THE VISION OF A COMPREHENSIVE SAFETY CONCEPT

Karl-Heinz Baumann
Dr. Rodolfo Schöneburg
Rainer Justen
DaimlerChrysler AG, Germany
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1. Abstract

A look at the various past achievements in the field of passenger car safety raises the question whether any dramatic steps towards its improvement can still be expected. Will progress be confined to the optimisation of existing systems or does the future hold new substantial safety steps? This paper elaborates on the issue that the time available before a potential accident occurs can be used to improve the safety of occupants and other involved road users. Accident analysis confirms that this is feasible for about two-thirds of all accidents. The recognition of an imminent collision bears a noteworthy potential for accident prevention, reduction of accident severity and injury severity. The former boundary between active and passive safety thus fades continually (Fig.8).

Based upon this it is possible to describe vehicle safety by a comprehensive approach encompassing seven escalation levels. This approach underscores the future intention of Mercedes-Benz to increasingly embrace preventive protection systems in the form of "collision mitigation" on the active safety side, and "PreSafe™" on the passive safety side. This contribution, focusing on PreSafe™, presents various protective measures and describes their advantages.

2. Introduction and situation audit

Active and passive safety describe the overall safety of an automobile. The aim of active safety is to avoid accidents. Currently, development in this field focuses on operational safety, perceptual safety and, in particular, handling safety. The latter gains increasing importance since the introduction of the antilock braking system, Brake Assist, or electronic stability programs like ESP that provide assistance for braking and steering in difficult situations. The so-called average motorist, who quickly reaches his limits in critical situations, particularly profits from these driving dynamics systems. Based on the current results of accident analyses we can assume that the most recent developments have clearly reduced the danger of becoming involved in critical situations on the road, and have further diminished the risk of an accident in such situations.

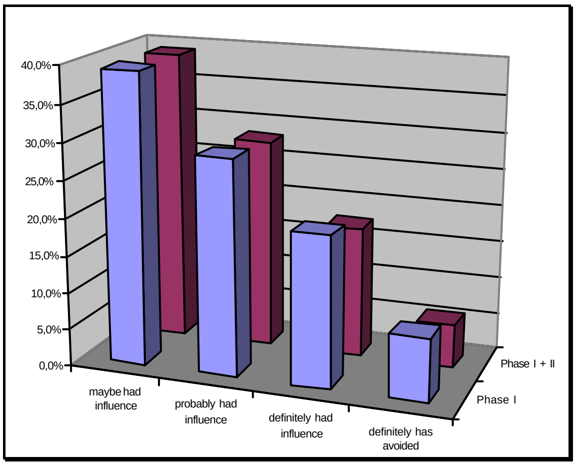

Fig. 1. ESP: Potential of Crash Avoidance (European Accident Causation Survey of ACEA)

In contrast to active safety, until now passive safety measures only become effective when an accident occurs. Passive safety then seeks to minimise the consequences for the persons involved in the accident.

If we compare the performance of vehicles on the market just a few years ago with that of current vehicles, the progress made in this discipline becomes evident. Even in quite severe accidents, the deformation zones are able to absorb sufficient energy and maintain passenger cell integrityfor the benifit of the occupants. In particular in the area of restraint systems, a very high level has been achieved with the development of three-point safety belts featuring belt pretensioners and force limiters and with as many as eight airbags per vehicle.

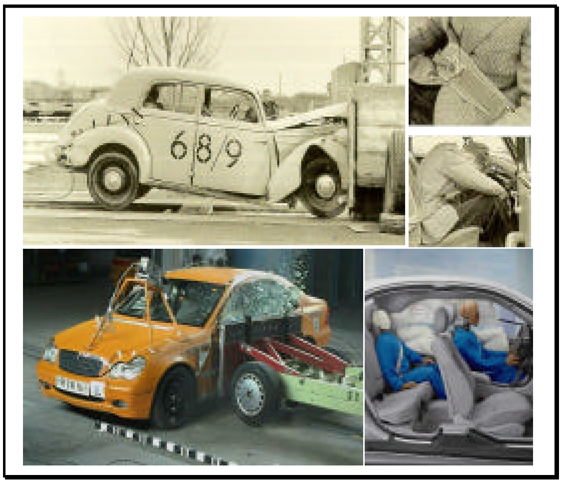

Fig. 2. Vehicle after Crash Test, Yesterday and Today

On a self-critical note, however, we must recognise that vehicles have frequently been optimised only in response to specific accident constellations resulting in usually serious injuries. The complexity of real-life accident experience has not always been adequately taken into account by lawmakers and assessment programs like NCAP or Euro NCAP. Designing vehicles primarily to withstand severe accidents has led to a situation in which vehicle structure and restraint systems are not always optimally designed to handle the much more frequent less serious accidents. Orientation to the "worst case" also called for quickly effective restraint systems with high activation speeds, contributing to the well known out-of-position problem. The motto of years past – "the higher the impact speed, the safer the vehicle" – in fact has clearly raised the overall safety standard of passenger cars, but cannot be the sole guiding principle for further advanced developments.

In future, we must make allowance above all for the fact that real-life accidents frequently occur as a consequence of an unusual situation. In these cases we cannot always assume that, at the time of impact, the occupants are in the position in which dummies normally are placed in laboratory tests. Designing vehicles for a standardised occupant also does not necessarily do justice to the specific demands of reality. Out of this necessity, Mercedes-Benz and various other manufacturers have already developed adaptive restraint systems to better adjust the restraining action of protective systems to the particular accident situation. Legislators, too, have recognised this need. For instance, the new version of FMVSS 208 in the USA aims at improved representation of the complexity of real accident experience and aspects such as accident severity, the differences between occupants and their position at the time of impact.

Fig. 3. Accident Severity Dependent Restraining Action of Driver and Front Passenger Airbag in the Mercedes-Benz C-Class

The following describes the current overall situation:

We believe that active safety has great opportunities for further improvement since experts say that only 50 percent of the total potential has so far been used. In contrast, a further optimisation potential of only about 10 percent is assumed for passive safety. This assessment is shared by Mercedes-Benz only if it refers solely to the use of conventional means.

It is our conviction that the challenge of the future is not to take conventional solutions further but to find ways which create new potential for passive safety as well.

3. Findings of accident analysis

Mercedes-Benz accident statistics show that in about two-thirds of all accidents a relatively long time passes from the accident-causing event to the actual impact. Relatively long is understood as a period in the range of seconds. This is an order of magnitude longer than the time which passes during the impact itself. When considering side collisions only, the proportion of impacts preceded by a fairly long precrash phase even increases to three quarters. The so-called spontaneous accidents in which the impact takes the driver completely by surprise are thus fairly rare. Surveys of persons involved in accidents confirm this. Drivers frequently report that the phase immediately preceding the impact is very consciously perceived. However, the drivers usually had only limited possibilities for intervening at that point, or no opportunity at all.

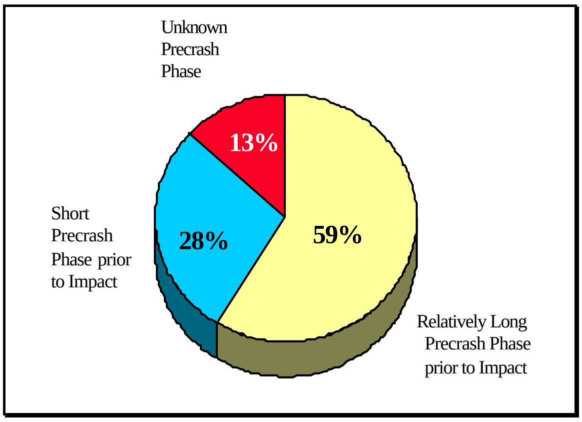

Fig. 4. Mercedes-Benz Accident Analysis

Below, several accident scenarios are described which occur frequently according to our statistics:

Accident Causes	Accident Scenarios	Possibilities of Detection
inattendance	impact with obstacle without previous driver reaction	distance and relative speed
inappropriate speed	obstacle impact with previous driver reaction (e.g. steering, braking)	distance and relative speed BAS
sudden change of road conditions	running off the road	distance and relative speed ESP
sudden appearance of obstacle	skidding	ESP
wrong reaction	accident at intersection	distance and relative speed BAS

Fig. 5. Accident Scenarios

Accident analysis thus also confirms that it is possible to take advantage of the precrash phase and that this may be the key to achieve decisive advances in motor vehicle safety.

4. Future vehicle safety

Active safety will experience its next development advances mainly from the fact that more and more information is available in the vehicle that can be used to avoid an accident, and increasingly also to reduce its severity (collision mitigation) by actions taken in the precrash phase.

If we review the topics of passive safety, to date the preliminary phase of an accident has played almost no role at all. This was exclusively within the domain of active safety. Safety engineers indeed have had an eye on precrash detection for years, but until now all activities have failed due to the fact that the detection of an accident before it occurs could not be assured with full reliability. Activation of non-reversible occupant protection systems like airbags through precrash detection therefore is unthinkable at this time. Nonetheless, from the viewpoint of Mercedes-Benz, passive safety can profit to a decisive extent from a precrash phase, in a first step, if this phase is used to prepare the vehicle for the possible occurrence of an accident in an accident-prone situation. Compared with the brief time span available for impact-activated systems, a relatively long period passes by from the beginning of a critical situation up to a possible impact. During this phase, a vehicle can change from an individual “comfort mode” to a “safety mode” in order to protect its occupants or other road users, thus substantially increasing its safety. Changing the vehicle mode in the “safer” direction are referred to below as PreSafe™ measures. Since a certain accident probability indicating an imminent accident not necessarily leads to its occurrence, all PreSafe™ actions must be reversible. If an accident occurs spontaneously, i.e. without a preceding critical situation, the occupants can still profit from the current familiar safety standard. PreSafe™ is thus purely a complementary feature.

The information needed to activate PreSafe™ systems is partly already available in today’s modern vehicles in the form of driving-dynamics signals. With improving accuracy of accident prediction via future vehicle surroundings sensors, PreSafe™ can further develop into a genuine precrash function.

As the development potentials of both active and passive safety shift into the immediate precrash phase, these disciplines come to overlap. The accident itself no longer is the dividing line between the two subject areas and the classic distinction between the two disciplines fades. For this reason, Mercedes-Benz has outlined the comprehensive safety approach in a new 7-phase model (Fig. 6).

It becomes clear that synergies in the overlapping area between active and passive safety give rise to new potentials for the advancement of overall safety, in particular passive safety. If these potentials are consequently exploited, passive safety still holds out great opportunity for development.

5. The Real Life Safety Concept

Based on these considerations and findings, the so-called Real Life Safety Concept evolved, embracing a holistic view of road safety. Individual safety systems, activated at different danger levels, rest on the well-known basic active and passive safety features of a vehicle.

Specifically, we distinguish:

The Warning Phase (1)

Sensors detect a safety deficit or a running state which deviates from the desired state. In a first stage, the driver or the passengers are informed of this. The aim is to provide a timely warning so that the danger can be recognised as it arises and an accident thereby avoided. For Mercedes-Benz, this is the form of safety most worth striving for.

The Assistance Phase (2)

If sensors detect a critical operating condition the driver is assisted by automatic safety systems (ESP, BAS, etc.). Already in this early phase, it is also possible to additionally activate preventive passive safety systems in preparation for a possible accident; at Mercedes-Benz these systems are called PreSafe™ systems.

The Precrash Phase (3)

The sensors detect a high probability of an accident. Along with further action designed to avoid an accident, in this phase protective measures can be activated. Unlike Phase 2, they do not rely on driver action, but intervene automatically. The aim is to reduce the severity of the accident (collision mitigation). In this precrash phase, more far-reaching PreSafe™ measures then can be activated to prepare the vehicle, the restraint systems and the occupants so that they can better survive an imminent accident.

Minor Accidents (4)

Special protective systems designed to counter minimal damage are activated. Non-reversible occupant protection systems for more serious accidents remain suppressed at this stage.

Less serious Accidents (5)

Occupant protection systems are activated in a “soft” stage depending on accident severity and the occupants’ weight, size, etc.

Serious Accidents (6)

Occupant protection systems for severe accidents are activated.

Postcrash / Rescue Phase (7)

Protective systems are activated to deal with possible secondary impacts. Vehicle-related measures designed to facilitate passenger rescue are initiated.

Active and passive safety systems meeting current assessment criteria are found mainly in phases 2 (active safety) and 5/6 (passive safety) of this model.

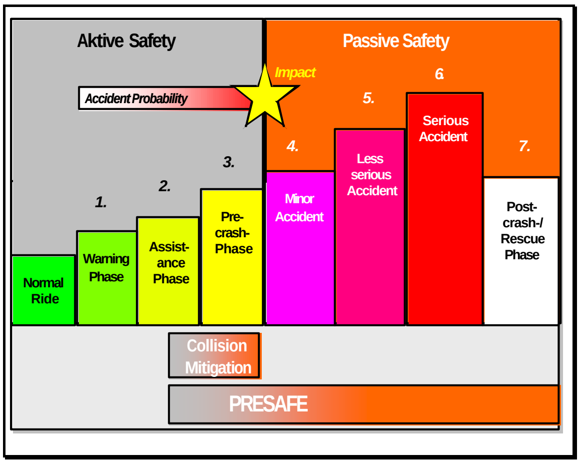

Fig. 6. Real Life Safety Concept

6. Focal points as seen by Mercedes-Benz

In vehicle development and in the evaluation of vehicle safety, in our opinion all seven stages of this comprehensive approach must be considered along with basic safety (i.e. current safety principles). First steps in the direction of PreSafe™ were made at the advent of the Mercedes-Benz automatic roll bar. However, full exploitation of the new potentials provided by PreSafe™ and collision mitigation takes development onto uncharted ground.

It is on this new ground that major steps for the further enhancement of overall vehicle safety will be taken. Mercedes-Benz therefore has made collision mitigation and, in particular, PreSafe™ important topics for the near future.

6.1 Collision Mitigation

Protective features designed to reduce accident severity can be effective both in the assistance phase and in the precrash phase. Collision mitigation is illustrated here by two examples:

The Brake Assist (BAS)

This is an assistance system that may contribute to accident avoidance, and also has the potential to reduce accident severity. For example, if “normal” panic braking (brake application by driver with better than average response; efficiency 0.7 in the first second) is initiated 30 m ahead of an obstacle at a speed of 100 km/h, the impact speed still is 64 km/h. If BAS braking is initiated in the same situation (efficiency 1.0 in the first second), the impact speed is now only 47 km/h; a reduction in impact energy of 46 percent.

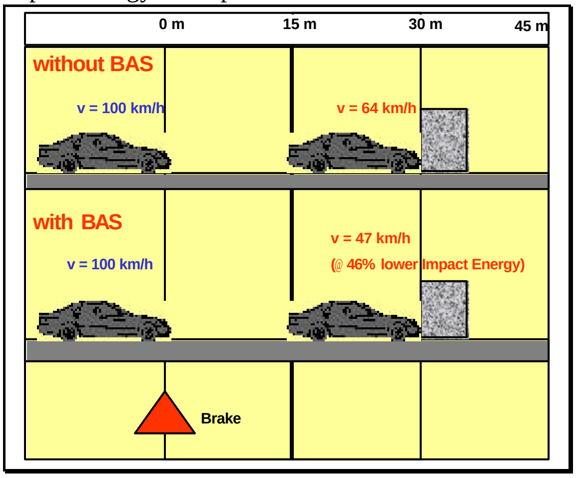

Fig. 7. Example of the Influence of the Brake Assist (BAS)

Automatic emergency braking systems

This is a classic collision mitigation system. The automatic initiation of emergency braking can make sense, for instance, if the driver fails to initiate the necessary braking action. Fig. 8 shows how impact energy and thus accident severity can be reduced by automatic brake application.

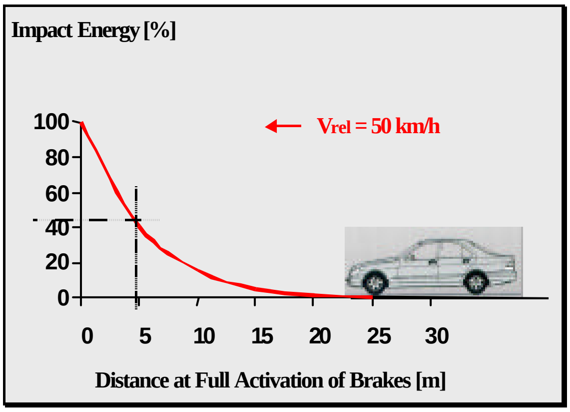

Fig. 8. Reduction of Impact Energy by Automatic Emergency Braking

If the brakes are applied 5 m from an obstacle and the initial speed is 50 km/h, the impact energy can be cut by 50 percent. This emergency braking feature equally serves to protect the occupants and other road users. It naturally requires that an imminent collision can be sensed with greater reliability than is possible today.

6.2 PreSafe Ô

Preventive reflex action in hazardous situations is a natural response. A cat falling offa tree spontaneously turns itself to the optimal position for free falling. Before touching down, the cat arches its back and extends its legs in order to better absorb the impact. A snow ball flies straight at one's face – in a reflex motion the eyelids close to protect the eye from damage.

In nature, therefore, protective mechanisms are activated preventively as soon as danger threatens. Nature also saves itself the trouble of detecting with absolute certainty whether or not the event will occur, in that it designs reversible (repeatable) protective mechanisms through evolution. PreSafe™ emulates this natural defensive strategy and applies it to vehicles.

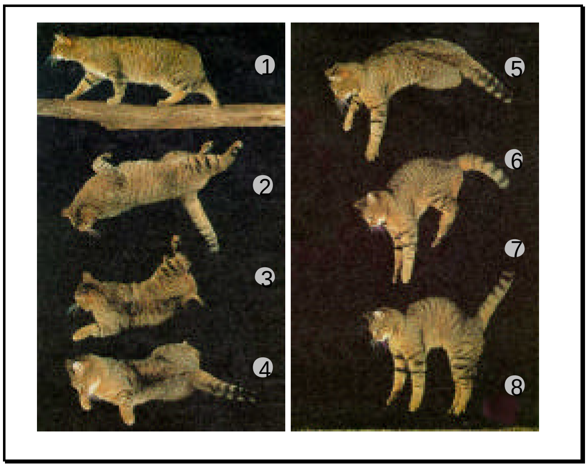

Fig. 9. Reflexes of a Falling Creature

In the vehicle, too, the time from the occurrence of an event with a potential for danger until the possible occurrence of an impact can be sensibly utilised even today. Supplementary preventive action which is reversible and which readies the vehicle or the occupants for a possible accident is taken. If the accident fails to materialise, the action can be interrupted and reversed.

PreSafe™ measures can remain active beyond a primary accident so as to provide protection against a possible secondary impact.

Effective PreSafe™ mechanisms can be:

Sensitisa-tion	Sensitisation of trigger thresholds for conventional protective systems depending on an accident-prone situation.

Fixation	Avoidance of undesirable movement by occupants due to the influence of accelerating forces in the phase preceding an anticipated impact.
Position-ing	Using the time in the phase preceding a possible impact to move the occupants into a better position for the impact.
Absorp-tion	Preventive moving of supplementary absorbing elements into possible passenger contact zones in the interior to enhance passenger protection.
Condi-tioning	Shifting of vehicle structural components into a more favourable position for an accident.

PreSafe™ measures are of smooth nature as they operate with low activation speeds. They do not necessarily have to accomplish their action by the time of the possible impact. The aim is rather to use the available time in each instance to make safety-improving adjustments to the vehicle. The condition for preventive action, however, is that it does not hamper or distract the driver in accident-prone situations. This restriction, however, does not apply to passengers.

7. Possible PreSafe Ô components and their potentials

Several examples are cited below which serve to describe the mode of operation and the benefit of PreSafe™.

Sensitisation of conventional trigger systems

The sensing of an increased risk of impact can be an important aid for sensitising the trigger algorithm for the activation of protective systems. For instance, during a skid it is possible to adjust the trigger threshold for sidebag activation to the situation in order to achieve a more rapid activation of the restraint systems. This will reduce the load on occupants in the event of a subsequent side impact.

Reversible belt pretensioner

An example of occupant fixation is preventive seat belt tensioning. Upon full application of the brakes, sensed e.g. through Brake Assist response, a passenger not prepared for the braking action experiences an undesired forward shift within the passenger compartment. If an impact then occurs as a result of the situation, the pyrotechnic belt pretensioner is ineffective since the belt slack has already been consumed. Under certain circumstances, an Out-of-Position (OoP) situation may arise. Through preventive belt tensioning at the start of the braking action, the undesirable braking-induced shifting of the passenger's body can be largely eliminated. In the considered example (Fig. 10.) it could be reduced by 150 mm upon unexpected emergency brake application. The reversible seat belt pretensioner thus makes it possible to diminish the loads on occupants in the event of a subsequent impact. The effect described here does not appear in any standardised laboratory crash test but is of great significance in real-life accidents.

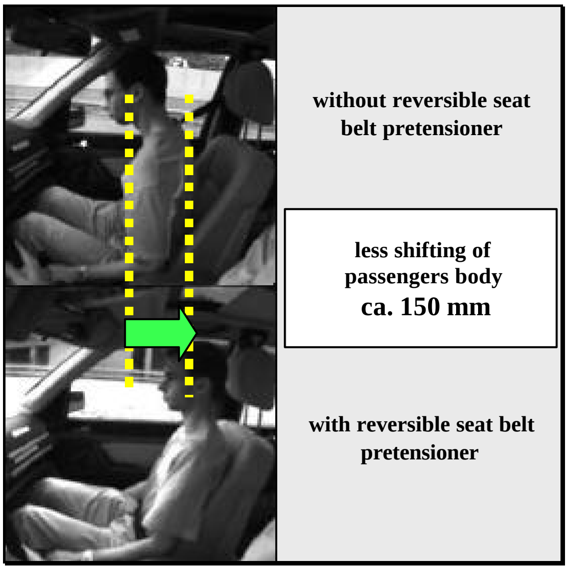

Fig. 10. Influence of the Reversible Seat Belt Pretensioner in Panic Braking

Similar observations apply to skidding vehicles: Without preventive belt tensioning the occupant may perform a pendulum-like movement in lateral direction of as much as 400 mm. If a side crash occurs as a result of the skid and non-reversible protective systems are triggered, there is a risk that at the time of impact the occupants may be positioned relatively close to the inner side wall of the vehicle. Due to the undesirable pendulum motion they cannot benefit from the full effects of the sidebag or windowbag. In extreme instances, an OoP situation can result. With preventive belt tensioning during skidding, triggered by signals from the electronic stability program ESP, occupant movement can clearly be reduced, in this case by about 300 mm. Along with the advantages described for side impact, we find that this PreSafe™ measure is advantageous particularly also in rollovers.

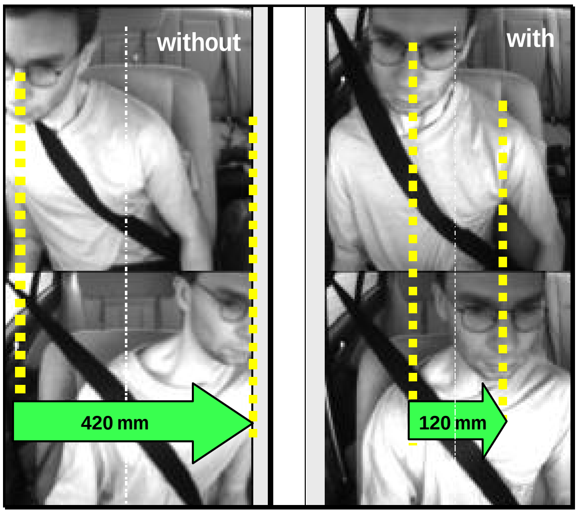

Fig. 11. Influence of Reversible Belt Pretensioners during Skidding

Seat conditioning

The protective action of restraint systems is greatest when the occupants and their surroundings find themselves in the intended design-position at the start of the impact. However, real accident experience shows that in many cases both the seats and the occupants are not in this position at the time of impact. This is frequently caused by the occupant selecting a comfort-emphasising seating position. This position may be disadvantageous in an accident. In particular the following settings have a negative effect:

- backrest inclined too far to the rear or front;
- seat surface not angled (no seat ramp);
- head restraint too low.

Based on the PreSafe™ idea, the time from the start of a critical driving situation to an impact can be used to correct the position of the seat and the occupant. Using existing actuators, in the event of danger the seats can be moved from a comfort position to a safety position, which is more beneficial to the occupants in the event of a subsequent impact.

Fig. 12 shows the change in occupant loadings depending on the seat position, which demonstrates its isolated influence on head acceleration and chest deflection (findings from computer simulation). Starting from the centre position of the longitudinal seat adjustment, which normally also conforms to the design position of the restraint systems, moving the seat further to the rear results in higher loadings. Shifting the seat position forward leads to a certain degree of reduction in loadings. From a certain point on, however, bottoming out occurs, which again leads to an increased injury risk.

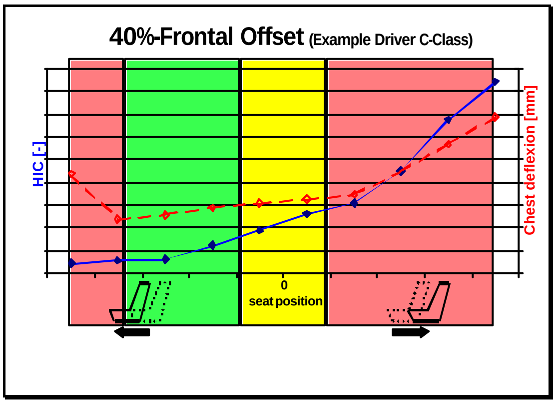

Fig. 12. Influence of Seat Position on Occupant Loads (Simulation)

Active padding

Crucial to the well-being of occupants of the vehicle passenger compartment is the presence of sufficient freedom of movement. This contradicts the requirements of passive safety, which basically seeks early transmission of vehicle acceleration to the occupants in order to achieve a high ride-down benefit. In keeping with the PreSafe™ idea, therefore, this comfort-relevant free space is reduced in favour of a greater safety potential when dangers arise.
To this end, in an accident-prone situation extensible or inflatable padding can be activated in potential occupant contact areas, having two effects:

- If the occupant is already close to the protective padding at an early point due to his seat position or to unintentional displacement during the precrash phase (pendulum motion during skid), he can be repositioned by activation of the padding. The distance thus gained is of advantage in the subsequent impact.
- The padding acts as an additional absorbing element, thus reducing the load on the occupants when colliding with parts of the passenger compartment.

Structural conditioning

Next to the interior and restraint systems, an application of PreSafe™ protective measures to the vehicle structure is also imaginable. This not only offers the potential for self-protection but also for partner-protection.

When danger threatens, for example, the front overhang of the vehicle can be automatically elongated. This extends the useful deformation length for the possible impact, thereby increasing the energy absorption capacity of the front-end structure. Alternatively, adapting the force level to the expected impact severity is thinkable.

Fig. 13. Basic Layout of a Telescoping Front End

In another example, Fig. 14 demonstrates the function of a vehicle ride-height adjustment feature, that could possibly be integrated in a hydraulic ABC (Active Body Control) system. In the event of a side impact, a higher position of the target vehicle would normally enhance collision compatibility since the penetrating front-end could better support itself against the side structure, which is notably stiffer in the sill area. Height adjustment can also result in better collision compatibility in a head-on car-to-car crash. However, since the design of the structural members varies greatly, it is essential to implement a technique for object classification.

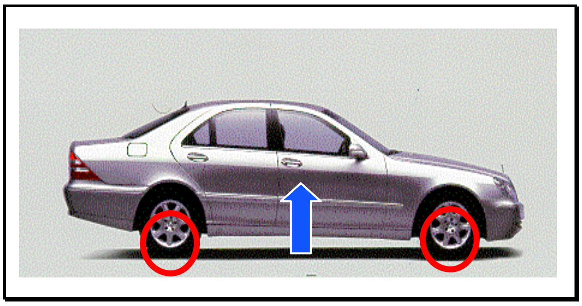

Fig. 14. Ride-height Adjustment for Improvement of Collision Compatibility

9. Summary/Outlook

Conventional safety engineering, particularly in the area of passive safety, is highly developed. Further advances are possible, but the effort and expense to realise them increase to an unreasonable degree. High potential for improvement results primarily from a visionary, comprehensive view of safety and strict orientation to what is really important in real world traffic. We need to understand that a well-directed warning to the driver at the right time can be just as crucial to the well-being of road users as designing the structure of a vehicle for certain types of loads. The safety of a vehicle cannot be reduced to individual characteristics. This global approach is the basis of the next step aspired to in safety engineering.

While active and passive safety have largely been developed independently of each other in the past, this new way of thinking produces increased synergy effects. Active safety seeks to a greater extent not only to avoid accidents, but has recognised that there are many ways to mitigate the severity of an unavoidable accident through the influence of active safety.

Passive safety's limited potential for further development has been recognised to stem primarily from the fact that developments of the past concentrated very strongly on the actual impact phase, as documented by the current familiar procedures of standard laboratory crash tests. In future, the essential possibilities for influencing safety will result from making purposive use of the pre-accident phase. In a first step, this phase already can be utilised in the short term by developing preventive, reversible protective measures. They can ideally complement the non-reversible protective systems we know today.

In a next step, parallel to the advances of techniques for detecting the environs of vehicles, such PreSafe™ systems will develop further into precrash systems. This will create further opportunities. For the benefit of enhanced occupant protection, non-reversible protective systems then can be triggered earlier and with lower deployment speeds.

10. References

European Accident Causation Survey
ACEA
Volume 4. Final Report

Justen R., Baumann K.-H., Pre-crash-Erkennung, ein neuer Weg in der PKW-Sicherheit, VDI-Berichte Nr. 471, 1999

Baumann K.-H., Schöneburg R., Die Forderungen des Herstellers an Crashtest-Programme, Symposium Weltweite Harmonisierung von Crashtest-Programmen, TÜV Köln, 1999

Schöneburg R., Rathje K., Frank T., Fußgängerschutz - Vision eines ganzheitlichen Sicherheitskonzepts, Technischer Kongreß VDA, 20./21. September 1999, Frankfurt

Kiesewetter W., Klinkner W., Reichelt W., Steiner M., Der neue Brake-Assist von Mercedes-Benz – Aktive Fahrunterstützung in Notsituationen, ATZ 99 (1997)

Kunert M., Kippelt U., Radarbasierte Nahfeldfsensorik zur Precrash Sensierung, VDI Berichte Nr. 1471, 1999