Evaluation of Occupant Protection Systems:
FROM A PREVENTIVE TO A PRE-IMPACTING RESTRAINT SYSTEM

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ABSTRACT

The safety of modern vehicles has reached such a high standard that experts view the remaining potential for improvement of conventional restraint systems as nothing more than minimal. However the use of information gathered during the pre-crash phase added to the combination of preventive and conventional restraint systems can reveal additional potential.
One example of this is the reversible pretensioner of the PRE-SAFE® system, launched in 2002, which can hold occupants in their position shortly before a potential collision and thus reduce forward displacement to offer improved protection in an accident.
This approach was further developed with the introduction of PRE-SAFE® Impulse, which debuts in the current S-Class of MJ 2013. PRE-SAFE® Impulse systems rapidly accelerate occupants at an early phase of the crash by moving them in the direction of the impact force so that the difference in kinetic energy between the vehicle and occupants can start to be reduced as early as possible. As a consequence the total energy does not have to be dissipated entirely during the crash itself, but is distributed over a minor initial impact and a major impact whose intensity is reduced accordingly.
The new PRE-SAFE® Impulse Side System, a pre-impacting restraint system, does not only applies this idea for side crash but brings the concept one step further. Previous measures for improving side impact protection were primarily implemented on the vehicle itself and did not directly influence the occupants prior to the crash. With PRE-SAFE® Impulse Side, a defined energy, is transferred to the occupant, who is set in motion already before the collision occurs. Therefore PRE-SAFE® Impulse Side is the very first of a new generation of pre-impacting restraint system whose field of action will be extended prior to the collision due to the integration of active and passive safety.
To this end, the PRE-SAFE® Impulse Side system uses a 360-degree sensor system, which permanently senses the car surroundings, to anticipate an unavoidable collision.
Using numerical simulation as well as sled and vehicle testing, relevant occupant loads have been shown to be reduced by 30 percent on average with the use of PRE-SAFE® Impulse Side.

INTRODUCTION

Due to improved structure, seat belts and airbags the safety level of modern vehicles has reached a very high standard. Even small cars offer an impressive degree of protection.
Further improvement of occupant protection, even implementing modern restraint systems such as adaptive airbags and switchable belt force, is only possible to a certain extent.

To date, occupant protection systems have only been actively deployed after the accident has started to transpire. The enhancement of driver assistant systems offer opportunities to reliably detect accidents in advance, the time window in which restraint systems can offer protection increases dramatically. This, in turn, leads to great potential for further improving occupant protection in a passenger car.

In the future Advanced Driver Assistance Systems will largely contribute to reduce the number of injured occupant by avoiding crashes or mitigating their consequences. However side crashes remain very challenging for sensors to detect. Indeed potential collision partners are often hidden and cannot be properly seen i.e. tracked by the car sensors until the collision is unavoidable. At least when our own car is standing on-board driver assistance systems are incapable of minimize the intensity of the accident or avoid the accident. In that case, the severity of the impact at the side of the vehicle is directly linked to the proactive measures undertaken by the colliding vehicle partner.

Nevertheless if restraint systems (passive safety) and driver assistance systems (active safety) taken individually cannot offers great improvement for side crash scenarios, the integral safety approach, combining both active and passive safety components in one system appears extremely promising.

In this paper a solution will be proposed that shows to what extent the pre-accident phase can be taken into account to prepare the occupant for a side collision impact.

OPERATIVE MECHANISMUS

Side Impact

Mechanisms of action in a side impact depend on the distance between occupant and vehicle structure as well as on the intrusion or contact speed of the vehicle structure to the occupant.

Compared to frontal impact there is less absorption way and time to protect the occupant in side impacts. There are only limited distance between the occupant and the struck side of the vehicle as well as short time between the beginning of the collision and the moment when the occupant is loaded by the impact of the door.

The vehicle's dimensional design usually limits the distance between the occupant and the vehicle structure. Potentials to reduce the intrusion velocity have been primarily achieved through structural measures. Present airbags for side protection are designed and dimensioned to be activated shortly after the beginning of the impact. Those conditions limit the performance of possible passive safety countermeasures.

Involving the occupant in the sequence of an accident event earlier or even prior to a collision has not been considered till now.

PRE-SAFE® Impulse

Today, occupant restraint systems are classified as reactive systems. The downside of these occupant protection systems is that they only take effect once the accident has already started. Occupants are then decelerated with a considerable time delay with respect to the initial collision sequence. Energy only begins to be dissipated once the

occupant has traveled a required distance within a specific time as a result of his or her forward excursion. In this time window, valuable deformation space has already been used to decelerate the vehicle but not the occupant.

The aim of PRE-SAFE® Impulse restraint systems is to couple the occupant as early as possible to the vehicle deceleration by distributing the total impact energy over a minor initial impact and a major impact whose intensity is reduced accordingly.

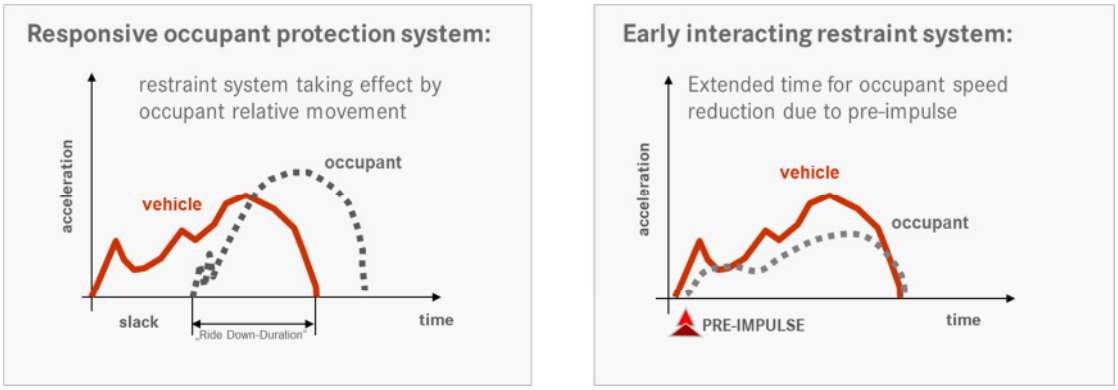

Figure 1: Comparison of responsive and early interacting occupant restraint system

Figure 1 shows a reactive and an early interacting restraint system. With an early interacting restraint system, the occupant is jolted in a very early phase of the accident, when the vehicle deceleration has not yet acted on him. The occupant perceives this as an acceleration impulse. This results in occupant deceleration, the occupant is briefly slower than the vehicle in which he is seated. The occupant is moved opposite the impact direction. The displacement path gained by the relative speed can be released again over the course of the accident via energy dissipation.

Such a restraint system influences the ride-down effect and occupant kinematics and can reduce the occupant load values via the longer deceleration period.

Assuming that the impact is known properly, the principle of reactivity can be augmented by actively moving the occupant in a defined direction. Prior to the impact occupants are not yet subjected to impact-specific inertial forces and can therefore be moved using little energy reaching comparable improvement with a lower pre-loading of the occupants (Figure 2).

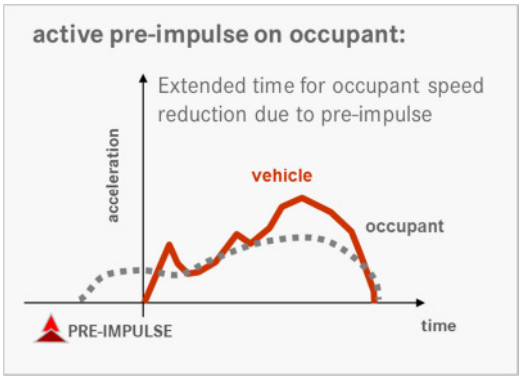

Figure 2: Active pre-impulse on occupant enable the change of velocity over the maximum of time

PRE-SAFE® IMPULSE SIDE - occupant protection system for side impacts

The PRE-SAFE® Impulse Side protection system demonstrates how a pre-impacting system could work. PRE-SAFE® Impulse Side is the very first of a new generation of pre-impacting restraint system whose field of action will be extended prior to the collision due to the integration of active and passive safety.

Occupant Impact as Operative Mechanism

At a precisely calculated time prior to the side impact, the occupant of a vehicle is laterally displaced by a movement of the backrest side bolster. This small impulse moves the occupant toward the center of the vehicle before the impact occurs.

Actively moving the occupant toward the center of the vehicle increases the distance between the upper body of the occupant and the door panel so that the side airbag can be safely and efficiently deployed.

The contact time between intruding structure and occupant also occurs later and therefore with reduced intrusion speed. In addition, the occupant is already moving at a certain speed in the direction of the impact. His/her relative velocity regarding to the intruding structure is smaller thus less kinetic energy has to be dissipated by the contact with the restraint system and/or the car structure.

PRE-SAFE® Impulse Side, like all other PRE-SAFE® systems, acts as an additional measure that does not replace the conventional restraint system, but enhance it.

PRE-SAFE® Impulse Side Actuator

The seat was equipped with a dynamic multi contour seat component. There, in the side bolster of the driver and passenger seat backrests, an air bladder is inserted that can be filled to improve lateral support during cornering.

To generate the impulse on the occupant, this air bladder was modified in terms of their size and filling characteristics so that they are strong enough to initiate the movement of the occupants toward the center of the vehicle. This process takes place within the seat without any damage and can therefore be repeated. The challenge with this setup is to create an upholstery concept, which on the one hand must allow sufficient movement, but on the other hand has to meet customer requirements in term of design and comfort.

Methods and Tools

The methodology for the assessment of the benefit of the PRE-SAFE® Impulse Side airbag is based on three tools: FEM crash simulation, sled tests and vehicle tests. In a first step FEM simulation was done to identify the optimal parameters of the airbag (pressure, geometry, volume) to reach the expected benefit. In static tests, the airbag design and deployment characteristic were performed and optimized. Sled tests were conducted to assess the reduction of the occupant injuries using PRE-SAFE® Impulse Side during a side impact. As final step the performance of the pre-impacting actor was ensured by vehicle tests.

Once a first prototype seat was available, the first step was to take some measurements of lateral excursion using different dummies in order to define a first set of parameter for the system and so insure the feasibility of the system. At each step, the data collected on dummies were validated against tests persons, both in static tests. For dynamic test validations, sled and car tests were compared to numerical simulation using Human Body Model to make sure that pre-impacting restraint systems do not induce any unwanted side effects.

Results

Like every PRE-SAFE® system, PRE-SAFE® Impulse Side unfolds its fully potential in real life accident scenarios. To show the benefit of the system in this paper two common side crash scenarios have been chosen: a pole and a barrier test.

Pole test The pole test has following configuration: impact speed: 29 km/h, angle: 90°, ES2re-Dummy. Compared to conventional restraint systems, the benefit of PRE-SAFE® Impulse Side vary between 25% in lower rib up to 35% in middle and upper rib (Figure 3). The potential in the upper area is the highest and decreases slightly with respect to the lower rib. The effect of the displacement is at its greatest in the upper thorax region and corresponds to the acceleration of the occupants.

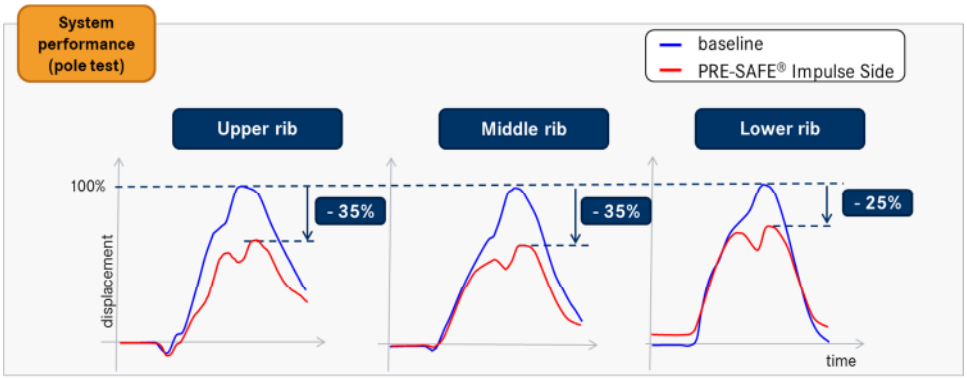

Figure 3: Benefit of PRE-SAFE® Impulse Side in pole test with ES2re dummy

Barrier test The barrier test was done according following configuration: impact speed: 50 km/h, movable deformable barrier with a mass of 1450 kg, SID2s-Dummy.
The PRE-SAFE® Impulse Side effect can also be seen in the barrier load case. Due to the lateral excursion, the loading of the shoulder begins later as it can be seen on the shoulder force curve in Figure 4. As a consequence, the rib intrusion value is also significantly reduced.

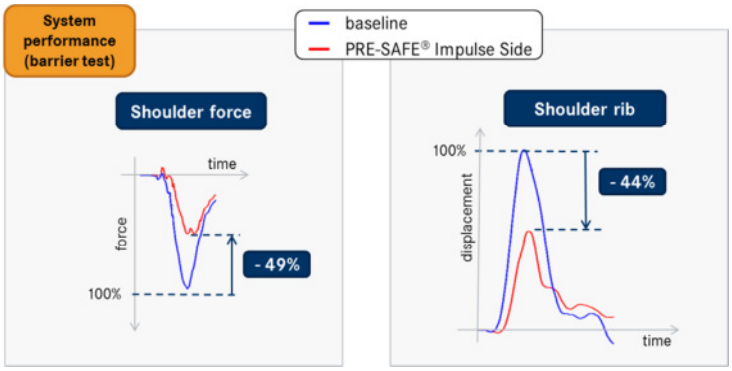

Figure 4: Benefit of PRE-SAFE® Impulse Side system for barrier test configuration

This improvement can further be observed on the thorax and the abdominal ribs. The PRE-SAFE® Impulse Side effect in the lower thorax region is also less pronounced than in the upper one in this load scenario, same tendency as for the pole load case (Figure 5).

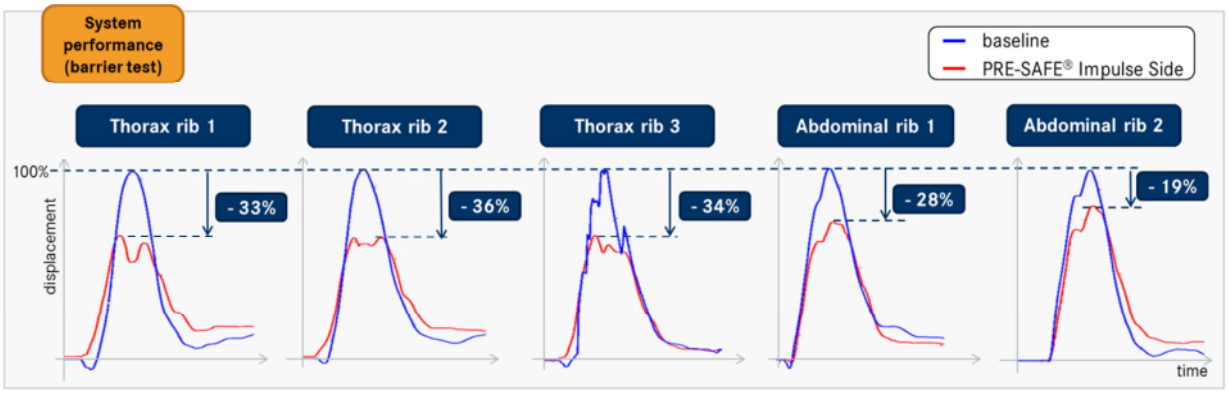

Figure 5: Benefit of PRE-SAFE® Impulse Side in barrier test configuration

System robustness

As PRE-SAFE® Impulse Side is the very first pre-triggered restraint system it was crucial to realize a robust system. The robustness of the system regarding to variation of the triggering time was analyzed. Investigations were undertaken in a PRE-SAFE® Impulse Side actuator time window starting from half a second prior to crash up to t0. An optimal operating point has been found and the response of the system around this point has been analyzed.

With a 25% error in the triggering time of the actor, the benefit compared to the baseline remains significant, showing the robustness of the PRE-SAFE® Impulse Side system (figure 6).

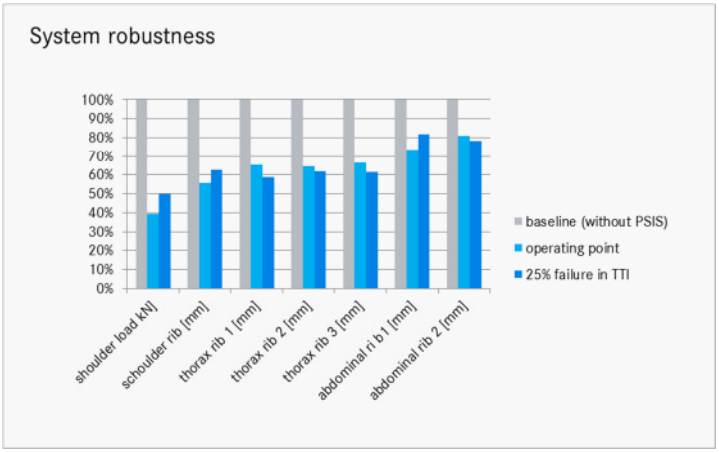

Figure 6: System robustness: Displacement of SID2s Dummy with 25% failure in TTI (time to impact)

SENSOR SYSTEM AND AREAS OF COVERAGE

Capturing and recording the environment, which primarily encompasses radar sensors, but also cameras and ultrasonic sensors, has established itself as an enabler for assistance systems in modern vehicles.

These sensors as used for driver assistance systems could also be used to develop spin-off applications that offer protection in an accident.

For this purpose, special algorithms were created that analyze the sensor data to detect directly "collision objects". Such detection can be realized independently of the assistance functions and operating status of the vehicle. The overarching objective is to detect "objects on a collision course", whereby this detection refers to the vantage point of the respective sensor. From this perspective, a passing vehicle in oncoming traffic is just as much an "object on a collision course" as a bridge pillar that the appropriate vehicle is approaching. Potential collision objects can also be detected when the vehicle is stationary.

The relevant space of time for detecting collision objects begins nearly half a second before the impact. From this time onwards it is possible to predict whether the collision is unavoidable or not. As a consequence the short distance area to the vehicle (typically under 15 meters) must be covered by the sensor system for such functions.

In the event of an impending frontal or rear-end collision, graduated preventive safety measures are activated. These measures are up to now always reversible in line with the underlying idea of the PRE-SAFE® concept.

Current Mercedes-Benz carlines equipped with a driving assistance package utilize targeted algorithms to detect collision using forward-facing sensors and the sensor in the rear bumper.

To realize the PRE-SAFE® Impulse Side function sensors that monitor the side area near to the car are needed. Accident analysis data were used to establish a basis for the observation area. Figure 7 (left) shows the distribution of impact angles in side crashes based on analysis of GIDAS (German In-Depth Accident Study) compared with today crash test scenarios required by regulations and ratings.

These areas on both side of the car have to be covered by the sensors. Figure 7 right illustrates the installation location and visibility of these sensors, whereby angles α and β depend on the exact application constraints and sensor concept.

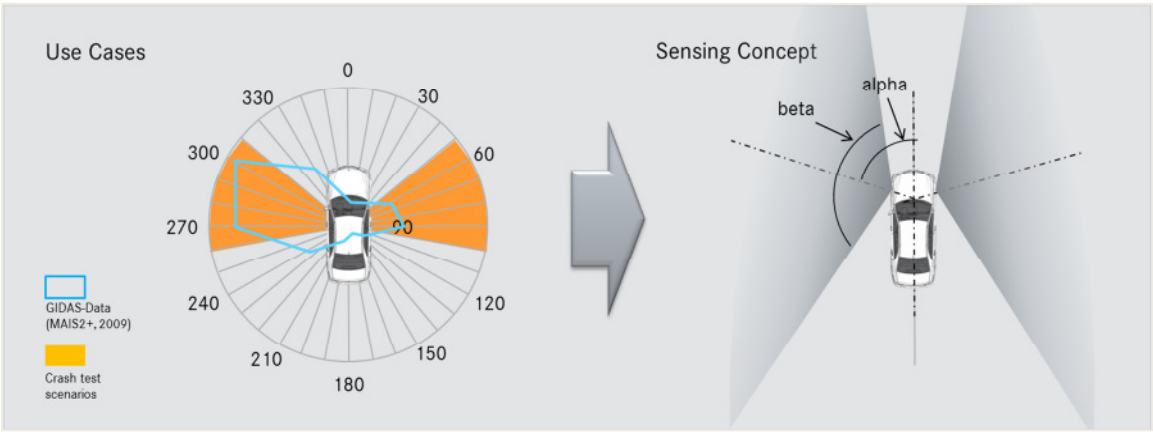

Figure 7: Schematic illustration of the sensor visibility areas required for PRE-SAFE® Impulse Side

The sensors needed for the PRE-SAFE® Impulse Side function filled the existing gap in the sensor coverage (Figure 7) achieving a 360-degree monitoring of the car surroundings.

SYSTEM RELIABILITY

Driving assistance

While the functional development for so-called "fire cases" (collisions that are detected in the pre-crash phase and for which a system enable is required on demand) is typically conducted on test tracks and using corresponding "soft targets", validation against false deployment must be handled parallel in two ways.

First, specially equipped test vehicles – as is the case with the development of driving assistance systems – are operated in normal, international road traffic in order to encounter as many different traffic and road-based situations as possible. As actual, "accident-critical" situations only arise very rarely, however, this type of testing must be supplemented with deliberately induced accident scenarios conducted on test tracks. In the process, very close drive-by or swerving situations must also be taken into account as well as conceivable special or misuse situations.

Testing and validating these "no-fire cases" is very expansive in scope when it comes to development.

As "PRE-SAFE® Impulse Side" and all other PRE-SAFE® measures always refer to additional, proactive measures that supplement the conventional basic occupant protection system, a deployment strategy must be chosen that prevents firing, or enabling, in the event of uncertain situations. PRE-SAFE® Impulse Side will help to further reduce occupant loads, however.

Customer Acceptance Study

Due to the triggering character of the PRE-SAFE® Impulse Side system, the function could be activated in the absence of a subsequent crash in isolated cases. Should this happen, the design of the system has to ensure that the driver is not influenced in his or her driving task.

To investigate this issue, the moving based driving simulator was used to analyze the effect of PRE-SAFE® Impulse Side activation completely free of risk and with a high rate of reproducibility.

During the driving simulator study, the driver's response to PRE-SAFE® Impulse Side activation in normal driving situations and the resulting reactions were assessed. Acceptance of false deployment was likewise examined. Three driving situations were constructed to activate the function and verify two driving situations with comparative natural disruptions (crosswind and flying stones). The driving route consists of urban scenarios, country road, and highway sections. The situation was incorporated into the route with 4 variants.

Data of objective measurement for assessing the driver response (driver behavior, driving dynamics, lane tracking, and environment) were recorded. In the study 175 PRE-SAFE® Impulse Side deployments and 54 comparative disturbances were evaluated.

PRE-SAFE® Impulse Side activation during the driving study has not shown any influence on lane tracking in the urban scenarios. On highway, the influence of PRE-SAFE® Impulse Side is less disturbing than experiencing a crosswind while passing another vehicle. Activation of the PRE-SAFE® Impulse Side induces driver responses that do not lead to critical driving situations and can be compared with natural disturbances such as crosswinds.

CONCLUSIONS

To date, occupant protection measures have only been actively deployed after the accident has started to transpire. In response to this, Mercedes-Benz launched PRE-SAFE® in 2002, the first reversible protection system that acts before the accident starts to take place.
As future possibilities encompass the opportunity to reliably detect accidents in advance, the time window in which restraint systems can offer protection increases dramatically. This, in turn, leads to great potential for further improving occupant protection in a passenger car.
To this end, the PRE-SAFE® Impulse Side pre-impacting restraint system utilizes initial information about the unavoidable side impact to optimally prepare the vehicle's occupants. This is achieved by coordinating actions with the 360-degree environment sensor system, which senses the relevant areas of the vehicle and provides the required signals and information for triggering the protective system.
With PRE-SAFE® Impulse Side a defined force and energy is exerted to actively integrate the occupant in the side impact at an early stage when the vehicle has not yet started to decelerate or has just begun to slow down. Analysis in numerical simulation, sled and vehicle testing, show that occupant loads could be significantly reduced by the benefit of the system.
As PRE-SAFE® Impulse Side is a preventive protection system and false deployment of it cannot be ruled out entirely, a driving simulator study was conducted to investigate the effects on a driving situation and the driver's acceptance of undesired activation.
To ensure adequate validation, the highest priority and challenge is to avoid undesired deployment, even if this means missing an opportunity to deploy when needed.
As PRE-SAFE® Impulse Side is an "on top" protection system, when it does not deploy, all protection capability of the side airbag will be still there.
Automated driving functions directly or indirectly will change the basic conditions associated with passive safety. Synergies with sensor technologies and situation assessment enable further innovative occupant protection strategies, like PRE-SAFE® Impulse Side, to be implemented in the future.

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