What the Car Industry Can Do, Mercedes-Benz’ View

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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 article 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

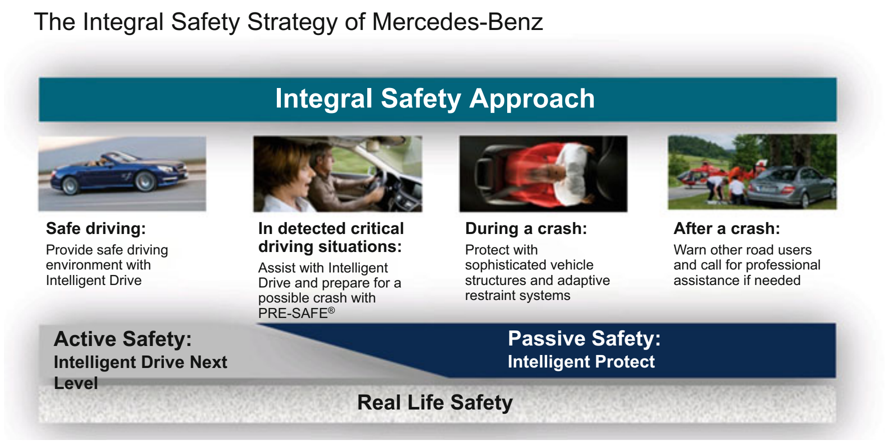

Fig. 1 The Mercedes-Benz concept of "Integral Safety"

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.

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.

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.

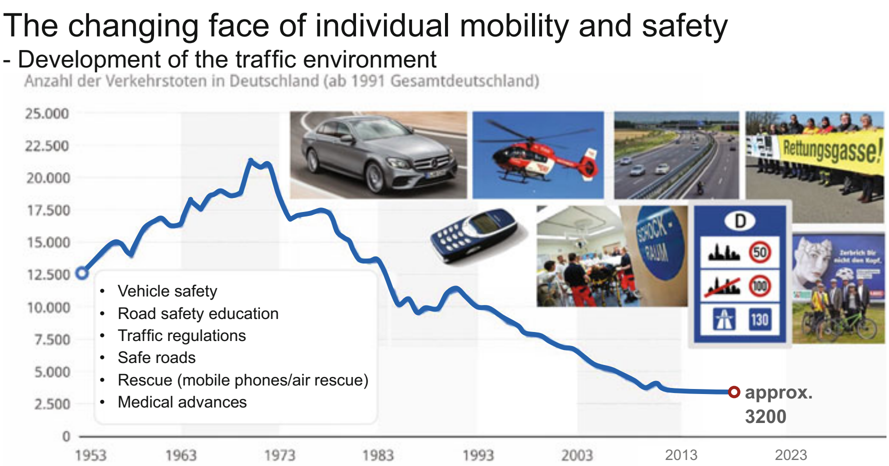

Fig. 2 Road traffic fatalities in Germany since 1953 and the development of associated factors

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.

- 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

Fig. 3 Factors influencing road safety

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

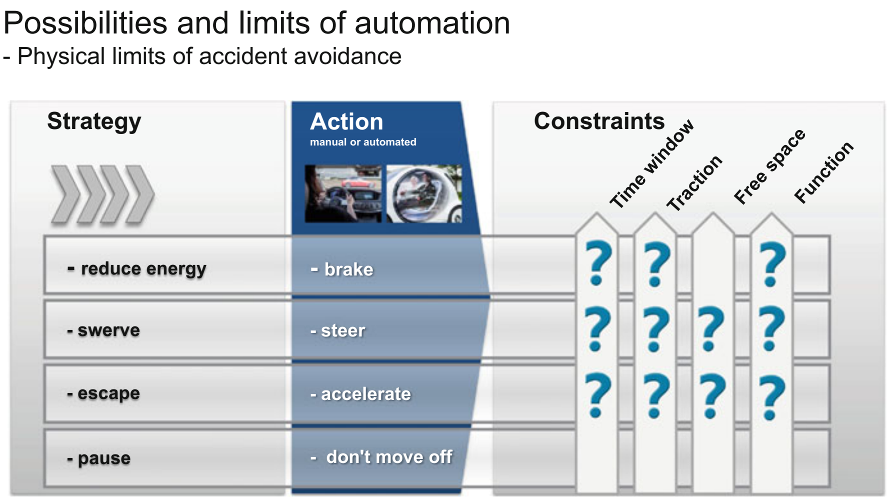

Fig. 4 Physical limits of accident prevention

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 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.

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

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:

- 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).

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

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 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

Fig. 7 Informed confidence/cooperative communication with the environment

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 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-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

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

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

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, 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 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,

Fig. 10 The virtual “crumple zone”

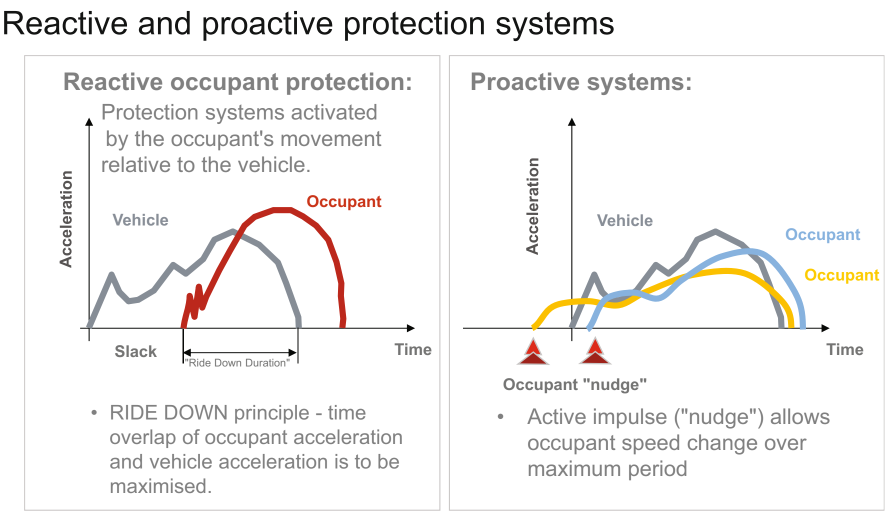

Fig. 11 The concept of "proactive" protection systems – PRE-SAFE® Impulse

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 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.

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

Fig. 12 New steering wheel and pedal cluster concept

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

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.

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

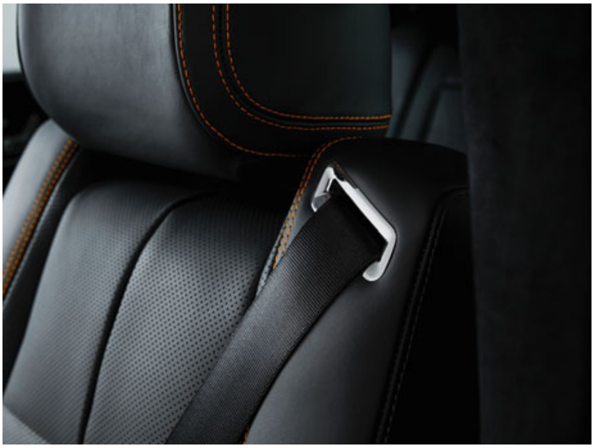

Fig. 14 New driver airbag for highly automated vehicles

Fig. 15 Integral sidebag for any seat position

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 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

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

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 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

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

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

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. 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

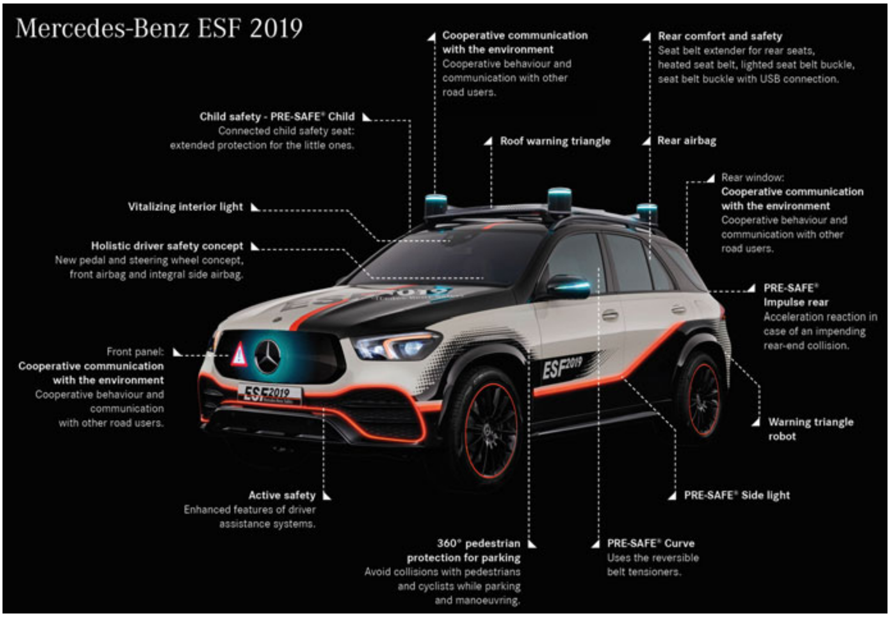

Fig. 19 Overview of the innovations found in the ESF 2019

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 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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