ENHANCEMENT OF ACTIVE & PASSIVE SAFETY BY FUTURE PRE-SAFE® SYSTEMS

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ABSTRACT

Advanced driver assistance systems in combination with new preventive safety systems offer great potential for avoiding accidents, reducing accident severity and increasing occupant protection. This paper presents the activities in this field at the Mercedes Car Group (MCG).

Driver assistance systems can be divided into systems that supply the driver with information during normal driving, systems that warn the driver when the probability of an accident increases, systems that assist the driver actively in avoiding an impending accident, and finally autonomously intervening systems. A special case of an intervention system is PRE-SAFE®: developed and first introduced by the MCG in 2002, PRE-SAFE® is a system that acts in the intervention phase. PRE-SAFE® has opened up new possibilities for vehicle safety by shifting the paradigm from the formerly separate fields of active and passive safety to an integral view of these two fields.

The future task is to enhance the elements of driver assistance systems and to integrate them in a comprehensive system. Since most of the current systems have no or only little information about the vehicle's surrounding, new sensors providing such information (cameras, 24-GHz radar) are especially needed.

How can driver assistance systems be enhanced on the basis of additional and more precise sensor information? Firstly, the driver can be informed and warned much more selectively and accurately. Secondly, systems that act in the assistance phase can be activated more often and provide much more precise support. For instance, BAS activation and support can take objects in front of the vehicle into account to avoid or mitigate a collision.

Thirdly, in the intervention or PRE-SAFE® phase, new occupant protection systems can be activated if an imminent and unavoidable collision is detected. Additionally, it might be possible to apply the brakes automatically in such a case to reduce the collision energy, which is also considered a contributing factor to crash compatibility.

INTRODUCTION

In its white paper on the safety of road users issued on September 12, 2001 the European Union set a 50% reduction in the number of fatalities among European road users by 2010 as its common goal [1].

As a manufacturer of motor vehicles Mercedes-Benz also recognizes its duty to do what it can in this regard, and proposes the following measures for a comprehensive approach to automotive safety:

- ➔ Intensified analysis of the pre-accident phase
- ➔ Further improvement of basic safety
- ➔ Comprehensive safety design of the vehicles
- ➔ Accident avoidance and mitigation through driver assistance systems

IMPROVEMENT OF BASIC SAFETY THROUGH RATING TESTS

Rating and consumer tests in passive safety have gained importance over the past years. These standardized tests evaluate vehicles regarding their protective characteristics in identical crash trials. A clear-cut evaluation system enables even lay people to evaluate the safety levels of different vehicles of the same class.

A five star Euro NCAP result can no longer be disregarded as a developmental goal today. The related basic safety has been optimized by most manufacturers. The development of suitable structural measures and the optimization of restraint systems have contributed to improving crashworthiness across all vehicle categories. Even small vehicles now feature this basic safety level, and yet we must keep in mind that results for different vehicle categories cannot be compared.

Owing to their greatly increased importance, rating tests, and therefore the committees initiating them, also bear a high responsibility for the future development of vehicle safety. Many comments on automotive safety in advertising refer to the safety quality of the vehicles in question in terms of Euro NCAP'S five star system. This concept and the rating as a measuring scale seem to have become established in consumers' minds.

When the EU's deficit analysis speaks of inadequate collision protection, then it is always in reference to the best tested vehicles of the particular category, which traditionally include Mercedes-Benz vehicles. For further developing the safety technology of these top-rated vehicles we had to ask ourselves the following critical questions:

➔ Are laboratory crash tests suitable for assessing the comprehensive vehicle safety that goes beyond basic crashworthiness?

➔ How can we measure improved crashworthiness if in the near future all vehicles will make the 5-star hurdle?

➔ Is further increasing the limits a useful measure?

➔ What adjusting levers can make a basic contribution to comprehensive vehicle safety?

Nowadays trials for developing and evaluating crash safety are standardized and performed in laboratories. For reasons of reproducibility and for assessing the progress of development, the same test speeds, vehicle overlap, seat positions, occupant weights and sizes are used. The results are applied in vehicle development and crashworthiness assessment. Specified limits and targets constrain the direction of development, and these standardized tests must always demonstrate the attainment of values.

But how is this related to vehicle safety in real-world accidents? Known variables for subsequent accident severity include the vehicle speed, with the collision configuration (type of collision, angle of collision, overlap, etc.) being a basic parameter. The criteria of New Car Assessment Programs refer only to passive collision protection, and therefore form only a small part of how a vehicle behaves in real-world traffic situations.

For example, standard systems for accident mitigation or accident avoidance, such as antilock brake systems, electronic stability programs and brake assistance systems, are not appreciated at present, although they have a large demonstrated potential for enhancing overall safety.

The interaction between occupants and the vehicle in the important pre-crash phase is also a basic variable in controlling the subsequent severity of injuries. Systems providing active support in this pre-accident phase have also not been evaluated to date, and yet significant reductions of subsequent crash load on real-world situations are possible.

Mercedes-Benz already developed a comprehensive approach to this matter in the mid-1990s and presented it in 1999 [2]. The aim of this approach is to describe the safety of vehicles in all phases of the traffic situation.

COMPREHENSIVE SAFETY DESIGN FOR IMPROVING VEHICLE SAFETY

This comprehensive approach to safety takes into account the individual phases with the potential for avoidance and mitigation, the potential for protecting occupants and other road users, and the potential for aftercare and rescue. This approach can be seamlessly incorporated in the relationships between the driver, the vehicle and the surroundings, and consequently serves as a guideline in the safety design of Mercedes-Benz vehicles [3].

Only this comprehensive consideration of vehicle safety in the normal driving condition, assistance and pre-accident phases, the variously influenced accident phases and finally occupant rescue can disclose further possibilities for reducing injuries and fatalities among road users.

For Mercedes-Benz vehicles we therefore have five areas of action for further enhancing overall vehicle safety:

- ➔ Safe driving and prompt warnings: the vehicle provides the occupants with a permanently safe work environment with the aim of avoiding hazards at their onset. Included are measures for driving safety, stress-reducing safety, operating safety and perceptual safety. The vehicle monitors its own condition, its environment and the interfaces to the driver and warns the latter in or prior to certain critical situations. Possible sensitivity-enhancing measures are implemented on the vehicle.

- ➔ Preventive action: in critical situations the vehicle supports the driver in avoiding danger, or applies measures for mitigating the severity of an accident in unavoidable situations. The vehicle prepares occupant protection systems for possible accidents in the best way possible.

- ➔ Protection: in accident situations the vehicle affords maximum protection to occupants and other involved persons in an adapted way.

- ➔ Aid and rescue: following an accident situation the vehicle automatically notifies rescue workers, supports the occupants and rescuers with information on the vehicle and victims and warns the following traffic to prevent subsequent accidents.

SYSTEMS TODAY: ACCIDENT AVOIDANCE / MITIGATION THROUGH DRIVER ASSISTANCE SYSTEMS

1. ESP®

Over the past two decades, especially electronic driver assistance systems have significantly contributed to enhancing driving safety, without this development being incorporated in New Car Assessment Programs. Here it becomes clear that the best form of accident safety continues to be avoidance, accordingly an essential factor in vehicle safety.

An example [4] of the effective reduction of single-vehicle accidents is the Electronic Stability Program (ESP®) safety system introduced ten years ago.

The ESP® developed by the MCG and BOSCH counteracts oversteering and understeering by applying the wheel brakes separately in order to stabilize the vehicle and maintain its controllability for the driver. Various studies under test conditions indicated the potential benefits for assisting the driver in critical driving situations, especially those with a high risk of loss of control over the vehicle. The MCG consequently made ESP standard in all its passenger cars.

More compelling proof came from four representative, anonymous 50-percent samples of all accidents involving vehicles registered between 1998 and 2002. These samples, purchased from the German Federal Statistical Office, document that the rate of loss of control accidents can be significantly reduced by ESP. A comparison of accident rates for registered vehicles involved in an accident over a period of two years reveals that Mercedes-Benz vehicles have been below average with respect to loss of control accidents since the year 2000 when ESP became standard in all Mercedes-Benz passenger cars (Fig. 1). While within the two-year period of 1998 - 1999 Mercedes-Benz's share of loss of control accidents was close to the average value of 19 percent, the figure dropped to 12 percent in 2000 - 2001 and was much lower than the mean.

The most recent data for 2001 - 2002 again confirms this finding, while the rate also declined for competing passenger cars increasingly using ESP in the meantime.

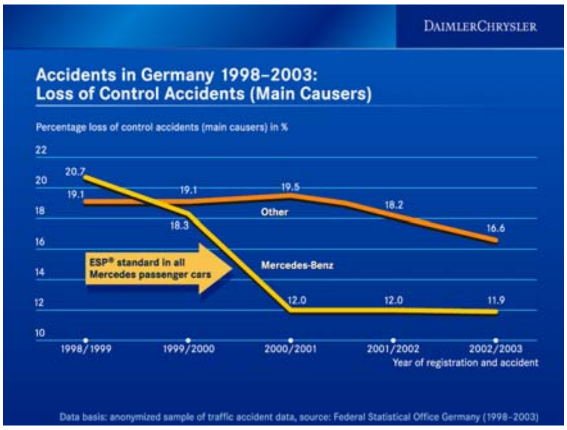

Fig. 1: Accidents in Germany 1998-2002: loss-of-control accidents (main causers)

2. Contributions to Protecting Occupants and Other Road Users: Brake Assist, DISTRONIC and Flashing Brake Lights

BRAKE ASSIST (BAS): While pedestrian accidents are not among the major causes for fatalities and severe injuries in road traffic accidents, they still are responsible for 13 percent of fatalities and 7 percent of injuries in traffic accidents [5]. According to NHTSA, these numbers were 11 percent and 2.4 percent, respectively, for the USA in 2002 [6]. Furthermore, this issue is given high priority within the European Union. Analyses by GIDAS (German In Depth Accident Study) of data collected in the greater Dresden and Hanover areas show that the risk for pedestrians to be killed compared with vehicle passengers is three times higher. A closer look at the different types of pedestrian accidents reveals that in 73 percent of the cases a passenger vehicle collides with a pedestrian and in most cases (65 percent) of pedestrian accidents, the pedestrian is struck by the front of a vehicle [7].

Besides measures of passive safety for reducing accident severity, active safety systems may help even avoid accidents or at least mitigate their severity. MCG research has shown that particularly the Brake Assist has special potential because it can reduce the stopping distance. Developed and first introduced by the MCG in 1996, BAS fully applies the brakes in emergency braking when the driver applies the brake pedal fast but not strongly enough to achieve full brake performance.

Early studies on BAS already demonstrated the benefits for emergency braking. A more recent study carried out by MCG safety engineers, using the DaimlerChrysler Berlin driving simulator, proved effective in the case of pedestrian accidents as well[7]. In this study, test-persons were driving on an urban road at approximately 50 km/h (31 mph) when suddenly a pedestrian (child) entered the road from left. The possibilities for evading the situation were limited (Fig. 3).

Fig. 2: Critical situation simulated by the DaimlerChrysler Berlin Driving Simulator: child crossing an urban street

In 45 percent of all situations a collision with the pedestrian occurred. Fig. 3 shows that there is a significant difference depending on whether the vehicle was equipped with BAS or not. Drivers with BAS had an accident rate of 32 percent only, whereas drivers without BAS had an accident rate of 58 percent, i.e. almost twice as many accidents. A closer look at the drivers of BAS vehicles reveals that all drivers who managed to activate the BAS also could avoid the accident. In other words, in this simulated situation accidents occurred only when the BAS was not activated by the driver's actions. BAS therefore proves to be very beneficial in this typical kind of pedestrian accident.

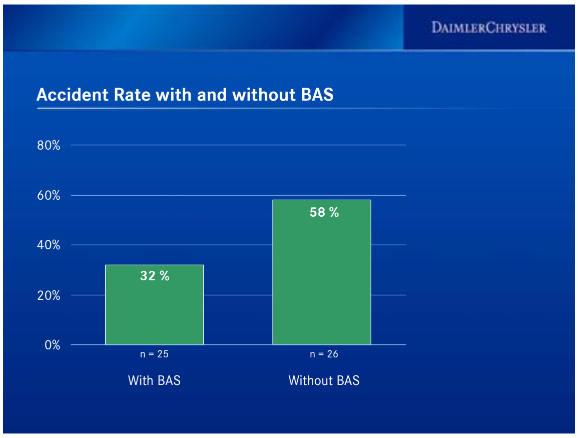

Fig. 3: Accident rates with and without BAS being available

DISTRONIC ACC - In the normal driving phase DISTRONIC maintains a safe inter-vehicle distance and provides the driver with information on the distance to the vehicle in front. In the warning phase DISTRONIC's associated Distance Warning Function signals the driver if the gap to the front vehicle becomes too small, so that (additional) braking by the driver is necessary to reestablish a safe distance. The Distance Warning Function can be used independently of DISTRONIC.

FLASHING BRAKE LIGHTS - Many rear-end collisions are caused by misinterpreting the traffic ahead, especially when the preceding vehicle brakes hard or in an emergency. Although conventional brake lights show the lead vehicle to be braking, they give no further indication about the brake force and the resulting deceleration. Advanced brake light design aims at filling this gap by providing the following vehicles with information about the deceleration of the lead vehicle. Opinions in the automotive industry differ on the best approach, be it additionally activated hazard warning lights (e.g. Peugeot), an enlarged lighted area and/or increased intensity of illumination (e.g. BMW) or flashing brake lights (e.g. Mercedes-Benz).

Mercedes-Benz examined different advanced brake light designs (conventional, additional hazard lights, brake lights flashing at 4 and 7 Hz) [8]. In this study, a group of 39 subjects had to follow a lead vehicle at 80 km/h (50 mph). At random places on the test track the lead vehicle unexpectedly performed an emergency braking maneuver, forcing the drivers of the following vehicles to brake accordingly. The brake reaction times were measured and subtracted from reaction times measured in a static test in order to receive standardized reaction times. The reaction times ranged from 0.31 to 0.74 seconds. It was found that brake lights flashing at 7 Hz provide the greatest benefit, significantly reducing the brake reaction times up to 0.2 seconds compared with conventional brake lights. This translates into a reduction of the stopping distance by 4.44 m. Additional hazard lights did not significantly decrease the reaction times. Subjective ratings gave highest values for flashing brake lights, too.

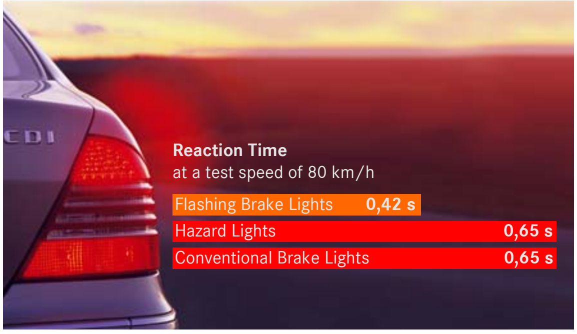

Fig. 4: MCG introduced flashing brake lights into the current S-Class in February 2005

INTERACTION BETWEEN THE OCCUPANTS AND VEHICLE IN THE PRE-ACCIDENT PHASE

3. PRE-SAFE®

The importance of a comprehensive approach for the overall safety of a vehicle is shown by the PRE-SAFE® system introduced in the Mercedes-Benz S-Class in 2002. PRE-SAFE® is a preventive protection system that activates measures for fixing occupants in place and positioning and conditioning them in advance of a collision, by analyzing the driving dynamics or the driver's braking.

For example, if emergency braking occurs prior to a collision, the resulting longitudinal deceleration moves the occupants forward within their seat belt slack.

In a vehicle with PRE-SAFE® this forward displacement is minimized by the activation of reversible emergency tensioning retractors, and the occupants are more coupled to the vehicle deceleration and prepared for a possible collision.

If the front passenger seat is in an unfavorable situation for the collision, for example, PRE-SAFE® automatically changes the seat to a safety position, and thereby improves the occupant's position.

These occupant-vehicle relations in typical emergency braking situations were studied with actual test persons. An average forward displacement of about 15 cm at the chest and about 20 cm at the head were measured.

Trials in which PRE-SAFE® fixed occupants in place minimized these forward displacements at the chest by about 10 cm to 5 cm. Thick clothing and large belt slack were not used on the test subjects, which would have led to even greater differences between PRE-SAFE®-equipped and conventional vehicles. The trials in the pre-accident phase were performed on actual test subjects since at present HIII measurement dummies do not yield results applicable to humans in this low acceleration range.

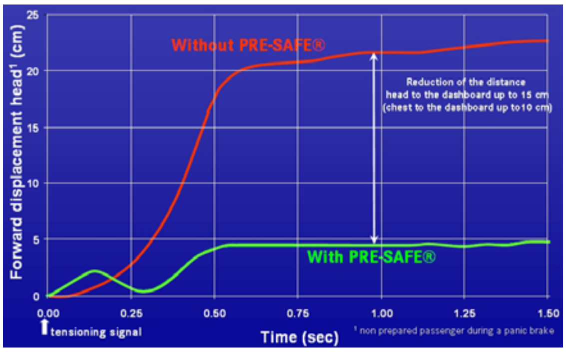

Fig. 5: Forward displacements with/without PRE-SAFE®

As of the start of collision, the results of the test subject studies were transferred to the dummy positions. The corresponding setups for collisions with and without a preceding PRE-SAFE®-supported braking situation were studied on an acceleration slide.

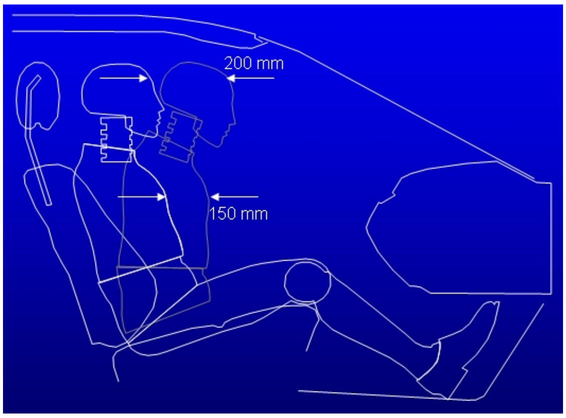

Fig. 6: Recreation of the real-world situation with the measurement dummy

Compared with conventionally equipped vehicles, the study revealed great potential for reducing load on occupants.

Particularly in the head area the loads could be reduced by 30 - 50%, depending on the load criterion, compared with a front passenger not protected by PRE-SAFE®. With a reduction by 20 - 40%, the neck region was also subjected to less stress [Fig. 7].

Particularly in the upper body regions, PRE-SAFE® has good potential for real-world accidents, since it fixes occupants in place very effectively. The measures for repositioning occupants from unfavorable and yet actually occurring seat positions were not considered or assessed; here too we can expect a further reduction of loads.

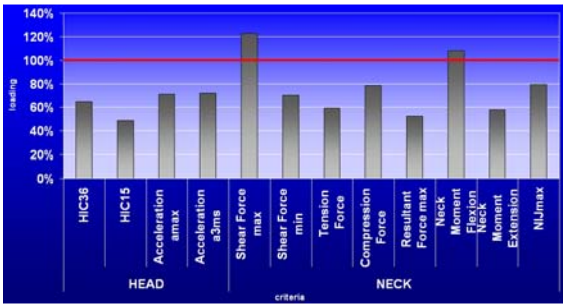

Fig. 7: Load reduction per body region

The aforementioned example of intelligent networking of active and passive safety shows the potential of a coordinated overall vehicle safety.

FUTURE APPLICATIONS

New generations of sensors and the integration of the 24 GHz short-distance radar allows further applications and operating ranges. The next generation of the new S-Class will have a further developed Advanced DISTRONIC.

This assistance system will allow the implementation of additional safety and comfort applications and will be incorporated by Mercedes-Benz in overall vehicle safety.

PRE-SAFE® Brake

In future, information on approaching an object will yield further opportunities. The sensor system and infrastructure of the Advanced DISTRONIC observe and analyze the traffic situation in front of the vehicle by means of long-distance (77 GHz) and short-distance radar (24 GHz).

If the driver brakes while approaching an object, the system uses the object's distance and relative speed to compute the convergence of the two vehicles continuously. PRE-SAFE® Brake compares the actual braking distance based on the adjusted brake pressure with the brake pressure that would be needed to prevent a collision with the preceding vehicle. If the driver incorrectly assesses the situation, or if the relative distance and speed of the two vehicles change, the driver is supported by an automatic and appropriate increase of the brake pressure. The aim of the system is to avoid accidents to the extent allowed by the physical environment parameters.

As of a certain specified braking threshold, the reversible systems of the standard PRE-SAFE® are activated for support and accident prevention at the start of the braking process prior to the possible forward displacement of the occupants, since the specified deceleration is already known from the observation of the environment. The driver can at any time initiate even greater braking pressure within the bounds of the available brake power, and thereby overrule the vehicle's system. The system can fully avoid an accident in many cases, or at least mitigate the severity. In cases where the driver brakes but has incorrectly assessed the longitudinal traffic situation, the system can operate with maximum deceleration up to the current wheel slip limit.

For longitudinal traffic situations in which the driver does not brake, a further application can help mitigate accident severity.

This system will be implemented in a later expansion stage. Here again the preceding traffic is observed by the sensor system. In case of an approach, the driver is visually and audibly warned as of a certain threshold, and thereby requested to perform the appropriate driving task. If the driver reacts by braking, PRE-SAFE® Brake will compute the situation and assist with braking power as required. If the driver does not react, in the next escalation stage the vehicle autonomously initiates partial braking, with the aim again of requesting the driver to act, while the accident severity is being reduced by a decrease in speed.

Parallel to partial braking, at the start of deceleration reversible PRE-SAFE® measures like belt tightening and adjustment of the front passenger seat and rear seats are also activated with the aim of preventive occupant protection.

The system can autonomously mitigate the accident severity in longitudinal traffic situations, as well as prepare the occupants and the vehicle for the subsequent accident in case the driver does not react.

Here the potential lies not only in the reduction of the deceleration energy; the automatically initiated brake application in combination with positioning and fixing the occupants in place also couples the occupants better to the vehicle deceleration following a collision. The result is an increase in the ride-down benefit.

In sudden situations in which the driver can no longer be warned in time or which do not allow longer-term observation, such as accidents in approaching intersections, accidents from cutting in, collisions after lane changes, etc., a collision-proximate situation assessment of the environment can make a short-term contribution to improving occupant protection. In this case only the short-distance radar analyzes the immediate vehicle environment ahead, and triggers sufficiently fast reversible actuators in the range of unavoidable collisions. For example, reversible belt tensioning can minimize actual deficits, such as those related to seat belt slack or thick clothing.

Here too fixing occupants in place and coupling them to the collision deceleration at an early point can reduce possible peak loads during the deceleration. Various constellations are conceivable in which the situation is improved, in some situations no significant improvement can be quantified, but in no situation is the load on occupants increased. Rather, the complex real-world situation cannot be studied in the lab, or only in part.

Information on approaching the object can also be used in making crash-active systems more sensitive. The escalation of the traffic situation is reported to the analyzing algorithm of the crash-active systems as of a certain threshold value. The basic parameter for lowering the triggering thresholds is the relative speed of the vehicle and the collision object. Of course, these systems cannot be triggered by the environment sensor system. Nevertheless, lowering the triggering threshold allows an earlier triggering decision to be made on the basis of the central acceleration sensing. The anticipatory observation of the traffic environment can positively affect conventional protective systems.

Faster and more stable triggering decisions for pyrotechnical emergency tensioning retractors and airbags are the result.

The information on the approaching collision speed can be further applied to predict the possible severity of the collision. Besides the occupant parameters like size, seat position, weight, etc., the expected collision severity is a basic unknown for controlling the energy-absorbing characteristics of the belt and airbag.

The variable of relative speed can at least be used for an energy prediction, for making decisions in controlling the adaptation of restraint systems on a broad informational basis [9].

CONCLUSIONS

In introducing the PRE-SAFE® preventive protection system in the S-Class in 2002, Mercedes-Benz launched a system that for the first time employs the critical assessment of a vehicle's condition prior to a collision for activating reversible safety precautions [10, 11]. In many real-world situations these measures will help improve occupant protection.

The expanded environmental assessment will afford new possibilities in the future for comprehensively enhancing vehicle safety. This comprehensive approach based on real-world accident situations will enable us to mitigate situations that today are responsible for occupant injuries and fatalities. In our view, greater depth of the laboratory assessments of vehicle safety and tightening the limits are not effective approaches, since the high level of collision protection already attained today offers an excellent basis. Consumer pressure and the established rating procedures will also drive those automotive manufacturers forward in their development endeavor who have not yet achieved the previous assessment targets.

In our view, the real potential for reducing loads on the occupants lies only in the full consideration of all accident phases and in networking the systems beyond the present boundaries. An isolated assessment of the collision phase or active safety systems can reflect real-world accident situations only inadequately. Rather, the real-world accident situations must be analyzed to a greater degree in order to assess previous and current traffic safety problems objectively.

These results should guide a broadly coordinated vehicle safety concept. The performance of our products in real-world traffic is the yardstick for achieving our goal.

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