | Require component suppliers to follow a road safety management program (e.g., ISO 39001) | Advance safe design at every opportunity including speed limiters and driver impairment detection | Require distribution carriers to follow safest routes to dealerships and that professional drivers comply with safety rules | Provide vehicles with at least the UN-recommended eight minimum safety standards for every global market | Provide training on use of safety devices and free safety checkups for first and subsequent owners |

(continued)

| | Inbound logistics | Operations | Outbound logistics | Marketing and sales | Service |
|---|---|---|---|---|---|
| **Clothing producer** | Require textile and garment assembly firms to provide safe transportation to and from the factory for workers | Set expectations and monitor safety performance by contracted trucking operations | Contract only with freight carriers that use an effective safety management program | Promote active and safe mobility with clothing design and in advertising | Design bicycle helmets and offer at reduced cost to clothing customers |
| **Local government authority** | Require procured services to act safely, use safe vehicles, and have a system for safety management | Require employees to choose the safest travel options and practice safe behaviors while traveling on duty | Ensure that shipping is performed by services that comply with safety requirements | Publish safety performance and results openly | Advise citizens on safe travel options, such as safe routes to school |
| **Insurance company** | Require facilities, advertising or other service providers to follow a road safety management program | Purchase only vehicles with highest NCAP ratings for corporate fleet | Reduce unnecessary travel with electronic communications | Reward safe driving by insured using voluntary speed monitoring systems | As part of basic service, provide safety devices such as bicycle helmets and child safety seats to customers |
| **Mobility service provider** | Ensure that navigation maps are produced with boundary conditions reflecting safety and environmental needs | Use only vehicles with the highest NCAP score and minimal $CO_2$ and noise impact | Use geofencing to make sure delivery of services is safe and sustainable | Publish safety & environmental impact of the service | Advise citizens on safe service options, such as selection of safe routes |

Beyond direct control of their value chain, large corporations and non-government organizations also have political influence. A number of authors have suggested that sustainability reporting also addresses corporate political activities that are relevant to the achievement of the SDGs. National policies and regulation are critical for driving SDG achievement, and corporate engagement in the political and legislative process is an important influence on such rules (Lyon et al. 2018; Vogel 2005).

Finally, while corporate action and reporting are vital for road safety and the full range of SDGs, the same applies to governments, who have primary responsibility for review of SDG progress and follow-up. Governments at every level can report on sustainability actions in their own operations and, through their governance practices, can influence reporting by the private and non-profit sectors. The UN High-Level Political Forum for the 2030 Agenda provides a mechanism for countries to submit Voluntary National Reviews. Conducting such reviews is an important indicator of political commitment and is also likely to influence the quantity and quality of corporate reporting.

Between 2016 and 2018, 111 of the 193 Member Nations submitted Voluntary National Reviews, with an additional 73 Reviews scheduled to be presented in 2019 and 2020. Nearly all countries with populations greater than 100 million have submitted or plan to submit a Review by 2020. Together these countries represent more than 90% of the global population and large shares of economic and trade activities.

While the UN provides guidelines for the preparation of Voluntary National Reviews, the scope and depth of those submitted vary greatly in terms of institutional mechanisms for conducting the review, participation of non-government organizations, and the use of data and statistics to measure progress (HLPF 2018). More uniform quality and consistency in these Reviews could improve their impact.

#### This Recommendation Is Linked to Others Including

Procurement, Modal Shift, Child and Youth Health, Zero Speeding, 30 km/h, and Technology.

## Recommendation #2: Procurement

### Summary

In order to achieve the Sustainable Development Goals addressing road safety, health, climate, equity, and education, we recommend that all tiers of government and the private sector prioritize road safety following the Safe System approach in all decisions, including the specification of safety in their procurement of fleet vehicles and transport services, in requirements for safety in road infrastructure investments, and in policies that incentivize safe operation of public transit and commercial vehicles.

### Rationale

Corporations, businesses, and government organizations have tremendous influence on society through a range of factors, from political influence to the nature of their products and services. A substantial component of this influence is by means of their spending on the goods and services necessary for their function.

Government procurement is estimated to be 10–15% of gross domestic product on average (World Trade Organization 2019), with some analyses showing that the GDP portion of public procurement in low-income nations is slightly higher than that in high-income countries (Djankov and Saliola 2016). The World Bank reports a total global GDP of about 86 trillion US dollars in 2018 (World Bank Group 2019), with low- and middle-income nations contributing about $32 trillion of that total.

With total corporate procurement spending estimated at an average of 43% of revenues (Schannon et al. 2016) and the revenue of the 500 largest companies totaling $30 trillion (Ventura 2019), the aggregate public and private procurement sums are very large indeed. The social influence of this spending – if directed to incentivize sustainable practices and investments, including road safety – is substantial.

Both government and corporate spending is directed to a value chain – the full scope of activities to bring a product or service from conception to delivery. For companies that produce goods, the value chain starts with accessing raw materials used to make their products and includes every other step including distribution and use by purchasers. Corporate and government services have similar value chains, including the tools, materials, and contracted services needed to conduct and disseminate their function.

When a government controls the safety behaviors of individuals, the burden of enforcement is on the government, and as a result there are certain tolerance levels and inconsistencies in compliance. But when a government deals with a provider of goods or services, and road safety is an integral part of the contract, the burden of enforcement is delegated to the provider. The firm that is supplying the goods or services is motivated to keep the contract and compelled to comply with its terms. Thus, it is important that businesses contracted in public procurement demonstrate capability to comply with safety standards, including having a system to monitor and correct incidents of non-compliance. This example of governance decentralizes monitoring of road safety compliance and can lead to widespread culture change.

#### Actions and Responsibilities

Each expenditure across the value chain could be used to improve road safety. For example, contingencies could be placed on procurements based on suppliers' policies or performance with regard to (Bidasca and Townsend 2015):

- *Specifications for vehicle safety levels, including powered two-wheelers*, to be used in carrying out procured services. These specifications could go well beyond minimum levels required by domestic governments, to include advanced safety technologies such as speed limiters and impairment detection systems, and could also set limits on vehicle age. In some countries, vehicles owned by businesses and corporations comprise more than half of total vehicle registrations, so the reach of such contingencies could be substantial.

- *Requirements for training of drivers involved in performing procured services, including those who ride powered two-wheelers and other motorized personal mobility devices*, in addition to traffic codes and appropriate extreme condition driving skills, such training could involve education regarding fatigue, distraction, speed, impairment, and other safety factors.
- *Expectations for road safety monitoring, reporting, and performance*. These expectations could require that firms receiving contracts demonstrate higher-than-average performance across their fleet in terms of crash involvement and traffic citations.
- *Standards for scheduling* and planning procured driving operations. These could include practices to manage driver fatigue, use of low-risk roads, use of lower-risk vehicles, and improved times for travel.

Standards and recommended practices for these safety practices and for overall corporate road safety risk management are available from a number of sources including the International Organization for Standardization (ISO) (2012).

Prioritizing road safety in procurement practices of corporations and governments could have far-reaching effects. Businesses underlie 84% of the GDP and 90% of the jobs in developing countries, and, by utilizing their full value chains, they can improve the lives of those who are at greatest risk for a range of threats including motor vehicle crashes (Bertelsmann Stiftung and Sustainable Development Solutions Network 2019).

When making decisions about using procurement to improve road safety, corporations and governments should keep Safe Systems principles in mind. Contingencies placed on procurements will have the greatest long-term effects if they are designed to accommodate predictable human errors and create an environment where crash forces are limited to human injury tolerances.

Safe System principles would favor vehicle safety requirements that accommodate driver errors, such as electronic stability control and automatic emergency braking, and devices that could reduce crash forces, such as intelligent speed adaptation. Other Safe System procurement strategies could include requirements that contracted services use routes with good road design including separated pedestrian and bicycling facilities, roundabouts, road diets, and traffic calming to reduce speeds around vulnerable road users.

### This Recommendation Is Linked to Others Including

Sustainable Practices and Reporting, Modal Shift, Safe Vehicles, Zero Speeding, 30 km/h, Technology, and Infrastructure.

## Recommendation #3: Modal Shift

### Summary

In order to achieve sustainability in global safety, health, and environment, we recommend that nations and cities use urban and transport planning along with mobility policies to shift travel toward cleaner, safer, and affordable modes incorporating higher levels of physical activity such as walking, bicycling, and use of public transit.

### Rationale

Evidence points to the widespread value of decreasing dependence on personal motor vehicles for transport and increasing use of safer, cleaner, and healthier alternatives. According to the World Health Organization, insufficient physical activity is the fourth leading risk factor for global mortality and is on the rise in many countries, adding to the burden of non-communicable diseases and affecting general health worldwide (World Health Organization 2011). Active travel can help prevent many of the 3.2 million deaths from physical inactivity, 2.6 million of which are in low- and middle-income nations.

The burden of insufficient physical activity is particularly severe for the younger population. The most recent estimates indicate that 81% of adolescents aged 11–17 years do not meet the WHO's Global Recommendations on Physical Activity for Health. Physical inactivity is estimated to cost more than $50 billion US annually in increased healthcare expenditures (Ding et al. 2016) or about 2–3% of national healthcare expenditures in high-, middle-, and low-income nations (Bull et al. 2017).

A critical prerequisite to modal shifts is safe environments for walking and biking and low-speed powered two- or three-wheelers. Evidence from developed countries ranks biking and walking among the least safe modes of transportation (ETSC 2019).

In our current environment, shifting individual trips from automobiles to walking or bicycling is often considered in terms of a trade-off between safety and health. For example, a systematic review conducted by the EU-funded PASTA (Physical Activity through Sustainable Transport Approaches) Project examined 30 independent analyses of the health impact of active mobility and found that the health benefits of increased physical activity far outweighed increases in safety and health risks associated with walking or bicycling. These results were consistent across analysis methodologies and geographic areas involved (Mueller et al. 2015) (Fig. 6).

However, in the context of the Sustainable Development Goals, safety and health should not be traded off against one another. Consistent with the principle that the Sustainable Development Goals are integrated and indivisible, priority should be given to actions that will allow improvements to both safety and health. The risks associated with pedestrian and bicycle travel are correctable by redesigning walkways and bicycle pathways to separate these modes from traffic moving at greater than 30 km/h and by providing better lighting and safer street crossings (Fig. 7).

### Actions and Responsibilities

The WHO Global Action Plan on Physical Activity points out that policies that promote compact urban design and prioritize access by pedestrians, cyclists, and users of public transport can reduce use of personal motorized transportation, carbon emissions, and traffic congestion as well as healthcare costs while stimulating the economy in local neighborhoods and improving health, community well-being, and

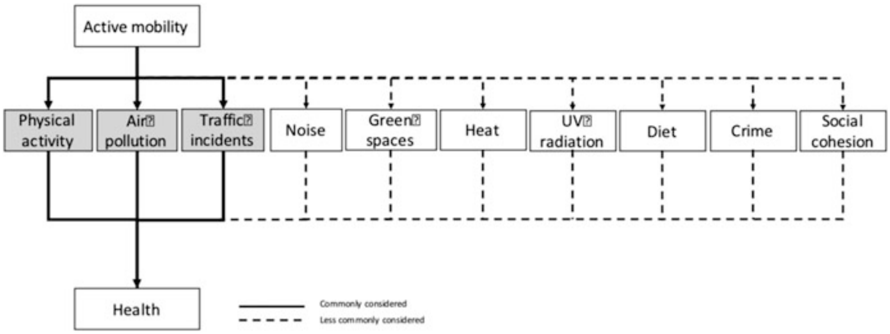


**Fig. 6** Health determinant contribution to the estimated health impact of mode shift scenarios to active mobility (Mueller et al. 2015)

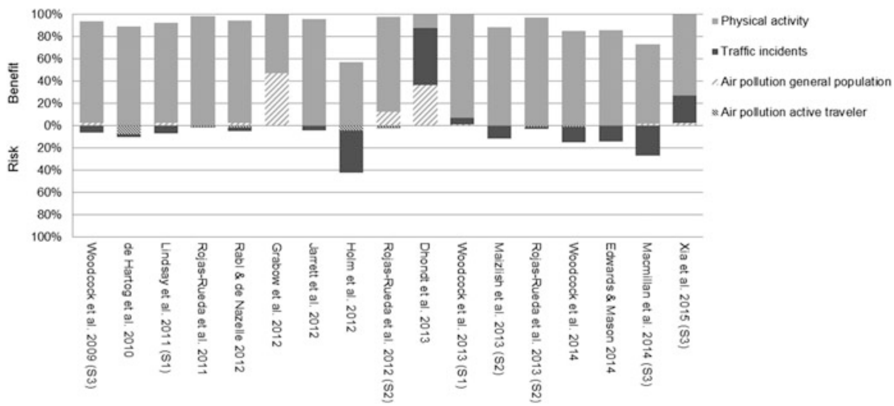


**Fig. 7** Health determinants of active mobility (Rabl et al. 2012)

quality of life (World Health Organization 2018b). Improved infrastructure, both physical and digital, could improve the availability and safety of shared micro-mobility options such as e-scooters and e-boards.

In addition to eliminating risks to pedestrians and cyclists from motor vehicle traffic, crime needs to be controlled to improve perceptions of security. A number of studies have documented the association between perceived personal safety and frequency of walking or bicycling. A study of attitudes and walking habits in 8 European cities showed that the odds of occasional walking were 22% higher among women and 39% higher among men who perceived their neighborhood as being safe (Shenassa et al. 2006). Similar findings were reported from a study in Nigeria which measured frequency of physical activity and found that women were far more affected by both traffic and crime perceptions than men (Oyeyemi et al. 2012).

The Global Action Plan on Physical Activity also indicates that beyond their direct effect on road safety and health, safer walking and bicycling routes could contribute to a range of Sustainable Development Goals, including Goal 4 (Quality Education), Goal 5 (Gender Equality), Goal 9 (Industry, Innovation and Infrastructure), Goal 10 (Reduced Inequalities), Goal 11 (Sustainable Cities and Communities), Goal 13 (Climate Action), Goal 15 (Life on Land), and Goal 16 (Peace, Justice and Strong Institutions).

Infrastructure investments and policies that improve perceptions of safety, both from traffic and crime, and especially address gender safety concerns, are important prerequisites to encouraging modal shifts to active mobility. Well-maintained sidewalks, walking and bicycling paths that are separated from fast-moving traffic, adequate pedestrian crossing facilities, and effective street lighting are critical safety measures.

The iRAP star rating program for roads has been effective in stimulating investment in road safety. A star rating program specifically for pedestrian and bicycling facilities could be effective in calling attention to the need for safety improvements such as physical separation from fast-moving motorized traffic and safe crossings where necessary. Geofencing (i.e., digital infrastructure to allow only specific vehicle types and speeds in designated geographic areas) could also be effective in reducing pedestrian and bicycling risk.

Policy evaluations have compared a variety of approaches for stimulating modal shifts. A study of experience in four midsize northwest European cities concluded that the greatest modal shift results from a mix of car-constraining "push" strategies along with "pull" policies that encourage alternatives to car transportation (Dijk et al. 2018).

#### This Recommendation Is Linked to Others Including

Infrastructure, Zero Speeding, 30 km/h, and Child and Youth Health.

## Recommendation #4: Child and Youth Health

### Summary

In order to protect the lives, security, and well-being of children and youth and ensure the education and sustainability of future generations, we recommend that cities, road authorities, and citizens examine the routes frequently traveled by children to attend school and for other purposes; identify needs, including changes that encourage active modes such as walking and cycling; and incorporate Safe System principles to eliminate risks along these routes.

### Rationale

Our children are our most valuable societal asset, and we cannot look into the future without special consideration for their welfare. This principle underlies the development of the UN declaration of children's rights (United Nations 1989). While mortality among children less than 5 years of age is down over the past decades (World Health

Organization 2019), the children of today are the first in history to have a predicted lifespan shorter than that of their parents (World Health Organization 2018b). Recent decreases in overall life expectancy have resulted from other factors, but motor vehicle crash deaths remain the leading cause of death globally for ages 5–29.

Another substantial risk to child health, lack of physical activity, is related to road safety in that the safety of roads affects decisions about when and where children will walk or bicycle. Both road safety and the frequency of physical activity could be improved by a few common measures. Widespread adoption of compact living centers and highly connected neighborhoods that reduce dependence on motor vehicles could facilitate both the frequency and safety of walking and bicycling for daily transportation. This type of physical activity as a regular routine is particularly beneficial to health.

However, the popularity of walking and bicycling is declining in many countries, especially in low- and middle-income nations where large numbers of people are switching from active mobility to personal motorized transport (Li et al. 2017), including scooters or mopeds, which can be driven by those as young as age 14 in many countries.

Two UN human rights conventions in the 1989 Declaration of the Rights of Children, the Right of Protection from Abuse and Neglect and the Right to Guidance from Caring Adults, have underpinned child safety legislation around the world, including child passenger safety laws. Because of widespread concern for the welfare of children, laws that protect children in traffic are often easier to enact than similar legislation addressing all ages. This has been the case with child passenger safety legislation in many countries, where such laws preceded seat belt laws or, in some locations, were among the first traffic laws of any kind.

Child safety legislation has often served as an introduction to the concept of traffic rules, and their enactment has increased the willingness of citizens and policy-makers to take further legislative steps that extend protection to the remainder of the population. Examples of child-specific safety legislation include child safety seat laws for infants and toddlers, booster seat and seat belt laws for older children, prohibitions against carrying children in cargo areas of trucks, bicycle helmet laws, bans on carrying children too small to reach footrests on powered two-wheelers, and enhanced penalties for drunk driving if children are in the vehicle.

Target 4.7 of Sustainable Development Goal 4, Quality Education, seeks to "ensure that all learners are provided with the knowledge and skills to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development." Safe routes to school can help ensure that children and youth are exposed to this type of education and that they have the opportunity to use their global citizenship to make a better world, possibly leading change for safer roads in the way that Malala Yousafzai has advocated for women's education and Greta Thunberg has championed environmental responsibility.

An important part of child and youth education is role modeling by parents and other adults. Young people are influenced by the behaviors of people they respect and admire, so it is important that adults demonstrate the types of road safety attitudes and behaviors that children need in order to be safe road users.

### Actions and Responsibilities

An important reason for the shift away from walking and bicycling is the perception of a lack of safety of public spaces. Studies indicate that investment to improve sidewalks and street crossings and provide designated bicycle lanes could increase the number of people using active forms of transportation (Aziz et al. 2018). Programs such as Vision Zero for Youth promote investment in road, pedestrian, and cycling infrastructure, targeting corridors frequently used by children on their route to and from school or recreational facilities. By improving the safety and frequency of walking and bicycling by children and youth, such programs address a range of Sustainable Development Goals, and by following the Safe System approach in designing infrastructure improvements, these programs could serve an important role in introducing communities to Safe System processes.

Infrastructure design needs to accommodate the special needs of children, particularly the younger ones, who cannot be expected to understand and comply with non-intuitive rules or behaviors. Routes traveled by children should use designs such as separated pedestrian walkways to limit risk exposure and include safe crosswalks where children are likely to feel the need to cross the road. Schools have an important responsibility to analyze, propose, and support implementation of safe routes to the schools.

Countries can pay particular attention to the age at which young people are permitted to operate cars, trucks, or powered two-wheelers to ensure that drivers have adequate maturity and judgment. Graduated driver licensing is proven to be effective in facilitating learning and controlling risk exposure for young drivers.

In many countries, children are frequent passengers on powered two-wheelers. Because of the inherent risks of this mode of travel and because smaller children are at particular risk since they often situated on the vehicle in an unstable manner, the goal should be to provide safer modes for child mobility. However, when families have no choice other than a powered two-wheeler for child mobility and needed changes such as transportation planning will take substantial time, countries and local jurisdictions should consider measures that could reduce the risk for children on powered two-wheelers in the shorter term. Such measures could include helmets for children, special lower speed limits for powered two-wheelers carrying small children, or route restrictions that would prevent these vehicles from traveling on busy or higher speed roads where alternatives are available.

### This Recommendation Is Linked to Others Including

Zero Speeding, 30 km/h, Modal Shift, Safe Vehicles, Infrastructure, and Procurement.

## Recommendation #5: Infrastructure

### Summary

In order to realize the benefits that roads designed according to the Safe System approach will bring to a broad range of Sustainable Development Goals as quickly and thoroughly as possible, we recommend that governments and all road authorities allocate sufficient resources to upgrade existing road infrastructure to incorporate Safe System principles as soon as feasible.

### Rationale

Road design is critical in the Safe System approach. While each component of the system – people, vehicles, the road, and the environment – is important, road design is perhaps the most powerful means for achieving high levels of system safety. In-depth crash investigations have shown strong interactions between the roles of vehicles, road infrastructure, and road users in contributing to serious crashes and indicate that road infrastructure factors are most strongly linked to crash fatalities (Stigson et al. 2008).

Well-designed roads and roadsides encourage safe driving speeds, heighten driver attention where risks are increased by the presence of vulnerable road users, prevent the types of crashes that lead to the most serious injuries, provide segregated traffic flows, and reduce risks of serious outcomes in run-off-the-road crashes when drivers make errors. Poorly designed roads not only fail to protect road users from crashes; they also encourage behaviors that drastically increase risk such as inappropriate speeds and interactions between vehicles and crossing pedestrians.

In the Safe System, roads are designed according to their function using a range of classifications with each type having features that ensure safety for all road users. Residential or business district streets have narrower lanes and frequent lane shifts, elevation changes, or other features to maintain safe speeds, as well as visual cues to keep drivers attentive for interactions with vulnerable road users. Roads intended to carry higher speed traffic have wider lanes and longer sight distances, along with roundabouts or other intersection treatments to prevent the most serious crash types, and separation of vulnerable road users to protect them from the higher vehicle speeds. All roads should be designed to control speeds and manage the kinetic energy of moving vehicles so that when drivers or other road users make errors, they will be protected from crash forces that could cause death or serious injury.

Upgrading design standards so that new roads are built according to Safe System principles and bringing existing roads to the same standard is essential to achieving the road safety targets among the Sustainable Development Goals. The World Resources Institute analyzed changes in road deaths in 53 countries over a 20-year period and found that nations which experienced the greatest declines in road fatalities and achieved the lowest fatality rates were those that adopted the Safe System approach (Welle et al. 2018).

The benefits of safe roads go beyond reductions in serious injuries and deaths. Slower and smoother traffic flow improves air quality, reduces noise, and enhances community health and quality of life. Roads designed according to Safe System principles have a dramatic effect on the safety of vulnerable road users and, by improving the comfort of walking and bicycling, encourage healthy modal shifts for short trips.

The costs of road improvements are manageable in context. Studies indicate that as little as 1–3% of road construction budgets are needed to make road safety improvements (Welle et al. 2018) and that when the value of lives saved and serious injuries prevented are considered, the return on investment is positive.

Two additional factors contribute to the urgency of investment in safe roads, urbanization and motorization. The global trend toward urbanization will cause widespread expansion of cities and create new urban areas in the coming decades with an increasing mix of traffic users. The UN Department of Economic and Social Affairs predicts that urban areas will grow by more than 50% over the coming 30 years, with the great majority of this expansion occurring in Africa and Asia (World Urbanization Prospects 2018). New roads and infrastructure will be necessary to accommodate the urban expansion, and this creates an opportunity to incorporate Safe System design features from the beginning.

A 2014 study by RAND and the Institute for Mobility Research on the future of driving in developing countries analyzes factors affecting adoption of personal vehicles and found that, based on the experience of developed nations, car-friendly infrastructure is the second most critical factor after spatial dispersion of the population in determining eventual dependence on personal motor vehicles for mobility (Ecola et al. 2014).

The authors of the RAND study point out that the trajectory of automobile dependence is likely to be shaped during the period of motorization and that many developing nations are in this period at the current time. Investment in roads that are designed according to Safe System principles can reduce serious crash injuries, encourage active mobility, create healthier urban living spaces, and help shape sustainable communities.

Infrastructure upgrades could also include digital resources to support the availability of digital speed maps as well as road fixtures and markings that can be recognized by advanced vehicle safety systems. For example, road markings that can be read by the vehicle can enable vehicle systems to prevent unsafe lane changes and run-off-the-road crashes. Studies of such systems have shown a clear safety effect (Sternlund 2018).

### Actions and Responsibilities

It is recommended that infrastructure providers apply infrastructure safety measures according to Safe System principles. A number of comprehensive references are available to guide such investments, including the compendium of knowledge published by Austroads in 2018 (Woolley et al. 2018).

### This Recommendation Is Linked to Others Including

Zero Speeding, 30 km/h, Safe Vehicles, Technology, and Child and Youth Health.

## Recommendation #6: Safe Vehicles Across the Globe

### Summary

In order to achieve higher and more equitable levels of road safety across the globe, we recommend that vehicle manufacturers, governments, and fleet purchasers ensure

that all vehicles produced for every market be equipped with recommended levels of safety performance, that incentives for use of vehicles with enhanced safety performance be provided where possible, and that the highest possible levels of vehicle safety performance be required for vehicles used in private and public vehicle fleets.

### Rationale

Vehicle safety technology has proven to be effective both in preventing crashes and in saving lives when crashes happen. Vehicle safety systems serve an important role in the Safe System approach by addressing these core principles:

*Accommodating human error*: Crash avoidance technologies such as automatic emergency braking systems – available in two- and four-wheeled motorized vehicles – or electronic stability control systems compensate for driver errors in vehicle control in emergency conditions.

*Limiting crash forces to levels within human injury tolerance*: Crashworthiness technologies, including seat belts, airbags, frontal and side impact protection, and pedestrian protection, reduce forces by extending deceleration times and managing the manner in which forces are directed to the body. Some of these technologies are also applicable to powered two-wheelers.

*Pursuing a commitment to proactive improvement*: Mandated safety standards apply to all specified new vehicles, ensuring that virtually all such vehicles will be equipped over a period of time.

Safety standards in place in many developed nations have been highly effective in saving lives over the past 50 years. For example, an analysis of mandated passenger car, bus, and truck safety technologies in the USA indicates that between 1960 and 2012, technologies associated with Federal motor vehicle safety standards prevented more than 600,000 crash deaths (Kahane 2015).

However, there are stark disparities around the world in the adoption of mandatory vehicle standards covering the most critical safety technologies. The 2018 Global Status Report on Road Safety identifies 8 critical safety vehicle standards and indicates that while 40 countries have implemented 7 or 8 of these standards, 124 countries worldwide have implemented none or just 1 of these requirements (World Health Organization 2018a).

Since 2011, only six nations have acceded the 1958 Agreement on Harmonized Technical Regulations for Wheeled Vehicles, Equipment, and Parts. Without such standards, manufacturers could produce vehicles for these markets without safety devices as a cost-savings measure. The countries that lack critical vehicle safety standards are mostly developing nations where 50% of new vehicles are sold and road travel is most hazardous (World Health Organization 2015).

A study of the potential benefits of adopting key safety standards in Latin America examined the improvements that could be realized if Argentina, Brazil, Chile, and Mexico adopted international standards for electronic stability control, pedestrian impact protection, and automatic emergency braking for vulnerable road users. Researchers estimated that about 14,000 lives and 290,000 serious injuries could be saved between 2020 and 2030 if these countries adopted regulations requiring these devices.

This study also examined the costs and benefits of these regulations and determined that the per-vehicle cost would be about $50 US for electronic stability control, $261 for automatic emergency braking for vulnerable road users, and $258 for pedestrian impact protection. The economic benefits resulting from the reduced crashes, serious injuries, and death these technologies would bring across the four countries over this period would total $28.9 billion. Benefits would exceed costs beginning in 2023 (Wallbank et al. 2019).

The UN vehicle standards apply to passenger cars, large trucks and buses, and motorcycles. However, such safety standards for other road transport modes like bicycles and scooters are lacking, an issue that should be addressed as soon as possible.

In addition to improvements of safety standards for new vehicles, the overall safety of vehicles in low- and middle-income nations could be improved by limiting the import of secondhand vehicles that were built to comply with older, less stringent standards. The effectiveness and economic feasibility of such import policies should be studied.

#### Actions and Responsibilities

Regulation can be effective in establishing minimum levels of vehicle safety. A voluntary industry agreement specifying similar levels of safety could also be effective if it were widely adopted by manufacturers. Other approaches, including consumer information and fleet purchases, can be effective in lifting safety performance beyond minimum levels.

Consumer information regarding auto safety is available through New Car Assessment Programs (NCAP) which work in conjunction with national regulatory functions to motivate consumer demand for improved vehicle safety and influence the level of safety provided by vehicle manufacturers. A number of regional, national, and domestic NCAP are active and have shown success in stimulating the market for passenger cars with crash avoidance and protection performance beyond minimum local standards. These programs serve an important educational role, using crash test results to inform users of the need for safe vehicle design and the differences in safety between specific makes and models.

NCAP have shown success in stimulating the market for safer cars, and a similar approach should be pursued to educate consumers about safety features and crash performance of trucks, buses, and powered two-wheelers. It is important to note that NCAP are not comparable among regions, which prevents the promotion of consistently safe vehicles all over the world.

All vehicle manufacturers should present information to consumers on the safety performance of their vehicles beyond minimum standards, either through NCAP testing, their own testing, or both. One such measure that should be included by every passenger car manufacturer is the ability of their vehicles to safely accommodate small children without the need for extra equipment. Another test that would further improve NCAP effectiveness is the capacity of crash avoidance technologies to identify and avoid vulnerable road users, including powered two-wheelers.

The potential for informed purchasers to shape the market for safer vehicles can be pursued at an even higher level by engaging corporate and government fleet purchase operations. Fleet purchases are an important way for governments and corporations to contribute to Sustainable Development Goals and can have far-reaching effects on overall road safety.

In some countries, two of every three new car sales are to corporate fleets (Deloitte Insights 2017). Corporate and government fleet purchasers can specify the types of vehicle purchased, the safety features required, and policies concerning driver behavior and vehicle use. Safety information from New Car Assessment Programs, together with business standards such as the Road Safety Management System Standard 39001 from the International Organization for Standardization (ISO), can help fleet purchasers make the best decisions.

An additional opportunity for improving road safety around the world is to upgrade safety technology in heavy trucks and buses. Global safety standards specify fewer advanced safety technologies for large trucks and buses than for passenger cars, and safety features such as electronic stability control, forward collision warning, lane departure warning, and blind spot detection warning have not been widely adopted in these vehicles. Factors affecting this disparity include limited information on technology effectiveness and additional complexity in fitting some systems to long or articulated vehicles (Sweatman 2017).

A study of heavy vehicle safety in Oman suggests that technology could be especially important in low- and middle-income countries where improving economies could increase heavy vehicle use and consequent safety risks (Al-Bulushi et al. 2015). New global safety regulations for heavy vehicles together with an NCAP-type consumer education approach would be effective in stimulating improvement in truck and bus safety.

The safety of powered two-wheelers could be improved by requirements for limiting speed, improving stability, and incorporating design features that would protect passengers and other vulnerable road users from injury during impacts. This should be done by both regulation and through NCAPs (Strandroth et al. 2011).

In addition, new vehicle types entering the market, such as motorized personal mobility devices, should be regulated with regard to maximum operating speed and safety performance and subjected to consumer tests.

#### This Recommendation Is Linked to Others Including

Sustainable Practices and Reporting, Procurement, Child and Youth Health, 30 km/h, Zero Speeding, and Technology.

## Recommendation #7: Zero Speeding

### Summary

In order to achieve widespread benefits to safety, health, equity, climate, and quality of life, we recommend that businesses, governments, and other fleet owners practice a zero-tolerance approach to speeding and that they collaborate with supporters of a range of Sustainable Development Goals on policies and practices to reduce speeds to levels that are consistent with Safe System principles using the full range of vehicle, infrastructure, and enforcement interventions.

### Rationale

Speed management is essential to reductions in crashes, serious injuries, and fatalities. Road users from around the world report significant rates of speeding by as much as 20 km/h over the speed limit (Meesmann et al. 2008). The Safe System approach optimizes the speed of mobility while minimizing the number of road user casualties. In the Safe System, designers specify speed limits based on evidence of vehicle and road safety and the assumption that drivers and other road users will make errors. Vehicle and road design can help prevent certain errors. For example, roundabouts eliminate traffic lights, reduce speeds, and prevent drivers from red light running.

When an error happens, vehicle and road design can also help avoid a crash. For example, electronic stability control will intercede to keep a vehicle in control when a driver makes a control error. If a collision does occur, vehicle and road design can help limit the crash forces that reach the occupants to levels that will not cause serious injuries. However, speed determines the amount of energy that must be managed in a crash, and even the best vehicle and road designs have limits. When speeds exceed the ability of the road and vehicle to manage crash forces, serious injury or death may result.

Speeds in the Safe System are set so that vehicle and road design features can limit crash forces to human injury tolerance limits. For example, vehicles that meet UN or equivalent national standards are designed to limit crash forces to their occupants to survivable levels in side impacts up to collision speeds of 50 km/h. Therefore, the Safe System would limit speeds to 50 km/h or less on roads with intersections where side impacts can be expected. Standards require that vehicles limit crash forces to their occupants to survivable levels in frontal crashes up to 70 km/h. Consequently, speed limits should be set to 70 km/h or less on roads where there is no center barrier and head-on collisions are possible and where no pedestrians or other types of vulnerable road users are present. While these estimates have been developed for passenger cars, further research is needed to confirm safe travel speeds for other vehicle types in various environments (Ohlin et al. 2019). Other research estimates that lower speeds may be necessary to reduce the probability of serious injury to less than 10% (Jurewicz et al. 2016).

The relationship between speed and the probability and severity of crashes has been well researched in both theory and practice. In general, higher speeds increase both the likelihood of crashing and the severity, though the magnitude of the effect varies according to the absolute speed and environmental circumstances (Elvik 2013). Studies have shown that relatively small changes in travel speeds can result in substantial changes in death or injury in crashes (Elvik 2009). A review of empirical studies from ten countries by the International Transport Forum confirms the theoretical relationship and demonstrates that reducing travel speeds by just a few km/h can greatly reduce the risks and severity of crashes (International Traffic Safety Data and Analysis Group 2018). Conversely, a study of speed limit increases over a 25-year period in the USA published by the Insurance Institute for Highway Safety found that speed limit increases between 1993 and 2017 were responsible for 36,760 deaths (3.8% of the total), with 1900 lives (5.2%) lost in 2017 alone (Farmer 2018).

Vehicle speeds are directly linked to a number of Sustainable Development Goals, and this opens the potential for new partners to support the implementation of speed management methods. While the most direct link to speed would be the road safety targets 3.6 and 11.2, there are also strong links to Goal 5 (Gender Equality) and Goal 10 (Reduced Inequalities) due to the improved perception of safety for vulnerable road users that is associated with lower road speeds in populated areas. A higher level of perceived safety is likely to lead to greater mobility and expanded opportunities for social needs including education (Goal 4) and employment (Goal 8).

Vehicle speeds are also related to environmental noise levels. A 2017 study used a comprehensive national noise measuring campaign in the UK and a refined methodology to measure traffic noise and found that 30 km/h road speeds reduced acoustic energy levels by about half (Beuhlmann and Egger 2017). Environmental noise has been linked to sleep disorders, heart disease, stress, and, among children, decreased school performance, including decreased learning, lower reading comprehension, and concentration deficits (Hammer et al. 2014).

### Actions and Responsibilities

Speed limits in the Safe System need to be determined according to the principles described above, and system owners – the officials who set the standards for road design and vehicle safety – must take responsibility for integrating effective speed management methods to ensure that vehicles remain in compliance.

A variety of methods can be used to control speeds, including:

- Appropriate speed limits determined according to the Safe System approach.
- Public education on the risks associated with speeding along with awareness of active enforcement activity.
- Road designs that cause drivers to travel at the desired speeds by constraining visual fields or introducing obstacles that are most easily negotiated at the safe speed limit.
- Vehicle technologies that detect speed limits and prevent higher speeds or provide warnings when the speed limit is exceeded.
- Businesses, governments, and other fleet owners practice a zero-tolerance approach to speeding in their own or procured transport operations.
- Effective enforcement methods and practices, along with substantial penalties for offenders.

Vehicle speed is so fundamentally related to Safe Systems and societal health that responsibility for compliance and assurance should permeate the community. There can be no tolerance limits for unsafe speeds. Incorporating speed compliance as a contractual prerequisite in public and corporate procurements is an important strategy for modeling this zero-tolerance approach. In such business relationships, providers of products or services are motivated to utilize their own speed compliance methods to avoid violating conditions of the agreement and losing the contract.

The best approaches for ensuring compliance with safe speeds will be consistent with Safe System principles. These approaches will utilize infrastructure and vehicle design to reduce opportunities for drivers to unintentionally – or intentionally – exceed speed limits. Roads can be designed so that drivers find it most comfortable to travel at safe speeds. Connected vehicle technology can be used in conjunction with speed limiters and geofencing to control speeds in specific areas.

Speed enforcement is also of importance, and the use of automated speed cameras is shown to be effective. Section control, sometimes called camera-to-camera systems, is found to be effective not only for safety but also for emissions including significant reduction in $CO_2$ noise levels (Thornton 2010). Section controls as part of an integrated enforcement strategy require only limited margins for error as variations in speed will be picked up by measuring the average speed rather than the point speed.

### This Recommendation Is Linked to Others Including

Sustainable Practices and Reporting, Procurement, Child and Youth Health, Safe Vehicles, 30 km/h, and Technology.

## Recommendation #8: 30 km/h

### Summary

In order to protect vulnerable road users and achieve sustainability goals addressing livable cities, health, and security, we recommend that a maximum road travel speed limit of 30 km/h be mandated in urban areas unless strong evidence exists that higher speeds are safe.

### Rationale

In the Safe System, roads and vehicles are designed to accommodate human errors without resulting in serious injury or death. Allowable vehicle speeds in the Safe System are a function of the level of safety provided by other parts of the system.

While this concept holds true for many parts of the system, dense urban areas present a special case. Safe vehicle and road design features are especially critical in urban areas where vulnerable road users, including pedestrians, bicyclists, and motorcyclists, are a constant part of the road user environment. The concentration of vulnerable road users in urban neighborhoods, together with the complexity of traffic patterns and the frequency of road user interactions, creates extraordinary crash and injury risk. In these dense urban areas, even the best road and vehicle design features are unable to adequately guarantee the safety of all road users when speeds are above the known safe level of 30 km/h.

A maximum speed limit of 30 km/h in urban areas is widely supported by researchers and safety experts to provide adequate protection for vulnerable road users (Global Road Safety Partnership 2008; Kroyer 2014; International Traffic Safety Data and Analysis Group 2018). A review of available international research on the relationships between impact velocity change, impact speeds, and probability of serious or fatal injuries suggests that the safe limit for pedestrians struck by passenger cars may be even lower. Figure 8 illustrates that the risk of serious injury begins to climb sharply at 20 km/h (Jurewicz et al. 2016). A study of bicycle crashes also shows that 30 km/h may still produce serious injuries for these vulnerable road users (Ohlin et al. 2019).

A systematic review conducted by Cairns et al. found 10 independent studies of 30 km/h or 20 mph zones or limits and concluded that these measures show convincing evidence of reductions in crashes, injuries, traffic speed, and volume. The studies also include evidence of cost-effectiveness, improved levels of perceived safety by residents, and positive community response for the speed limits (Fig. 9).

The review by Cairns et al. points to evidence of socioeconomic inequalities in crash injuries internationally, and, while none of the reviewed studies directly addressed this effect, the authors extrapolate from available evidence and suggest that 30 km/h zones or limits could be effective in reducing these inequalities (Cairns et al. 2015).

Reducing urban speeds to 30 km/h has a range of additional benefits such as noise reduction and more active mobility. A 2017 study by Buehlmann and Egger published by the Institute of Noise Control Engineering used a comprehensive national noise measuring campaign in the UK and a refined methodology to measure traffic noise and found that 30 km/h road speeds reduced acoustic energy levels by about half (Beuhlmann and Egger 2017). Environmental noise has been linked to sleep disorders, heart disease, stress, and, among children, decreased school performance, including decreased learning, lower reading comprehension, and concentration deficits (Hammer et al. 2014).

It is clear that 30 km/h urban speed limits improve the quality of urban life in a number of dimensions. In addition, 30 km/h speed limits could have a long-term effect on community mobility patterns. A 2014 study by RAND and the Institute for Mobility Research on the future of driving in developing countries analyzed factors affecting adoption of personal vehicles and found that, based on the experience of developed nations, car-friendly infrastructure is the second most critical factor after spatial dispersion of the population in determining eventual dependence on personal motor vehicles for mobility (Ecola et al. 2014).

The authors of the RAND study point out that the trajectory of automobile dependence is likely to be shaped during the period of motorization and that many developing nations are in this period at the current time. Policies that slow motorized traffic, reduce serious crash injuries, create healthier urban living spaces, and encourage active mobility can shape communities that are on a path toward realization of a range of Sustainable Development Goals as suggested under the recommendation for Modal Shift.

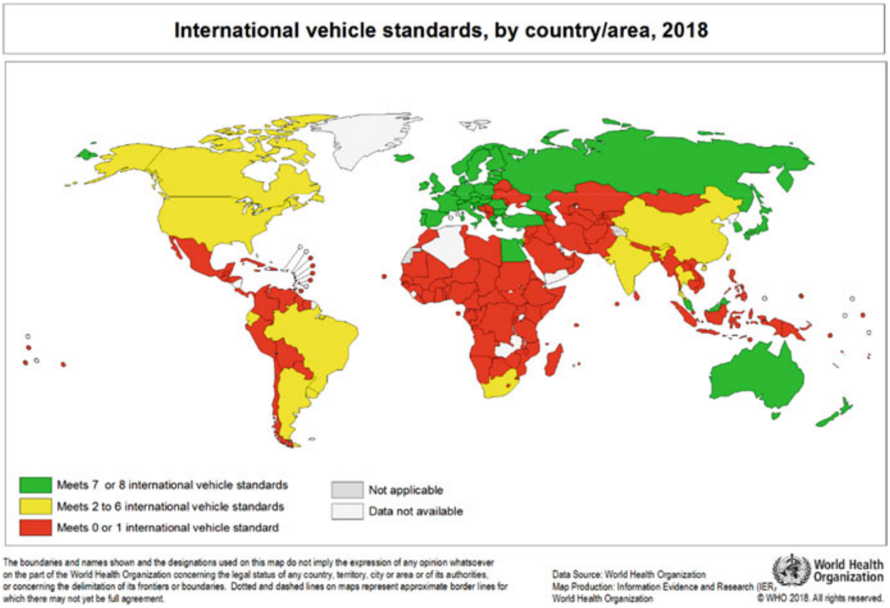


**Fig. 8** Compliance with international vehicle safety standards (World Health Organization 2018a (UNECE data))

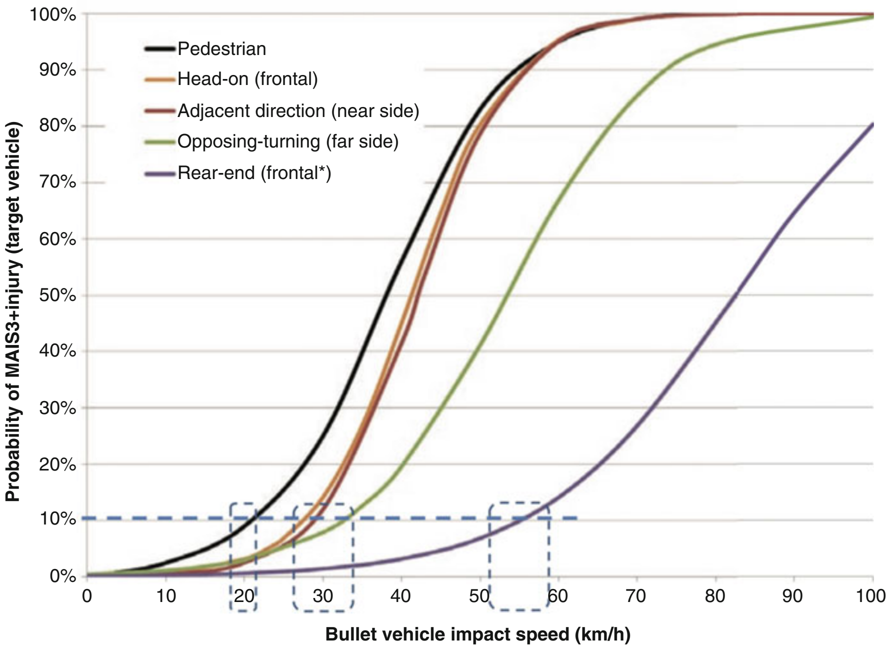


**Fig. 9** Probability of severe injury when struck by a motor vehicle (Jurewicz et al. 2016)

### Actions and Responsibilities

Compliance with the 30 km/h urban speed limit is best achieved through techniques that are consistent with Safe System principles and thereby reduce the opportunity for drivers to unintentionally – or intentionally – exceed the speed limit. These include infrastructure designs such as road diets, chicanes, raised intersection tables, and other road features that calm traffic by affecting the comfortable driving speed for most vehicles.

Adopting connected vehicle technology would allow vehicle speed limiters to be used together with geofencing to control speeds in designated areas. Automated speed enforcement could include section control, where the mean speed over longer distances is measured along with point camera enforcement.

### This Recommendation Is Linked to Others Including

Sustainable Practices and Reporting, Infrastructure, Safe Vehicles, and Zero Speeding.

## Recommendation #9: Technology

### Summary

In order to quickly and equitably realize the potential benefits of emerging technologies to road safety, including, but not limited to, sensory devices, connectivity methods, and artificial intelligence, we recommend that corporations and governments incentivize the development, application, and deployment of existing and future technologies to improve all aspects of road safety from crash prevention to emergency response and trauma care, with special attention given to the safety needs and social, economic, and environmental conditions of low- and middle-income nations.

### Rationale

The role of advanced technology in improving road safety in high-income countries has been well discussed in scientific, policy, and ethics literature. There is little doubt that automated vehicles will save lives over the coming decades. But opinions differ widely on questions such as how many will be saved, how soon the savings will begin, and how many deaths might be caused by imperfect technologies during the development period. Perhaps the most reasonable observation is that vehicle automation in the form of automated driving systems, including electronic stability control, lane change warnings, and automatic emergency braking, is currently saving lives in many countries (National Highway Traffic Safety Administration 2017). This development fits very well with the Safe System approach. Full self-driving technology is likely to reach and be adopted in different countries at different stages due to political, economic, technological, and infrastructural reasons.

Advanced vehicle safety technologies are among the most effective of all automotive safety devices. An early example of crash avoidance technology, electronic stability control, has been shown to be 30–50% effective in preventing fatal single vehicle passenger car crashes and 50–70% effective with sport utility vehicles (Ferguson 2007). A recent study by TRL Limited indicates that the cost of electronic stability control if adopted in Latin America would be about $50 per vehicle (Wallbank et al. 2019).

Whether Moore's Law on declining costs for computing power continues to hold true is under debate (Simonite 2016). However, history has shown that the consumer price for computer equipment dropped by 95% between 1997 and 2015 (Bureau of Labor Statistics). So it is not unreasonable to expect that the cost of the computational technology needed for electronic stability control or similar crash avoidance technologies, such as automatic emergency braking or intelligent speed adaptation, will decrease over the coming decades. This could facilitate widespread adoption in low- and middle-income nations, particularly if the domestic regulatory upgrades encouraged by the World Health Organization, Global New Car Assessment Program, and others are pursued.

The question of whether new in-vehicle technologies could be developed over the coming decades that might be suitable for use in low- and middle-income nations could almost certainly be answered in the affirmative. However, realization of that potential will require the commitment of both the public and private sectors. Automotive technology is changing at an unprecedented rate, so it seems highly likely that there will be candidate safety devices in the coming years. The availability of advanced safety technology in low- and middle-income nations could also be expanded by corporate investment in road safety through their value chains as part of their commitment to the Sustainable Development Goals. Such investment could include provision of fleet vehicles in these regions with high levels of safety equipment.

Technologies outside the vehicle could also make a difference in low- and middle-income countries. One example is post-crash care, where communications technology – perhaps built upon the near-ubiquitous mobile phone – could facilitate effective bystander care for the injured. Where ambulances are not available, technology could provide route guidance for delivering crash victims to the nearest medical facility capable of trauma care.

Another important infrastructure application for advanced technologies is speed management, including geofencing and infrastructure-to-vehicle communications. Studies of the benefits of Intelligent Speed Adaptation using such technology predict potential crash reductions of up to 33% in urban areas and reductions in $CO_2$ emissions of up to 5.8% on high-speed roads (Lai et al. 2012).

Vehicle-to-vehicle and vehicle-to-infrastructure communications have potential for contributing to a number of Sustainable Development Goals, including climate, energy, and economic growth, as well as road safety. These technologies can enable vehicles to detect the movement of others on the road, including vulnerable road users, and adjust speed and direction to avoid conflicts. This capability could be particularly beneficial for the safety of pedestrians, bicyclists, and powered two-wheelers. Similar technology can also permit route planning to reduce congestion, reduce emissions, and optimize safety.

Communications and logistics technologies can reduce the need for travel by connecting people electronically for business and commerce and facilitating efficient and safe shipping of products and materials. However, some analysts have shown that these technologies may actually stimulate travel when first deployed because of the new opportunities for revenue and human interaction they produce. Later stages of adoption can involve both reductions in the amount and modifications in the types of travel needed to efficiently utilize the new technology (Banister and Stead 2004).

### Actions and Responsibilities

Stimulating the development of safety technology that would be appropriate for developing nations is a leadership challenge. In order to move those candidate safety technologies into large numbers of new cars destined for low- and middle-income nations, auto manufacturers will need to commit to installing the devices in the appropriate vehicles, and governments will need to create a demand by enacting necessary safety standards.

Businesses can also play a role in introducing safety technologies in low- and middle-income countries. For example, speed adaptation to local conditions using geofencing could be used by firms that operate fleets of heavy trucks in populated areas as a means to ensure safe speeds and protect vulnerable road users. Geofencing and crash avoidance technologies should be encouraged as part of micro-mobility services, such as scooters and e-bicycles, to manage speeds and prevent crashes especially where interactions with pedestrians or larger vehicles are likely.

### This Recommendation Is Linked to Others Including

Sustainable Practices and Reporting, Infrastructure, Safe Vehicles, Zero Speeding, and 30 km/h.

## Discussion

As we approach the end of the Decade of Action for Road Safety 2011–2020, we find ourselves with a strong foundation for change, but little progress overall in reducing the number of global road deaths and serious injuries. While it is disappointing that we were not able to bring the numbers down, the value of the foundation should not be underestimated. Substantial achievements were made in increasing awareness and recognition of the road safety crisis, gathering high-level leadership commitment, establishing a solid structure of measurement and targets, and developing a framework for action and a set of evidence-based tools.

## Lessons Learned from the Decade of Action 2011–2020

Among the important accomplishments of the Decade of Action was identifying and promoting a comprehensive set of evidence-based tools for improving road safety. These tools – organized under five pillars – cover a wide range of needs from road safety management to post-crash response. Over the decade, many of these tools have been used in a variety of environments around the world. The World Health Organization's Global Status Report on Road Safety 2018 highlights examples of drink-driving legislation reducing crashes and deaths in Brazil, road improvements in school zones in sub-Saharan Africa getting an improved star rating, and new e-bike regulations in China resulting in improved motorcycle safety (World Health Organization 2018a).

While the tools included in the five pillars are generally supported by evidence of effectiveness, in many cases, this evidence was generated in high-income counties, and results could differ in other situations. More research is needed to verify the effectiveness of these interventions across the range of environments found in middle- and low-income nations.

A strong and diverse road safety movement has been active for many years. The movement was well-developed before the Decade of Action 2011–2020 and was nurtured and expanded as a result of the UN leadership during the Decade. Considering its scale relative to the enormity of the global road safety crisis, the movement has been remarkably successful. The scientific community within the movement has established a substantial understanding of the social, economic, and technical factors influencing road safety. The public policy community has disseminated effective laws and regulations, and the capacity-building community has made significant inroads in enabling local decision-makers and implementers to pursue road safety interventions. Road safety advocacy groups, especially victims' organizations, have been influential in calling attention to road safety problems and motivating enactment of stronger laws. This ongoing work is responsible for the tremendous road safety progress seen in many nations over the past decades and will remain the essential guiding core as we move into the next decade.

A central lesson learned in the Decade of Action 2011–2020 is that while our tools are effective, we need to greatly expand their utilization across the globe. Our current road safety army is making great contributions, but simply is not of sufficient scale to affect change at a global level. There is currently a lack of capacity in terms of both road safety knowledge and action among governments and private sectors across the globe.

## Opportunities Beyond 2020

As we turn to the next decade, we can reflect on the evolution that has taken place in our methods to change road transportation and look forward to a further level of progress. From a prior dependence on the four E's – engineering, enforcement, education, and emergency medical services – many countries adopted the five pillars of road safety over the Decade of Action 2011–2020 and consequently developed a more comprehensive set of road safety interventions.

During the Decade of Action, other countries moved from a road safety program consisting of a set of disconnected interventions to adoption of the Safe System approach, which brought a fundamental shift in objectives and methods and resulted in more widespread and effective change. From a focus on using interventions to adapt human behavior to a complex and dangerous road and vehicle system, these countries evolved to an approach which seeks to adjust the system to accommodate the characteristics of human behavior. Many of the tools developed over the past decades as part of the four E's and five pillars of road safety remain essential in the newer context, with their application aligned with Safe System principles. Most of the countries that have adopted the Safe System approach are in the early stages of this change, and the results seen from those who are furthest along in the process are very encouraging.

Looking forward to the coming decade, we see a further evolutionary opportunity that could build upon both the tools of the five pillars and the methodology of the Safe System approach and result in widespread and sustainable change. This next level will involve integration of road safety in activities contributing to the Sustainable Development Goals and in the daily operations of a far-ranging collection of public and private sector organizations.

The specific inclusion of road safety targets in the 2030 Agenda for Sustainable Development reflects universal recognition that death and injury from road crashes are now among the most serious threats to the future of our people and planet. Moreover, the explicit characterization of the 17 Goals as "integrated and indivisible, global in nature and universally applicable" means that road safety is no longer a need that can be compromised or traded off in order to achieve other social needs. Further, the 2030 Agenda points out the deep interconnections among the Goals and targets, beginning with the fundamental interconnection of the health of people and the health of the planet and extending to many other interdependencies.

Together, these factors motivate a broad range of businesses, corporations, and government units to seek new opportunities to contribute in measurable ways to the Sustainable Development Goals, and whether their primary mission concerns the environment, social welfare, or human rights, road safety can be a relevant and viable element of that entity's contribution.

Governments, through their lead road safety and public health agencies, are a cornerstone of the road safety movement. They have the responsibility to address the full range of human needs for their citizens, including safe mobility, and serve the lead role in achievement of the Sustainable Development Goals. We have learned that governments cannot carry this burden alone and are compelled to use the opportunity of the Sustainable Development Goals to engage support from the business and corporate sectors.

## Recommendations from the Academic Expert Group

The Academic Expert Group, convened by the Swedish Transport Administration to advise on priority directions for road safety following the first Decade of Action, offers nine recommendations. Two of these, *Sustainable Practices and Reporting* and *Procurement*, concern corporate or governmental contributions to the Sustainable Development Goals. Three recommendations, *Modal Shift*, *Infrastructure*, and *Technology*, focus on the design of our future transportation system. Four others, *30 km/h*, *Zero Speeding*, *Safe Vehicles Across the Globe*, and *Child and Youth Health*, highlight specific interventions that are among the existing pillars, but so critical to progress that they warrant special attention.

The recommendations are interrelated and intended to be considered as a set rather than individually. For example, the potential of *Procurement* will be best realized if organizations are motivated to pursue *Sustainable Practices and Reporting*. Likewise, both *Procurement* and *Infrastructure* will facilitate achievement of *30 km/h* speed limits in urban areas, *Zero Tolerance for Speeding*, and *Modal Shifts*.

## Next Steps for Progress

Realizing the potential of these recommendations will require effective engagement – and meaningful contributions – of additional stakeholders and sectors of society in road safety activities. Even though compelled to contribute to the Sustainable Development Goals, these new partners – both public and private sectors – are not likely to spontaneously focus on road safety and launch effective interventions. They will need guidance, tools, and policy models.

To take advantage of this opportunity and engage new sectors in road safety interventions, we need to articulate a compelling case for their involvement; disseminate this message among leaders across the business, corporate, and public sectors; and create tools to assist these new partners in identifying how they can use their influence and their value chains to improve road safety. New measures will also be needed to track progress in engaging new sectors and assessing the outputs and outcomes of their road safety activities.

Engaging new sectors in road safety work will require significant preparation, leadership, and persistence from within the existing road safety community. Perhaps the greatest challenge as we move into the next decade will be to realize the potential of this new opportunity without detracting from our ongoing road safety work or neglecting the potential of the existing road safety community.

Capacity-building both among the public and private sector professionals already engaged in road safety activities and among new partners will be essential, and our current cadre of road safety technical experts will be urgently needed to design and conduct educational courses and programs. Many road safety professionals around the world currently lack the knowledge and skills necessary to develop and implement components of the Safe System. Knowledge of the Sustainable Development Goals is also critical, including an awareness of the full range of Goals, how road safety relates to these other needs, and how road safety could be incorporated in activities related to those Goals.

As we pursue this essential path, it is critically important that governments increase their efforts, both in direct response to road safety problems in their jurisdictions and also to engage active support of their Sustainable Development Goal partners. Through the combined efforts of governments, all those engaged in the road safety movement, and our new Sustainable Development Goal partners, achievement of the target of reducing road deaths and serious injuries by half by 2030 is feasible.

The Sustainable Development Goals offer tremendous hope and opportunity for the future of our people and our planet. The recommendations in this report reflect the combined experience, wisdom, and insight of the Academic Expert Group and point to transformative processes and tools that, if fully utilized, could achieve the road safety targets while contributing to other human, social, and environmental goals. We look forward to seeing national, sub-national, and city governments, businesses and corporations, and civil society consider these recommendations as they plan, implement, and report on their contributions to the full range of Sustainable Development Goals including road safety.

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# Miscommunications Based on Different Meanings of “Safe” and Their Implications for the Meaning of Safe System

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Chika Sakashita, R. F. Soames Job, and Matts-Åke Belin

## Contents



**Abstract**

While many countries are apparently adopting “Safe System” for road safety, the failure to deliver the vision of zero deaths and serious injuries continues in part due to the lack of a rigorous and agreed definition of “safe” in road safety. Multiple authoritative definitions of the adjective “safe” exist which may be categorized as probabilistic and absolute. While apparently similar, these definitions are in a fundamental sense inconsistent with each other. The probabilistic definition involves degrees of safety, through probabilities that harm is not likely or unlikely, or that there is little risk. The absolute definition presents safety as free from harm or not involving any risk or protected from danger. Road safety is currently communicated as though there is an agreed meaning of safe, but the vital conversation around what is meant by safe is not undertaken because the difference in usage of the term safe is not appreciated. For example, in road design and engineering, road design standards are generally developed to achieve this probabilistic definition of safety and not absolute safety: the road can be

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described as safe because it by itself (with perfect use) will not cause a crash, even though people still die on it. Based on the absolute definition of safe, such roads are not safe as unambiguously demonstrated by people dying on them. Calls for roads to be made safe employing the absolute definition are often met with the response that they are already safe (in the probabilistic sense), having been built to "accepted" design guidelines. The acceptance of the probabilistic definition of safe for Safe System hinders progress toward its fundamental aims of zero deaths and serious injuries. In order to achieve zero deaths and serious injuries, uniform understanding and acceptance of "safe" adopting the absolute definition is needed.

**Keywords**

Safe · Vision zero · Shared responsibility · Safe system · Absolute · Probabilistic

## Introduction

Deaths and injuries from road crashes remain an enormous burden worldwide. Each year, 1.35 million people are killed in road traffic crashes globally (World Health Organization 2018). Deaths and injuries from road crashes involve a violent event, life-changing grief and psychological suffering in injured victims and families left behind, reduced household income, living with permanent disability, and fighting for justice (Global Alliance of NGOs for Road Safety, 2020). Deaths and injuries also generate enormous costs to national economies and retard national economic growth (World Bank, 2017; Wambulwa & Job, 2019).

In 1997, the Riksdag, the Swedish Parliament, adopted Vision Zero as a new goal and strategy for road safety in Sweden (Swedish Government, 1997). Vision Zero as an overall public road safety policy differs from a more traditional road safety in how it defines a road safety problem and its causes, the long-term goal of road safety, how responsibility is shared between individuals and system providers (Job et al., 2022) and what the most appropriate strategies are to create a safe system (Belin et al., 2012). In the more than 20 years since the Vision Zero policy was adopted, it has spread internationally as a model of a public road safety policy (ITF/OECD, 2008, 2016; World Health Organization, 2017; World Bank, 2013, 2020; Job, 2017). It is not only in the transport sector that Vision Zero has attracted interest, but it has also spread and continues to spread to other sectors of Swedish society such as fire safety, patient safety, occupational accidents, and suicide (Kristianssen et al., 2018).

The Vision Zero approach began formally with adoption by the Swedish Parliament in 1997. In this approach, as adopted elsewhere, the Safe System is the state of the road transport system required to deliver the vision of zero deaths, acknowledging the need to provide a system which protects road users by accommodating the inevitability of human error and the vulnerability of the human body to physical force in crashes. A similarly system-based approach was also developed in the Netherlands with the name Sustainable Safety, and the Safe System approach has spread gradually to many countries. One of the first countries after Sweden to adopt the approach was Australia, most likely for two visible reasons. First, Claes Tingvall, a leading architect of Safe System in Sweden, moved to Australia for over 2 years and advocated for Safe System from his role leading road safety in the state of Victoria. Second, this advocacy fell on fertile ground ready for change: A push already existed for the system to be addressed rather than just the road user (for example, the assertion that road crashes are a political issue in the 1980s: Job et al., 1989), and Australia (especially including the states of Victoria and New South Wales) had reached highly effective levels of behavior change including high levels of safety-belt usage and powerful drink-driving enforcement through random breath testing resulting in large reduction in deaths (Job et al., 1997), yet leaving large numbers of people being killed or seriously injured. An improved approach was needed, and the broad road system was already the recognized target. Many countries representing all global regions have followed, including New Zealand, Canada, Qatar, Nigeria, and the countries of the European Union, and more recently the United States has adopted toward zero deaths. Globally influential organizations advocate for Safe System including the OECD, GRSF, the World Bank, World Health Organization, the United Nations Road Safety Collaboration which made Safe System a centerpiece of the *Global Plan for the Decade of Action on Road Safety 2011–2020* (UN Road Safety Collaboration, 2011), and most recently the "Stockholm Declaration" of the third Global Ministerial Conference on Road Safety 2020 (Government Offices of Sweden, 2020) as well as the United Nations General Assembly resolution on road safety included Safe System (General Assembly of the United Nations, 2020).

There are well-established evidence-based solutions which have proven to be effective in greatly reducing deaths and injuries (Welle et al., 2018) especially as related to speed management (Job & Sakashita, 2016a). Speed managing interventions deliver strong yet often underappreciated benefit-cost ratios (Yannis et al., 2008; SafetyNet, 2009; Elvik et al., 2009). It would seem justified to expect that a full suite of interventions comprehensively adopted would have the potential to eliminate road trauma, although no country has yet fully adopted the required interventions.

Comprehensive solutions and legislated requirements to ensure safety are adopted for other areas of human activity, such as workplace health and safety, yet oddly exclude road crashes generally. For example, in many high-income countries (HICs), companies are required to ensure the safety of their employees at work in offices as well as high-risk situations such as construction. While many countries are apparently adopting "Safe System" for road safety, the way it is commonly described, defined, and promoted in road safety hinders delivery of the zero deaths and serious injuries target which forms part of the Safe System Approach (Job et al., 2022; Belin, 2016).

This chapter argues that this failure to comprehensively address road safety is in part due to the lack of a rigorous and agreed definition of "safe" in road safety, presents an analysis of the meaning of "safe," and offers a rigorous definition of "Safe System" necessary to achieve elimination of deaths and serious injuries from road crashes.

## The Meaning of the Adjective "Safe"

Multiple authoritative definitions of the adjective "safe" exist. Various dictionaries (with the exception of the Oxford English Dictionary) offer slightly differently worded versions of what are clearly two different definitions of safe: probabilistic and absolute (as summarized in Table 1). While apparently similar, these definitions are in a fundamental sense inconsistent with each other. The first type of definition (see examples in Table 1, Probabilistic Definitions) involves degrees of safety, through probabilities with definitions including that harm is not likely or unlikely, or that there is little risk. The second class of definitions presents safety as absolute with definitions which include free from harm or not involving any risk or protected from danger (see examples in Table 1, Absolute Definitions). These two inherently inconsistent conceptualizations of "safe" in terms of absolute versus relative are also highlighted in previous literature (Hansson, 2012).

Another way to conceptualize the different uses of the term safe is to consider their perceived opposites. The probabilistic definitions of safe can be conceptualized as being the opposite of dangerous: A hungry great white shark is dangerous to anyone in the water near it, whereas the water without a shark is relatively safe (i.e., safe under the probabilistic definition). The absolute definition presents safe as the opposite of any risk. Thus, the water is not safe because people can make mistakes in the water such as swimming out too far from shore, swimming while impaired by alcohol, or not detecting and avoiding a rip (current) on a surf beach or in a river with consequent deaths. The vast majority of human deaths in water are due to drowning not sharks, yet the media and the generation of fear (perception of risk) are more focused on the remote risk of a shark attack (reflecting the sometimes significant gap between perceived and actual risk). The solutions typically offered for drownings emphasize swimmer responsibility with swimming lessons, as well as teaching water skills and awareness. Globally per year, there are around 320,000 drownings *(World Health Organization,* 2020*)* indicating that current approaches are not delivering real safety, compared with just over 100 provoked and unprovoked shark attacks combined, with most not being fatal (Florida Museum of Natural History, 2017).

Paralleling the contrast of sharks and drownings, road safety too often demonstrates a focus on emphasizing road user responsibility via training, awareness, and other elements of behavior change with similar failures to deliver absolute safety. Claims of safety are commonly based on the absence of danger in the sense that the road will not **cause** a crash, the parallel of sharks. The road causing a crash would be, for example, where the signage and the environment do not match, such as a curve advisory speed warning of 80kph for a curve which requires a speed of 30mph to be negotiated, or a junction where the signage and lines (or lack of them) indicate to drivers on all approaches that they have right of way. These are quite rare instances, and thus, fixing them as the criterion for safe results in little road safety value (Job & Sakashita, 2016b). The large majority of crash deaths (parallel to drownings) remain demonstrably ineffectively addressed with this approach to safety – with over 51 million failures each year globally (1.35 million deaths and up to 50 million

**Table 1** Definitions of "safe" in various dictionaries

| Source | Probabilistic definition | Absolute definition | Other definitions not as relevant to road safety |
|---|---|---|---|
| Cambridge Dictionary https://dictionary.cambridge.org/dictionary/english/safe | Not in danger or likely to be harmed<br>Not dangerous or likely to cause harm | Not harmed or damaged<br>Used to refer to things that do not involve any risk | (of a place) Where something is not likely to be lost or stolen<br>Used to say that you like and approve of someone or something |
| Collins Dictionary https://www.collinsdictionary.com/dictionary/english/safe | A safe place is one where it is unlikely that any harm, damage, or unpleasant things will happen to the people or things that are there | Something that is safe does not cause physical harm or danger<br>If a person or thing is safe from something, they cannot be harmed or damaged by it<br>If you are safe, you have not been harmed<br>If people or things have a safe journey, they reach their destination without harm, damage, or unpleasant things happening to them<br>If you are at a safe distance from something or someone, you are far enough away from them to avoid any danger, harm, or unpleasant effects | If something you have or expect to obtain is safe, you cannot lose it or be prevented from having it<br>A safe course of action is one in which there is very little risk of loss or failure<br>If you disapprove of something because you think it is not very exciting or original, you can describe it as safe [disapproval]<br>If it is safe to say or assume something, you can say it with very little risk of being wrong<br>If you say to someone that their secret is safe with you, you are promising not to tell it to anyone |
| Oxford English Dictionary https://www.oed.com/viewdictionaryentry/Entry/169673 | (The Oxford English is the only dictionary identified as not presenting an applicable probabilistic definition of safe) | Presenting no risk of physical harm; posing no threat, not dangerous<br>Unhurt, uninjured, unharmed; having escaped or been preserved from some real or apprehended danger | In sound health, well; healed, cured, restored to health<br>Mentally or morally sound or sane<br>Affording security from theft, loss, escape, etc. |

(continued)

**Table 1** (continued)

| Source | Probabilistic definition | Absolute definition | Other definitions not as relevant to road safety |
|---|---|---|---|
| | | Made without harm to the traveler | Affording guaranteed immunity from arrest, capture, attack, etc.<br>Certain to happen or be the case<br>Sure in procedure<br>Excessively cautious; unadventurous, unimaginative; bland, boring<br>Free from errors or flaws<br>Not likely to be wrong |
| Dictionary.com https://www.dictionary.com/browse/safe?s=t | Involving little or no risk of mishap, error, etc. | Free from hurt, injury, danger, or risk | |
| Lexico.com https://www.lexico.com/definition/safe | Not likely to be harmed or lost<br>Not likely to cause or lead to harm or injury; not involving danger or risk | Protected from or not exposed to danger or risk<br>Uninjured; with no harm done | (of a place) Affording security or protection<br>(derogatory) Cautious and unenterprising<br>Based on good reasons or evidence and not likely to be proved wrong |
| Merriam Webster https://www.merriam-webster.com/dictionary/safe | Not threatening danger<br>Not likely to take risks | Free from harm or risk<br>Secure from threat of danger, harm, or loss | Successful at getting to a base in baseball without being put out<br>*Obsolete*, *of mental or moral faculties*<br>Unlikely to produce controversy or contradiction<br>Trustworthy, reliable |
| Oxford Learner's Dictionary https://www.oxfordlearnersdictionaries.com/definition/english/safe_1?q=safe | Not likely to lead to any physical harm or danger<br>Where somebody/something is not likely to be in danger or to be lost | Protected from any danger, harm, or loss<br>Not harmed, damaged, lost, etc.<br>Not involving any risk | Not likely to be wrong or to upset somebody<br>Doing an activity in a careful way<br>Based on good evidence |

(continued)

**Table 1** (continued)

| Source | Probabilistic definition | Absolute definition | Other definitions not as relevant to road safety |
|---|---|---|---|
| | Not involving much risk | | Used by young people to show that they approve of somebody/something<br>Used by young people as a way of accepting something that is offered |

**Table 2** Two meanings of safe (probabilistic or relative vs absolute) and their implications in safety management

| Context | Degrees of safety | | | |
|---|---|---|---|---|
| | Danger of death | Moderate risk of death | Low risk of death | Zero risk of death |
| **Water safety** | Great white shark close by | No sharks but few other effective safety actions | Swimming lessons, promotion of safety, enforcement, and some limits on water access | Lifejackets, access restricted to safe swimming locations with lifeguards and monitoring systems |
| **Road safety** | Roads cause fatal crashes | Roads do not cause fatalities but few other effective safety actions | Driving lessons, promotion of safety, enforcement, and some limits on road access | Crash barriers, protective vehicles, and speeds constrained to survivable impact forces in crashes |
| **Safe system** | NA | NA | Probabilistic safety (but not Safe System) | Absolute safety (Safe System) |

injuries: World Health Organization 2015, 2018) almost all not involving a crash caused by the road (as described above). These contrasting definitions of "safe" are visually represented in Table 2. Applying the absolute definition of safe to the road transport system would require that the system does not allow deaths and injuries to occur – the Vision Zero Safe System goal.

## Confounded Use of "Safe" in Safe System

Appreciating the uses of these distinct meanings of safe in road safety is vital to resolving existing miscommunications. Road safety is a multidisciplinary field with different disciplines employing different meanings of the term safe while communicating as though there is an agreed meaning. In road design and engineering, safe generally takes the probabilistic form: The road is designed not to cause a crash and to guide the user to reduce errors. Thus, the road can be described as safe because it by itself (with perfect use) will not create danger, even though people still die on it. Road design standards are developed to achieve this probabilistic definition of safety not absolute safety. In most countries, road design standards are the equivalent of ensuring that we do not build swimming pools with sharks in them, and audits as commonly applied in many countries are the equivalent of removing sharks from swimming pools, while still allowing people to drown/die in crashes. This approach is facilitated by a continuing powerful culture of victim blaming, allowing the road to be presented as safe while those who crash are blamed for their unsafe behavior (Deborah, 2007; Job, 2020) or the unsafe behavior of a road user other than the victim. In the eyes of genuine Safe System advocates, such roads are not safe (as unambiguously demonstrated by people dying on them) because the absolute definition of safe is being employed. Vital miscommunications arise in this context. Calls for roads to be made safe by Safe System advocates are often met with the response that they are already safe, having been built to "accepted" design guidelines. The vital conversation around what is meant by safe is not undertaken because the difference in usage of the term safe is not appreciated. Highlighting this difference to the community may also increase broad appreciation of Safe System, the deeper (absolute) safety it offers, and the responsibility of governments and system operators for safety instead of being allowed to avoid this responsibility through victim blaming. Community understanding and demand could be a key driver of more genuine development of safe road systems.

A deeper problem in Safe System is also revealed by the visibility of the different meanings of safe: The Safe System concept fundamentally includes vision zero, and thus the names are interchangeable, though they emphasize different elements of the approach: Safe System is that which is required to deliver Vision Zero, whereas the name Vision Zero highlights the final objective. Vision Zero is the logical outcome of aiming for, and ultimate achieving, absolute safety: no risk and no danger, not low risk or little danger. However, Safe System itself has fallen victim to the use of probabilistic definitions of safe in various applications of Safe System. Two examples are apparent.

First, shared responsibility with road users is commonly articulated explicitly as a Safe System principle both in global guidance documents and in national strategies adopting Safe System, with only slight variations of description which retain the responsibility of road users for their safety (shared with system owners and operators). Examples abound: the classic *World Report* (World Health Organization and World Bank, 2004) asserted as part of safe system that "At the same time, the road user has an obligation to comply with the basic rules of road safety"; the *United Nations Global Plan for the Decade of Action on Road Safety* (UN Road Safety Collaboration, 2011) included "The individual road users have the responsibility to abide by laws and regulations"; the *Road Safety Strategy for South Australia* (Government of South Australia, 2011) and the *National Strategy for Ireland* (Road Safety Authority [Ireland], 2013) both included shared responsibility, described identically as: "Shared responsibility – everyone has a responsibility to use the road safely with organisations, businesses and communities taking responsibility for designing, managing and encouraging safe use of the road transport system." The Canadian Road Safety Strategy (Canadian Council of Motor Transport Administrators, 2016) and the United States road safety vision, *Towards Zero Deaths* (Towards Zero Deaths, 2014), similarly still include road user responsibility for their own safety.

While this is how safe system is commonly described and defined in many recent policy documents, this is not in line with the original ideas adopted by the Swedish parliament in October 1997. According to the decision, the responsibility for safety is split between the road users and the system designers (i.e., infrastructure builders and administrators, the vehicle industry, the haulage sector, taxi companies, and all the organizations that use the road transport system professionally), on the basis of the principles that:

- The system designers have ultimate responsibility for the design, upkeep, and use of the road transport system and are thus responsible for the safety level of the entire system.
- As before, the road users are still responsible for showing consideration, judgment, and responsibility in traffic and for following the traffic regulations.
- If the road users do not take their share of the responsibility (for example due to a lack of knowledge or competence) and personal injuries occur or other risky situations occur, the system designers must take further measures to prevent people from being killed or seriously injured.

The latter point is now pervasively omitted in policy positions.

Though this understanding of shared responsibility may not have been the original intention of Safe System in Sweden (While this is how safe system is commonly described and defined in many recent policy documents, this is not in line with the original ideas adopted by the Swedish parliament in October 1997. According to the decision, the responsibility for safety is split between the road users and the system designers (i.e., infrastructure builders and administrators, the vehicle industry, the haulage sector, taxi companies, and all the organizations that use the road transport system professionally), on the basis of the principles that: The system designers have ultimate responsibility for the design, upkeep, and use of the road transport system and are thus responsible for the safety level of the entire system. As before, the road users are still responsible for showing consideration, judgment, and responsibility in traffic and for following the traffic regulations. If the road users do not take their share of the responsibility (for example, due to a lack of knowledge or competence) and personal injuries occur or other risky situations occur, the system designers must take further measures to prevent people from being killed or seriously injured. The latter point is now pervasively omitted in policy positions), the subsequent descriptions of shared responsibility with road users under the banner of or in association with Safe System implicate the probabilistic definition of safe. With human fallibility acknowledged as a fundamental principle of Safe System, making (fallible) road users responsible for their own safety means that errors with fatal consequence are inevitable. This subtle acceptance of probabilistic definition of safe for Safe System hinders progress toward its fundamental aims of zero deaths and serious injuries.

Second, increasingly over time various documents refer to “Safe System Speed Limits” (e.g., ETSC, 2008; Government of South Australia, 2011; Ministry of Transport [New Zealand], 2010; Road Safety Authority [Ireland], 2013). The risk curve indicating the risks of deaths for different levels of speed – 30kmh where vulnerable road users are present, 50kmh where side impact crashes are possible, and 70kmh where head-on crashes are possible –has been (mis)employed to define what constitutes a “safe” speed limit, supposedly adhering to Safe System principles. Subtly merged “Safe System” limits are almost universally agreed, promoted (e.g., OECD, 2006; Sustainable Mobility for All, 2019; Tingvall and Haworth, 1999), and ubiquitously expressed in Safe System road safety strategies and plans even though those limits still carry a 10% probability of death in crashes. This 10% death risk generally presented as a part of Safe System clearly reflects the adoption of a probabilistic definition of safe not an absolute definition of safe. This subtly accepts a 10% death rate in crashes at these speeds as low risk (safe in a probabilistic sense) in addition to the many serious injuries which will occur at these speeds. This transformation of the use of “Safe System” moves away from its fundamental aims for zero deaths and zero serious injuries. Therefore, setting speed limits according to tolerance against kinetic energy needs to be seen as a step in the right direction rather than absolute safe speed limits. We still need more research to clarify appropriate operating speeds and speed limits from a safe system perspective (Belin and Vadeby, 2022).

## Conclusions: The Necessary Meaning of Safe System Including Vision Zero in Road Safety

In order to achieve zero deaths and serious injuries, the definition of “safe” in Safe System must be rigorously the absolute definition. Thus, a Safe System is a road system “***in which road users cannot be killed or seriously injured regardless of their behaviour or the behaviour of other road users***” (Job et al., 2022). This definition accurately encapsulates the absolute meaning of “safe” in terms of “protected/free from hurt, injury, danger, harm, damage or risk.” A Safe System must *protect* users and not *rely* on (fallible) users to protect themselves by behaving in a particular (safe, legal, and responsible) way. A system is not safe if the behavior of a user could cause death of that user or another person. In a Safe System, whether anyone suffers a death or a serious injury cannot be left to be dependent on the behaviors of human road users even as a share of responsibility. Once it is agreed that humans inevitably make mistakes and that the human body is frail and will not survive certain forces, the system must literally protect us from dangerous forces even in the event of error or when breaking the law intentionally or unintentionally. A uniform understanding of “safe” in road safety as the full accommodation of inherent human flaws and full protection with no serious harm under any circumstance is vital in order to facilitate a better understanding of Safe System and thus deliver Vision Zero on deaths and serious injuries.

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