PRE-SAFE - THE NEXT STEP IN THE ENHANCEMENT OF VEHICLE SAFETY

Rodolfo Schöneburg
Karl-Heinz Baumann
Rainer Justen
DaimlerChrysler AG
Germany
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ABSTRACT

In times when the potential for further optimizing passive safety become ever smaller, new ways for improving vehicle safety must be found. Accident analyses shows that the pre-crash phase provides room for substantial improvement, calling for reversible systems that exploit this available time before the accident for the benefit of the occupants. Preventive occupant protection is realized for the first time with PRE-SAFE, initiating the next phase in the enhancement of vehicle safety. PRE-SAFE is embedded in Mercedes-Benz's integrated safety concept, and combines active and passive safety systems.

Announced in theory at the ESV 2001, PRE-SAFE has now seen its first series application in the 2003 S-Class model, and initial field experience has been gathered. Taking nature's reflex as a role model, the vehicle reacts to critical driving conditions identified by the sensors of the Electronic Stability Program (ESP) and the Brake Assist (BAS) that may lead to an accident. Reversible belt-pretensioners for occupant fixation, passenger seat positioning and sunroof closure are activated. However, these are merely first steps in this new and evolving safety technology. Further PRE-SAFE applications might be introduced in the future. Individual safety and environment sensing will mark the next major steps.

INTRODUCTION

In the final 10 years of the 20th century, great advances were made in passive safety of passenger cars. A substantial step in this direction was provided by the worldwide employment of offset crashes against a deformable barrier. This reality-based test method was initially developed as offset test by Mercedes-Benz in the 70s [1] and further developed in the early 90s into the offset deformable barrier test (ODB) [2]. It places much higher demands on the vehicle structure and restraint systems than was the case in prior, standard tests against a rigid and flat barrier. In a strong endorsement of the ODB test, most new car assessment programs (NCAP) use this test method for evaluating vehicle safety.

Nearly all new vehicles therefore offer high structural safety with a non-deforming passenger compartment and numerous standard automatic restraint systems in the vehicle interior.

In the opinion of many experts, conventional systems for passive safety have become very effective. Further increasing the level test severity beyond the very high impact velocity used in the NCAP ratings is not met with enthusiasm since it could lead to restrictions in the compatibility design.

Where then does future potential lie for additionally increasing vehicle safety? DaimlerChrysler responded to this question by developing the Mercedes-Benz integrated safety approach [3] that was presented at the 17th ESV Conference in 2001 in Amsterdam [4].

Based on this strategy, an initial integrated safety system for preventive occupant protection has been introduced in the Mercedes-Benz S-Class for model year 2003 named PRE-SAFE [5,6]. The goal of this article is to introduce the PRE-SAFE system and give a preview of future developments.

In February 2003, PRE-SAFE was awarded the Paul-Pietsch prize by the automotive journal auto motor und sport and his European partner journals for forward-looking achievements in the field of automotive technology.

REAL-LIFE SAFETY

Today, the yardstick for passive safety is largely dictated by the NCAP rating tests. Extreme demands must be satisfied in these crash tests to achieve the best evaluation.

Despite all the successes in improving the level of new vehicle safety, we must not forget that the NCAP tests are worst-case laboratory experiments. Precisely defined test conditions for the vehicle and occupants can only cover a very limited slice of possible real world accident scenarios. In concentrating on the positive results of the laboratory crash tests, we have to keep in mind how safety measures perform in much more complex real world accidents. We must ask if increasingly complex systems that may yield marginal improvements in precisely-defined laboratory situations are actually useful to real occupants.

In contrast to standardized conditions in a crash test, numerous vehicle components can be moved into a comfortable position under actual traffic conditions, and this can impair safety in an accident. In addition to a wide range of occupants who may differ in size, weight, age and other safety-relevant parameters, the vehicle occupants can also assume any number of individual seating positions.

Figure 1. Example of a comfort-oriented, but potentially hazardous passenger seating position.

Frequently preceding an accident, the vehicle is in a critical driving situation, or the driver reacts reflexively. As a result of skidding or emergency braking for example, the occupants can be subject to undesirable movement within the vehicle that can lead to unintentionally problematic, hazardous positions in a collision.

Here are a few examples of hazards occurring in real world accidents that are not covered in laboratory crash tests:

- Occupant movements resulting from inertia during braking and skidding reduce the effectiveness of pyrotechnic emergency tensioning retractors.
- The occupants can be very close to interior or intruding vehicle parts in a collision.
- The occupants can be closer to the airbag.
- Hazard of submarining in unfavorable seating positions.
- Reduced occupant support in unfavorable seating positions.
- Outside objects can enter through an open sunroof.
- Occupants or body parts can be thrown out of an open sunroof.

DaimlerChrysler is therefore pursuing the philosophy of real life safety; this means that the yardstick for evaluating safety measures is efficiency in both, crash tests and real world accidents. This philosophy and the evaluation of thousands of real world accidents yielded the Mercedes-Benz integrated safety concept, the basic premise of which is to stop strictly differentiating between active and passive safety, but rather view them as parts of a whole.

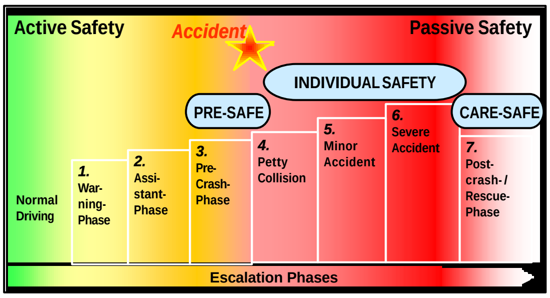

Figure 2. Mercedes-Benz Integrated Safety Concept.

This integrated perspective of vehicle safety can be realized with a network of safety sensors, especially with a completely new type of anticipatory, preventive safety measures with the goal of offering maximum protection of the vehicle and the occupants against an impending accident (PRE-SAFE). In addition, there exists further potential for safety in the collision itself by a more individualized adaptation of the safety systems to specific occupant requirements (INDIVIDUAL SAFETY), and improving the chain of emergency response after an accident (CARE-SAFE).

THE PRE-SAFE SYSTEM

A central fact gained from DaimlerChrysler Accident Research is that the vehicle is in a critical driving situation before the actual collision in approximately two-thirds of all accidents. The PRE-SAFE system therefore uses the existing sensors of the dynamic driving control systems to identify critical driving conditions that pose an increased possibility of an accident, and prepare the vehicle, occupants and restraint systems for a possible crash to increase passive safety.

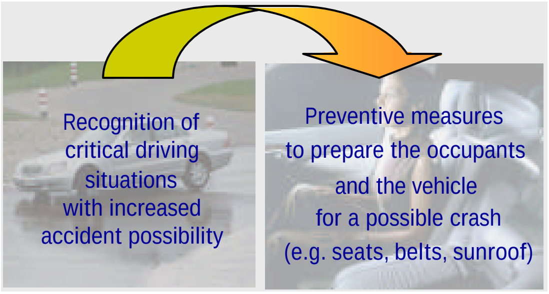

Figure 3. Linking active and passive safety.

A first example of the activation of protection systems prior to an accident is the well-proven safety roll bar of the Mercedes-Benz SL that was introduced in 1989 [7] and later adapted to the 4-seater convertibles in a similar form.

Recognizing a Critical Driving Situation

Numerous innovations for avoiding accidents have also been developed and introduced over the years in the field of active safety. Major examples of this are the antilock braking system (ABS), the brake assistant system (BAS), and the electronic stability program (ESP). When the control systems sensors recognize a critical driving situation, they intervene in the longitudinal and lateral dynamics of the vehicle to assist the driver and stabilize the vehicle.

Figure 4. Critical driving situations (emergency braking, skidding).

The brake assistant system (BAS) can assist in a hazardous braking situation. The system recognizes an emergency situation by the speed of a quickly depressed brake pedal. In this situation the brake pressure is automatically set to the maximum until the driver releases the brake pedal.

The antilock braking system (ABS) then controls the emergency braking to keep the wheels from locking, and the vehicle remains maneuverable.

If the vehicle leaves the lane beyond a given setpoint, the electronic stability program (ESP) controls the rotational speed of the wheels and accordingly corrects the direction of travel and lateral stability of the vehicle.

However, the physical reality is not altered by the actions of the dynamic driving control systems; that is, the increased danger of an accident still exists.

The PRE-SAFE system is therefore triggered under the following circumstances:

<u>Emergency braking</u>: If the driver's reaction is perceived to be an emergency braking by the speed the brake pedal is depressed and the brake assistant system is activated, PRE-SAFE is triggered.

<u>Understeering:</u> If a deviation from the target curve is identified that is greater than approximately $^{1}/_{2}$ the lane (speed-related) despite controlling the lateral dynamics, PRE-SAFE is triggered.

<u>Oversteering</u>: If a deviation from the target path is greater than approximately 10° (speed-related), despite controlling the lateral dynamics, PRE-SAFE is triggered.

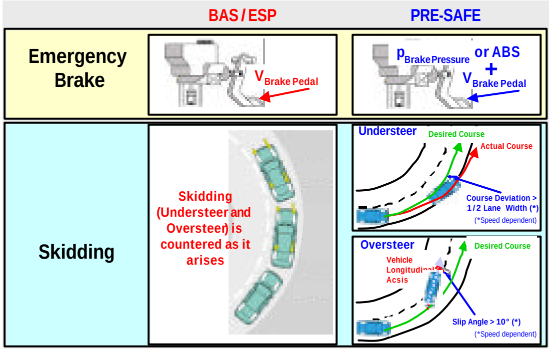

Figure 5. PRE-SAFE triggering criteria.

In skidding situations PRE-SAFE is triggered only after the ESP's intervention is not able to stabilize the vehicle.

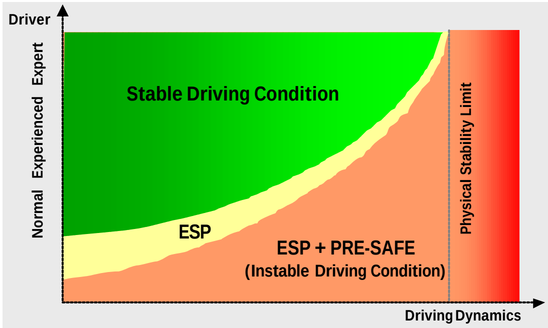

Figure 6. PRE-SAFE activation range (skidding).

Reversible Belt Pretensioner

A critical driving situation can cause the occupants to react more-or-less strongly depending on the intensity of the situation. There is hence a wide variation of possible occupant positions in a subsequent collision. Even occupants who initially were in a safe position in the vehicle may not be in the same position at the time of the collision. In particular, passengers are often not aware of a hazardous situation and unintentionally change their position in the vehicle. During braking, they may be shifted forward, or they may shift to the side in a skid.

In crash tests, only standard positions are used for the sake of reproducibility. Therefore safety systems and functions are optimized for these standard positions. In reality, however, numerous deviations are possible, and OOP situations only cover the worst-case scenarios.

The position of the vehicle occupants can be changed significantly in the phase before the collision that is not covered in lab tests. Evaluations have shown that during strong braking, the occupants can be thrown forward by more than 20 cm (head position). Preventive belt tightening directly upon recognition of emergency braking can reduce this forward displacement by up to 15 cm.

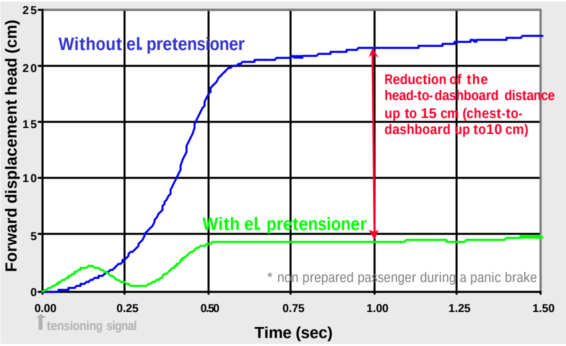

Figure 7. Example of forward head displacement over time in a situation with activated BAS.

In a major improvement of safety in real world accident scenarios, the PRE-SAFE system tightens the safety belt early on to reduce unintentional occupant movement. The occupants are held in an optimum position, and their freedom of movement is restricted in the critical phase. The restraint systems that are activated in a crash are hence able to provide optimum protection. If an accident does not occur, the belt is released and is ready for use in the next hazardous situation.

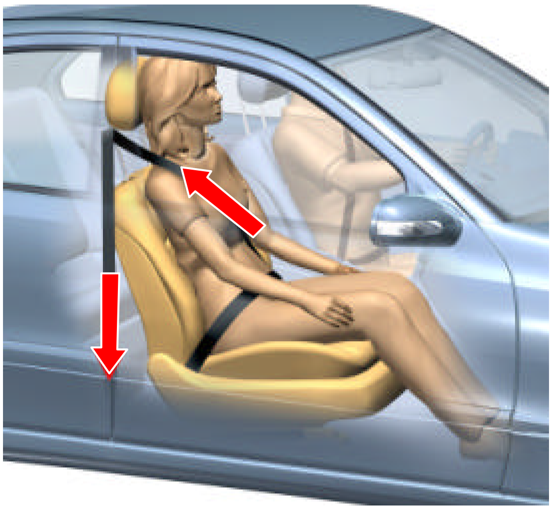

Figure 8. Reversible belt pretensioner.

Seat Adjustment

A poorly-adjusted seat is another factor not covered in standard developments of restraint systems that can occur in real life. For example, a backrest angled too far to the rear can be hazardous in an accident, and so can a seat cushion that is too flat, or a seat that is too far forward.

If the occupants are in such an unfavorable position for a collision, an activated PRE-SAFE system makes the following gentle corrections to the seat position:

- A front passenger's backrest inclined far back is moved into an upright position.
- When the cushions of the front passenger seat and optional individual back seats are flat, the seats assume a sharper angle.
- A front passenger seat that is adjusted far forward is moved back slightly.

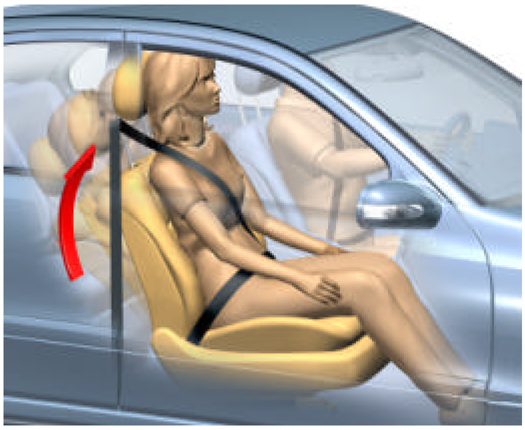

Figure 9. Conditioning of passenger backrest inclination.

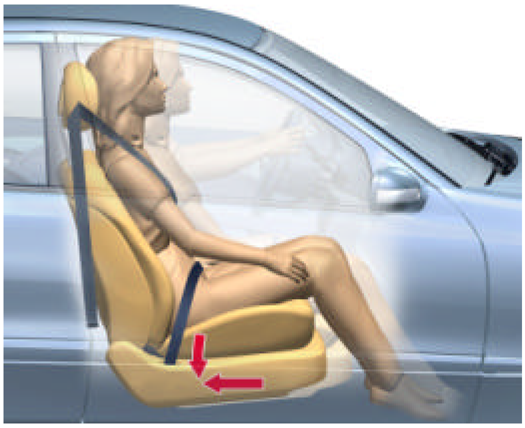

Figure 10. Conditioning of passenger seat cushion inclination and longitudinal adjustment.

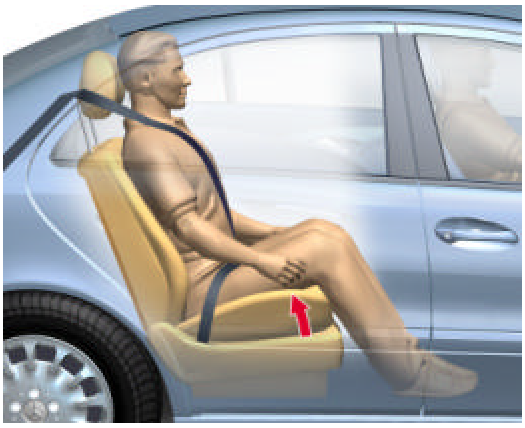

Figure 11. Conditioning of back seat cushion inclination (optional).

All seat adjustments are made at the normal adjustment speed for comfort settings. This prevents the occupants from being thrown into an even worse position from fast seat adjustments. In very extreme settings (reclining seat), the adjustment can take several seconds. If a collision occurs during the adjustment before the final position is reached, the seating position is at least improved.

Sunroof Closing

In skids in which there is also a increased rollover risk, an activation of PRE-SAFE closes the sunroof automatically (special equipment) at normal speed to reduce the risk of objects entering the passenger compartment and occupants being ejected.

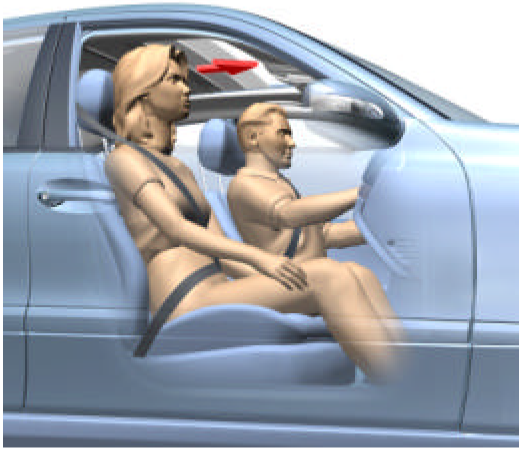

Figure 12. Sunroof closing.

Benefits of PRE-SAFE

Crash-active restraint systems are designed for precisely defined vehicle parameters, occupants and occupant positions. They have their maximum protective effect under these standard conditions. In reality, these standard conditions mostly do not occur. With a preventive safety system such as PRE-SAFE, the following advantages can be realized to increase occupant safety in actual crashes:

- Avoidance or reduction of undesirable occupant movement in the phase preceding an impact.
- Better fixation of occupants in their seats.
- Improved positioning of occupants prior to an impact.
- Greater distance between occupants and possibly intruding vehicle components.
- Greater distance to airbags.
- Danger of submarining can be reduced.
- Better seat support during an impact.
- Reduced risk of objects entering the passenger compartment through an open sunroof.
- Risk of occupant ejection can be reduced.

Another substantial advantage of preventive safety systems is that much more time is available to activate protective measures before a collision. For this reason, in the future preventive safety systems might be activated much slower and hence less aggressively, which in turn clearly reduces the OOP risk. And preventive safety systems also offer occupant safety that can be experienced.

FUTURE PRE-SAFE APPLICATIONS

The PRE-SAFE system introduced in the Mercedes-Benz S-Class in model year 2003 represents a first step toward preventive, anticipatory vehicle safety systems. Work is already performed on system expansions. This includes applications for early accident recognition and actuators. A few examples:

Environment Sensing

In the first step the PRE-SAFE system is triggered based on the evaluation of the vehicle's driving condition. If an unstable driving condition is identified, an increased accident hazard is assumed, and PRE-SAFE is activated. In the future, it is conceivable that the accident recognition system could supplement vehicle dynamics information with observations of the vehicle environment. Future PRE-SAFE systems may enable observation of the relative distance and speed of possible colliding objects to further improve the quality of information concerning collision probability. In this event, the PRE-SAFE system can be activated in cases where no critical driving situation is identified in the pre-crash phase.

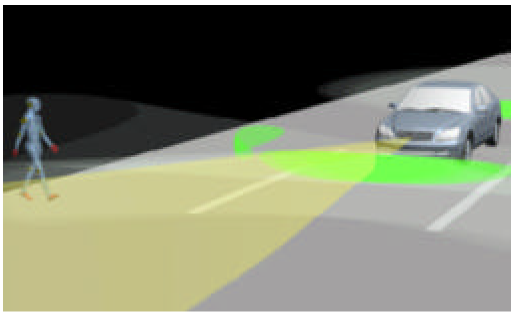

Figure 13. Surrounding recognition for precrash detection.

Many technologies for recognizing the relative speed, relative distance and collision angle are conceivable. From the standpoint of integrated safety, a modular expansion of existing assistance systems with available vehicle environment recognition is the most effective solution. Also conceivable is the use of radar sensors for distance control systems such as Active Cruise Control (ACC) or Parktronic. A series of other supplementary assistance functions are being developed that allow the integration of a pre-crash module.

Window Closing

An additional feature similar to the existing function of closing the sunroof would be to automatically close the electric side windows. This would also reduce the risk of occupants or occupant body parts such as the head or arms from being flung out. Likewise, closing the side window would improve the support of the sidebag or windowbag.

Figure 14. Closing the window.

Multifunctional Belt Pretensioner

Beyond the advantages described, additional future benefits could be obtained from actively controlled belt pretensioners in a synergy of safety and comfort features.

Depending on the amount of belt extension the specific spring characteristic of a belt retractor exerts different forces on the occupant’s shoulder. A buckled person experiences two different forces when wearing the belt: One when the belt pulls out, and one when it pulls in.

We can electrically adjust the extraction and operating force as well as the wearing comfort to individual settings. In addition, the seat belt load can be variously adjusted to different situations.

In the example in Figure 15, the belt force is relatively high while the car is standing still. This keeps the belt retracted. When the door opens, the belt force is reduced because belt extraction is anticipated. After buckling, the belt force increases to eliminate belt slack. After a period of time (delta t) and when driving, the belt force is reduced to an automatic wearing comfort mode, or the force can be individually adapted by the passenger. When out of position, the belt force is increased; it is reduced to the comfort mode when it is in position again, and the belt force is high when it retracts after being unbuckled.

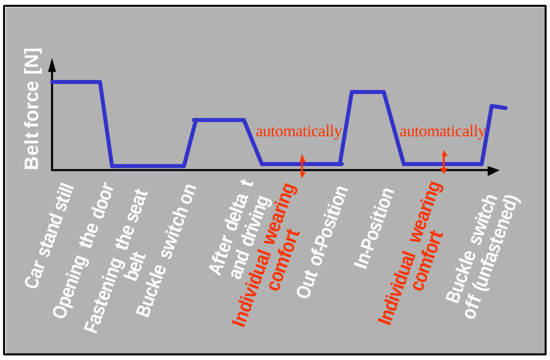

Figure 15. Different seat belt loads adjusted to different situations.

A wide range of additional adjustments is also possible that could, for example, depend on the vehicle velocity, cornering, or temperature.

Depending on the situation, particularly in a critical driving situation or potential crash, an electrically-controlled belt pretensioner could pull back passengers when they are out of position.

A variable retraction velocity and adjustable belt forces are required for this application.

In crash situations, it is also possible to variably limit the belt force depending on passenger weight.

Figure 16. Pulling back from OOP with a multifunctional belt pretensioner.

Active Interior Padding

Active padding in the occupant contact area of the interior could offer a lot potential protection. The padding could assume the task of moving the occupants out of the direct collision area in the pre-crash phase and could provide early support in a collision. This would allow the occupants to participate early in vehicle deceleration and could prevent a later interior contact at a certain relative speed. During the deceleration phase, the active padding could attenuate the collision by yielding a specific amount and hence reduce the load experienced by the occupants.

The following are examples of conceivable measures using the interior padding:

- Active head restraint
- Active seat side bolster
- Active door padding
- Active B-column padding
- Active knee protection

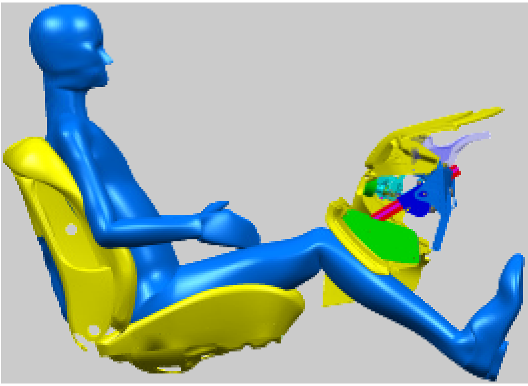

Figure 17. Movable knee bolster as an example of active interior padding.

INDIVIDUAL SAFETY

In addition to activating preventive safety systems, individualizing the safety systems could offer substantial potential for improving passenger protection to best prepare vehicle occupants for a possible accident.

Individual safety is to be understood as the future evolutionary step of adaptive safety systems.

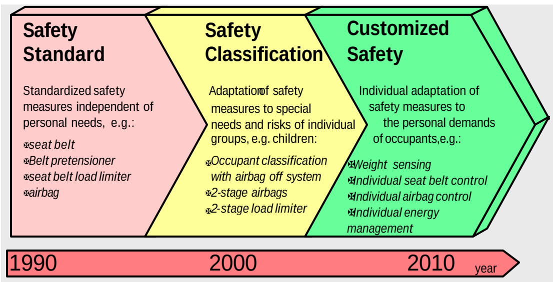

Figure 18. Evolution of passive safety standards.

To date, safety systems have been designed based on standardized laboratory situations. The following elements are standardized:

- Severity of the test
- Type of occupants (5%, 50%, 95%)
- Occupant position.

All protective measures are tailored to these conditions and offer maximum safety under those conditions. Elements that are also relevant for safety, but which are not covered by these scenarios, are for example:

- Occupant-specific parameters such as size, weight, age or individual disability
- Vehicle-specific parameters such as individual comfort settings of the seats and steering wheel
- Accident-specific parameters such as the type and severity of the accident
- Unintentional occupant movements in the pre-crash phase.

The potential risks are countered in current developments by classifying particularly endangered risk groups such as children and small, light adults (5% woman) to adapt the safety systems to the related special risks. This may include shutting off the airbag in the presence of children, or triggering the airbag with less energy.

This first generation of adaptive restraint systems that seek to minimize risk therefore only represents an intermediate step toward individual safety systems that offer vehicle occupants optimum protection in relation to their individual needs.

Possible individual adaptations can be made to the restraint properties of:

- Airbag (e.g. volume, venting)
- Belt (tension force, belt force limitation)
- Seats (force characteristic of displacement)
- Steering (force characteristic of displacement)
- Padding (force characteristic).

CARE-SAFE

In addition to preventive occupant protection measures in the pre-crash phase and possible improvements in the crash phase, there also exists potential in the post-crash phase for passenger protection. Measures that involve the vehicle include protecting the accident site, minimizing risk of fire and secondary accidents, and ensuring that occupants can escape the vehicle. Additionally, the chain of emergency response could be improved from the reporting of the accident to the actual ambulance response and follow-up medical care. In the view of many experts, improving the chain of emergency response in the "golden hour" is key for reducing the consequences of a traffic accident. Vehicle manufacturers could also substantially contribute to this effort.

Even in the middle of an accident, many Mercedes-Benz vehicles now activate systems to prevent or reduce further consequences. In an accident with pretensioner or airbag activation the following actions are conducted automatically:

- The fuel pump is automatically shut off to minimize the fire hazard in case of leakage.
- The doors are automatically unlocked to support the occupants rescue.
- The hazard warning flasher system is automatically turned on to prevent a secondary crash.

The market-related, partially optional emergency signaling system TELE-AID is also turned on in an accident with pretensioner or airbag activation, and it sends an automatic alarm via a service provider who has to inform a rescue command center. Information on the site of the accident is automatically transmitted. In addition, the service provider will attempt to establish a direct voice connection with the occupants of the crashed vehicle to gain further information on the occupants and type and severity of the injuries, and inform the occupants about oncoming help by the emergency assistance.

Additional improvements could be made to future vehicles to tailor the emergency response, select the best approach to accident site, optimize first aid for the injured occupants and possibly free them from the vehicle and optimize subsequent medical care. Specific information on the occupants and type of accident could be used to plan the emergency response such as:

- A detailed description of the location including the direction of travel.
- Specification of the vehicle's final position, e.g. on the roof.
- Fuel leakage.
- Number of occupants and possibly age.
- Possibly information about other participants in the accident if applicable.

For the on-site emergency response team, specific rescue measures can be derived from vehicle and occupant-specific information such as:

- Battery location.
- Number and position of airbags.
- Type of airbags (single-stage or multi-stage).
- Location of gas generators.
- Specific reinforcements in the columns that can hinder cutting.
- If available, specific personal data such as allergies to medications, special disabilities, and risks of infection.

CONCLUSIONS

Modern vehicles offer passenger protection systems with a high level of protection in all known types of crash tests. The trend is toward increasingly complex safety systems driven by the desire to attain the best ratings for worst-case scenarios with maximum demands on safety criteria. Improvements can be attained in laboratory situations, but the degree to which this helps vehicle occupants in a real world accident might be unclear.

For Mercedes-Benz, real-life safety therefore does not only mean a continuous improvement of occupant protection in laboratory tests, but rather a broad consideration of the possible spectrum of real world accident scenarios. Based on a holistic approach of active and passive safety, the true potential for further improving occupant protection in passenger car accidents can be realized by:

- Preventive occupant protection in the pre-crash phase
- Covering the individual needs of the occupants in the crash phase.
- Optimizing the chain of emergency response in the post-crash phase.

With PRE-SAFE, Mercedes-Benz has developed an initial system for preventive occupant protection. Other applications are in the development phase.

Other components of the real life safety strategy under development are INDIVIDUAL SAFETY and CARE-SAFE.

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