THE VISION OF ACCIDENT FREE DRIVING – HOW EFFICIENT ARE WE ACTUALLY IN AVOIDING OR MITIGATING LONGITUDINAL REAL WORLD ACCIDENTS

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ABSTRACT

Advanced technologies in environmental sensing, situational perception and new actuators that allow individual situational based interventions in braking, steering or controlling the chassis characteristics are giving new option for the enhancement of automotive safety. Especially primary and pre-crash safety systems profit from these new opportunities and their potentials. The vision of an “accident free driving” was born. In a first wave advanced systems for mitigating or avoiding longitudinal accidents were developed and were actually penetrating into the market. Therefore the question of the safety benefit that is achievable with these systems in real world accidents arises. The paper tries to find an answer for actual Mercedes-Benz primary and pre-crash safety systems.

Primary safety systems are designed to help to avoid accidents or, if that is not possible, to stabilize respectively reduce the dynamics of the vehicle to such an extent that the secondary safety measures are able to act best possible. The effectiveness is a measure for the efficiency, with which a safety system succeeds in achieving this target within its range of operation in interaction with driver and vehicle. Based on Daimler’s philosophy of the “Real Life Safety” the reflection of the real world accidents in the systems range of operation is both starting point as well as benchmark for its optimization.

Development objective for primary safety measure is the avoidance of accidents. But avoided accidents are not contained in an accident data base. Thus the efficiency of a primary safety measure in contrast to a secondary safety measure can not be determined directly from accident data. Up to now, the effectiveness of a primary safety system has usually been determined in retrospect, through changes in the accident statistics, or prospectively by appropriate tests such as, for example, driving simulator tests with test persons or driving tests in the field e.g. naturalistic driving studies. All methods have advantages, but also disadvantages. Challenge is to extract components needed and reassembling them in a new method to be able to estimate the safety benefit of the advanced systems usually consisting of warning and reacting components. This paper discusses the future requirements on these components, their establishment and on the accident data and its collection.

This paper deals with the methodology to perform assessments of statistical representative efficiency of primary safety measures. To be able to carry out an investigation concerning the efficiency of a primary safety measure in a transparent and comparable way basic definitions and systematic were introduced. Based on these definitions different systematic methods for estimating efficiency were discussed and related to each other. The paper is completed by estimating the safety benefit in real world accidents of purchasable Mercedes-Benz safety systems for assisting the driver in longitudinal accidents.

INTRODUCTION

In its white paper on the safety of road users the European Union set a 50% reduction in the number of fatalities among European road users by 2010 as its common goal. Japan has set a similar target and also the US is actively pursuing advances in road safety. The actual progress is illustrated in fig. 1.

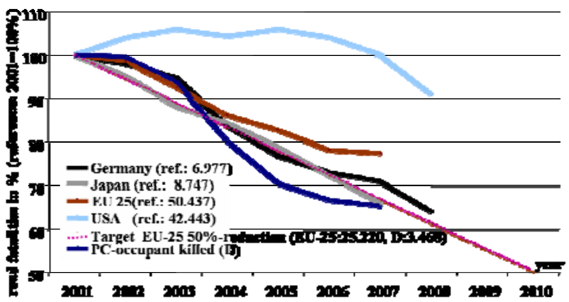

Fig. 1: Trend of fatalities in road accidents 2001-2007(08)

Mercedes-Benz contrasts these initiatives with its vision of *Accident-Free Driving*. For Mercedes-Benz, automotive safety is not just a question of fulfilling crash tests. Mercedes innovations in the area of vehicle safety have been based successfully on findings of accident researchers for 40 years. Reality still is and continues to be the benchmark for the development of effective primary and secondary safety measures made by Mercedes-Benz. The history of contribution to the increase of vehicle safety is long: defined crumble zone and stiff passenger cell, safety steering system, driver and front-passenger airbag, PRE-SAFE® – a system offering integrated safety by anticipating an impending accident based on data shared with primary safety measures and activating protective measures in advance - to name just a few examples for secondary measures. But there were also very effective primary safety measures which were developed in close cooperation with Mercedes-Benz and hence had their first offer to the market in a Mercedes: ABS in 1978, ASR 1987, ESP in 1994, BAS in 1996, DISTRONIC PLUS and Brake Assist PLUS in 2004, PRE-SAFE® Brake in 2005 (Stage 1) respectively 2009 (Stage 2).

These primary safety measures address primarily longitudinal accidents. For all accidents with fatalities they are second to crossing accidents (fig2). We obtain 14 percent for accidents with traffic moving ahead, waiting or starting and an amount of 7 percent for stationary vehicles manoeuvring or parking. The share of material damage only and fatalities is nearly 50%.

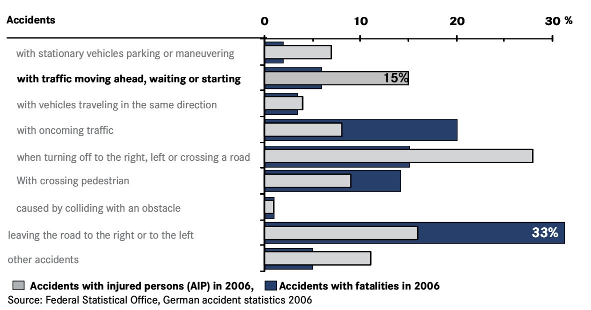

Fig. 2: Configuration of accident typs in Germany (accidents 2006)

The development of modern safety measures is a holistic process which is based on accident research, basic research on driver behaviour (situation based human or operating error) and the intensive investigation of driving scenarios that lead to a hazardous situation that might end in an accident. Building on that the development of new sensor, perception and actuator technologies as well as basic functionalities and their integration to a system takes place. A holistic approach and a close multi-disciplinary collaboration of different specialists are needed. An accident researcher as well as an expert on assisting systems, simulation, ergonomics or vehicle dynamics working on their own will produce insufficient results. Therefore Mercedes-Benz establishes interdisciplinary teams of experts to manage this demand. During the development process ample simulation series [18], system tests at test areas [12] and driving simulator tests are used to design and optimize the assistance systems [8]. During the final step customer-orientated testing of the system is organized. However, after the system is introduced it takes several additional years for it to penetrate the market. Only then it is possible to gain information on its efficiency based on real world accident statistics. Many of these systems take more than a decade of years to achieve a sufficient penetration rate.

Primary safety measures are designed to help to avoid accidents or, if this is not possible, to stabilize respectively reduce the dynamics of the vehicle to such an extent that the secondary safety measures are able to act as good as possible. Based on Daimler's philosophy of the "Real Life Safety" the reflection of the real world accidents in the systems range of operation is both starting point as well as benchmark for its optimization. This evidence based design approach is predicated on the work of Béla Barényi. Hence the efficiency of ABS and ESP is already demonstrated [6], [11], [13] we will concentrate on Brake Assist, DISTRONIC PLUS, Brake Assist PLUS and PRE-SAFE® Brake (Stage 1).

DIFFERENT STAGES OF SYSTEMS THAT SUPPORTS THE DRIVER BY AVOIDING OR MITIGATIONG LOGITUDANAL ACCIDENTS

Braking rapidly and firmly is the best way of avoiding an accident in many cases. As a matter of course it is assumed that braking especial maximal braking is possible stabile, track-adherent while keeping straight on as well as performing an evasive maneuver controllable for any driver, at any speed, at any load condition of the vehicle, at any road surface, property and at any weather condition (dry, wet snowy or icy). Hence a modern passenger car – especially a model out of the premium segment- is rather a complex system consisting of few subsystems intertwining

Stage 0 **Basic parts of the vehicle that set the stage for a powerful braking (toughen up car)**
Brake system and parts of it like e.g. booster, tires e.g. low-section or wide-base tire, chassis-technologies (suspension, damper, active and semi-active controlled devices),

Stage 1 **Systems that are able to optimize respectively stabilize the movement of the car while braking using sensors to measure the movement of the vehicle (feeling car)**
ABS (Antilock System), EBD (Electronic Brake force Distribution), ESP (Electronic Stability Program)...

Stage 2 **Systems that assist the driver by an optimal (adaptive) braking through recognizing his intention (adaptive car)**
BAS (Brake Assist), ADAPTIVE BRAKE...

Stage 3 **Systems that assist the driver by monitoring the area in front of the car and deduce warnings, assist by target braking or intervene automatically (seeing car)**
DISTRONIC PLUS, BAS PLUS,
PRE-SAFE® BRAKE, COLLISION WARNING...

Stage 4 **Systems that assist the driver by interpret complex critical situations and deduce warnings, assist by target braking or intervene automatically (the thinking car)**
Reacting on: Pedestrian, crossing vehicles, oncoming traffic, crossings, cocooning...

In table 1 the system "vehicle" was portrait as a human being respectively in corresponding education development levels. Remaining in this image, the roman idiom "*mens sana in corpore sano*" is the one who calls the shot here as well. The primary safety system of the stages 1 to 4 define requirements at the brakes as a result form their performance characteristics. On the other hand technical innovations are the enablers for the development of the systems defined in stage 1 to 4. It is the classical chicken or the egg dilemma. Who is driving and who is the one being driven?

As a result the average (usable on concrete) deceleration of a passenger car increases from 8.5m/s² in the early 90´s [10] to more than 9.5m/s² in the beginning of 2000. The 40m-barrier, a former limit for the braking distance out of a velocity of 100km/h, were gone below by many new launched cars. The penetration of ESP in the market provides braking systems that could be triggered additionally by a system – independently from the driver's brake initiation. ESP by itself requires an increased dynamic of the brake system.

The requirements pertain all parts of the brake system as well as their environment and design parameters, implemented respectively controllable functionalities, their ability to build up or reduce pressure and last but not least their communicational interface. Demands from a functional point of view are for example a close following of the build-up respectively decrease of the brake pressure and the brake pedal movement. In the case of a braking that is initiated and controlled by a system there has to be reproducible fast pressure build-up respectively reduction as well as slow and comfortable pressure build-up and decrease. The first is needed to realize BAS or autonomous pre-crash braking functionalities the second one to realize Advanced Cruise Control and Stop-and-Go functions. The brake pedal should not be moved or loaded by pulsations by the brake system in the case of an autonomous triggered or controlled braking (ABS ...). There should be a measurement for effort and travel of the brake pedal, an adaptive variable ration of the amplification of brake pressure and pedal effort is desirable. The requirements on the dynamics of a system triggered or controlled build-up or decrease of brake pressure is growing. Driven by pre-crash safety systems and primary safety systems for lateral control gradients of over 400 bar/s in the range of 5 to 100 bar for building-up pressure and of more that 1000 bar/s for decrease pressure in the whole range are realistic. The accuracy should be less 0.5 bar in the range up to 50 bar. There should be an open communication interface. Fig. 3 shows the interaction

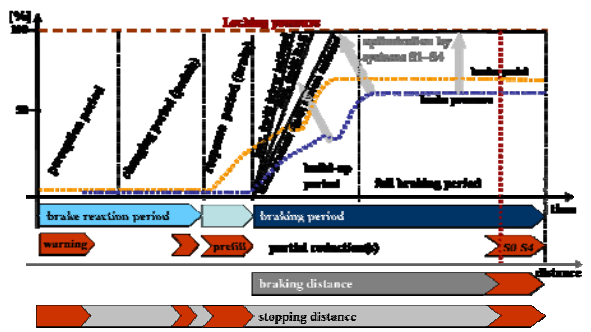

Fig. 3: **Presentation of the sequence driver reaction and brake reaction in the case of an emergancy brake reaction**

of the brake and the primary safety measures of stage 1 to 4. Area of action of the systems of stage 2 and above is the reduction of the stopping distance while the brake system reduces the brake distance and gives the basic parameters for the systems to build upon.

Each new car model has to meet the demand of the state-of-the-art in his segment at least during its manufacturing cycle of about 8 years. So there are growing requirements at each component of a new model especially at the braking system.

Enhanced safety when braking results from a powerful brake in combination with a configuration of primary safety measures of stage 1 to stage 3. Mercedes-Benz has very efficient systems on all these stages. This should be demonstrated in the next sections of this paper were systems of all stages are analyzed regarding their efficiency in Real Life Safety.

USEFUL DEFINITIONS ABOUT EFFICIENCY

For analyzing the effect of primary safety measures it is useful to define terms that describe abstract characteristics of an accident or concrete accidents of a given characteristic e.g. in an existing data base. A characteristic could be e.g. a parameter that produces an accident like the conflict, an environmental parameter like ice or a property like skidding. Another useful distinguishing feature is that between the relative and the absolute effect. To be able to do so the definitions from [24, 25] were adopted.

The **area of conflict** [**AoC**] of a primary safety measure is defined as the pooling of abstract standardized conflict situations, in which the primary safety measure should be operating, avoiding or reducing accident severity due to its specifications. Use-cases which can be categorized as accidents are an example that makes up an "area of conflict". A (representative) accident data base is the origin for the following explanations. It contains all kinds of accidents. Often it is useful to restrict the analysis to accidents which confirm to certain requirements – e.g. accidents with a certain severity.

The **area of reference** [**AoR**] is the set of cases that form the basis for the analysis. Depending on the type of question that has to be answered, a different set of accidents for the area of reference is selected, for example only fatal accidents or accidents with severely injured casualties. The **area of action** [**AoA**] is defined as the mapping of the area of conflict in representative real life accident data contained in the data base respectively the **AoR**. It is the totality of accidents contained in **AoR** which correspond to the conflict situations in the area of conflict.

The **area of efficiency** [**AoE**] is defined as the subset of the area of action, in which the primary safety measure is able to avoid or mitigate the severity of accidents. For this subset of **AoA** the design specifications satisfy the physical parameters of the accidents. The **degree of efficiency** [**DoE**] is defined as the quotient of the number of accidents in the area of efficiency and in the area of action. The adjunct **"representative"** is used to clarify that the allocation accident data base was representative. The **efficiency** is defined as the quotient of the number of accidents in the area of efficiency and the number of accidents in the area of reference. The **absolute efficiency** is given by the efficiency when AoR and AoA are equal to the accident data base. These definitions were introduced to reduce confusion resulting from ambiguous usage of the concept of "efficiency" for nearly everything in parallel. They should help to strengthen the way of looking at the thinks behind in a common way. By definition **AoR** is a subset of the (representative) accident data base, **AoE** is a subset of **AoA** and **AoA** itself is a subset of **AoR**. An illustration of the terms is shown in Fig. 4. Figuratively speaking, **AoC** of a safety system Y corresponds to those use-cases of Y that could be represented by conflict situations and if the worst comes to the worst result in an accident.

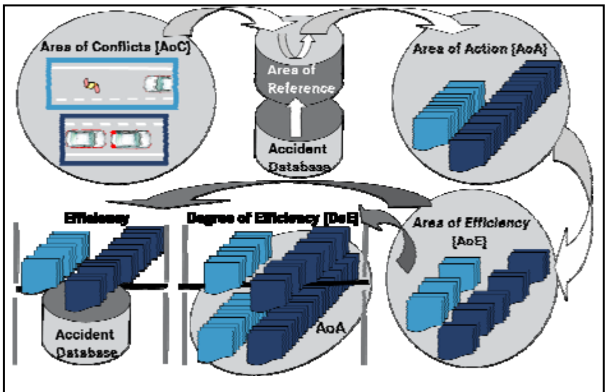

Figure 2: Illustration of definitions about efficiency

The Brake Assist System (BAS) was designed to assist the driver in is Here the **AoC** for example can consist of the accident types "collision with traffic moving ahead, waiting or starting", "collision with a pedestrian crossing the street". For illustration we choose GIDAS for the accident data base in this example. For exemplification **AoR** is chosen to be the set of all accidents (and their documentation) in GIDAS with injury MAIS 3+ (seriously injured). **AoA** then is a subset of all accidents contained in GIDAS with injury MAIS 3+ which were of the kind *collision with traffic moving ahead, waiting or starting* or *collision with a pedestrian crossing the street*. **AoE** is the subset of these cases where the (BAS) had / would have had an effect on the severity of this particular accident. The degree of efficiency is the proportion of elements of AoE and AoA.

So far efficiency quantifies the number of accidents which are likely to be influenced by the analyzed primary safety measure. So the efficiency is a proportion respectively a number. For the design or the assessment of a primary safety measure it is more important to get the two summands producing efficiency than the value for efficiency itself:

efficiency = *proportion of avoided accidents* + *proportion of accidents with mitigated severity*

The aim of primary safety measures is to prevent accidents. Thus the "proportion of avoided accidents" or the "efficiency in avoiding accidents" is the most important characteristic of a primary safety measure. The "proportion of accidents with mitigated severity" or the "efficiency in mitigating accidents" is hardly interdependent by classification measure that describes the performance of the mitigated severity over **AoE**.

DATABASES FOR ANALYZING EFFICIENCY

For the studies contained in this paper, three different databases were used:

[a] The 50 percent random sample selected out of two years from the accident statistics of the German National Statistics Office, were all Mercedes-Benz vehicles involved in one of the contained accidents are visible for evaluations carried out by Mercedes-Benz.

[b] The GIDAS-database.

[c] The central spare-parts logistics database of Mercedes-Benz. It describes in detail all delivered spare-parts (for the analyzed model) in Germany.

The choice of the accident data base used for an efficiency analysis of a primary safety measure determines whether the results can be applied to official accident statistics or not. The reflection of these figures by real world accident statistics is an essential benchmark for judging the system's efficiency. Representativity of an accident data base means that its composition and characteristics resemble (of a defined severity) with the composition and characteristics of the allocation base – here the entirety of all accidents e.g. in Germany. In other words a smaller sample set (accident data base) is a consistent image of the big allocation base. It is a popular fallacy that representativeness of an accident data base correlates respectively growths with its size. This is only true for a data base that consists of an undistorted sample of accidents. Here a minimum number of samples that could be analyzed are needed to become statistical significant. For a distorted respectively focused selection increasing samples size tightened its missing representativeness.

Representativity of an accident data base is the basis to be able to educe universally valid evidences for the entirety of all accidents from analyzing a smaller (but representative) image established in the accident data base. The GIDAS data base is proved to be representative for accidents with injuries and fatalities in Germany. This is why GIDAS is used in this paper.

Some results were supported by findings from driving simulator studies. The results for experiments at a driving simulator have the unique advantage that they demonstrate the variance of human driver behaviour in a fixed accident situation remaining the same for all different drivers. This investigation method provides conclusions about the thinks that can lead to hazardous situations. In [14] the use of a driving simulator in the development process of assisting systems is described. To cover the wide spread of conflicts that lead to a rear-end accident the efficiency is calculated as a mean of several typical rear-end accidents [1, 8, 26]. A lot of sensitivity and experience is needed to gain reliable figures that describe the real life efficiency.

GIDAS DATABASE - A STATISTICAL REPRESENTATIVE SAMPLE OF ACCIDENTS

Some analysis in this paper are based on accident data provided by the GIDAS project. GIDAS is an abbreviation for “German In-Depth Accident Study”. GIDAS is a cooperative project between the German Association for Automotive Technology Research (Forschungsvereinigung Automobiltechnik e.V., FAT) and the German Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt). In its current form it was founded in 1999 see [17], [30] for more details. Since this time the data for in-depth documentations of more than 2000 accidents per year is collected in two research areas – the metropolitan areas around Hanover and Dresden (fig. 5).

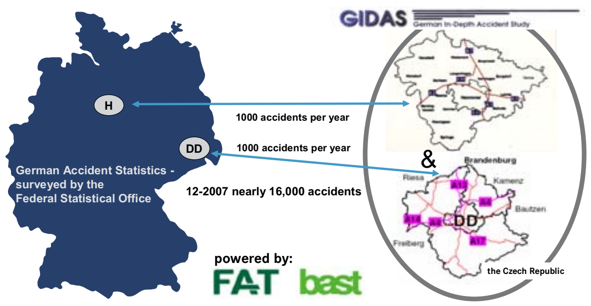

Figure 5: GIDAS-the research areas around Hanover and Dresden

The criterions for choice and collection are: (1) road accident, (2) accident in one of the research areas, (3) accident occurs when a team is on duty in a defined timeframe, and (4) at least one person in the accident is injured, regardless of severity. For each accident a digital folder is delivered according to carefully defined guidelines and coded in a database. Depending on the type of accident, each case is described by a total of 500 to 3,000 variables, containing e.g. accident type and environmental conditions (the type of road, number of lanes, width, surface, weather conditions, time of the day,…) surroundings of the accident scene, vehicle-type, vehicle specifications (mass, power, tires, …) and configurations (primary and secondary safety measures), documentation of damage of the vehicles and injury data for all persons involved and their medical care. Investigation of all cases is “on the spot” to ensure best visibility of traces for a best possible reconstruction. Each accident is reconstructed in detail including the pre-collision-phase. Available information includes initial vehicle and collision impact speed, deceleration as well as the speed sequence of the collision.

Half the battle of the pro of this database is that: (1) for standard AoA´s (needed for the assessment of actual safety measures) the number of cases is high enough to provide statistically significant results, and (2) each accident is documented in great detail, including in-depth-analyses and reconstructions of the course of the accidents including the pre-crash phase, and (3) most of all this database is proven to be representative to German National Accident Statistics.

PROVED EFFICIENCY OF BRAKE ASSIST – THE GRANDFATHER OF ALL COLLISION MITIGATION SYSTEMS

Brake Assist (BAS) was derived from the observation that drivers apply the brakes in emergency situations fast but normally did not reach maximum capability of the brake system. Brake Assist (BAS) identifies emergency braking situations by a continuous comparing of the speed at which the brake pedal is activated. If this speed exceeds a specific limit which also depends on the current velocity of the car and an actuation travel of the brake pedal, the Brake Assist (only true for design version of Mercedes-Benz other brand or supplier use different strategies for driver assistance) automatically builds up the highest possible brake pressure. The actual deceleration of the vehicle increases instantly to the maximum possible value. This implementation strategy reduces the braking distance substantially. Comparable with ABS, BAS is actually integrated into the architecture of the Electronic Stability Program (ESP) in Mercedes passenger cars. This guaranties a vehicle moving straight ahead or a vehicle performing a maximal evasive maneuver during the emergency braking true to the requirements of the driver and against the environmental conditions.

It was due to the decision of Mercedes-Benz to install BAS 1997/98 as standard equipment in all passenger cars that the efficiency of the system was measurable in the national German accident statistics of 1999/2000. On the basis of a representative sampling of the accident figures complied by the Federal Statistical Office in Germany, Mercedes-Benz has determined the accident rate of rear-end collisions per

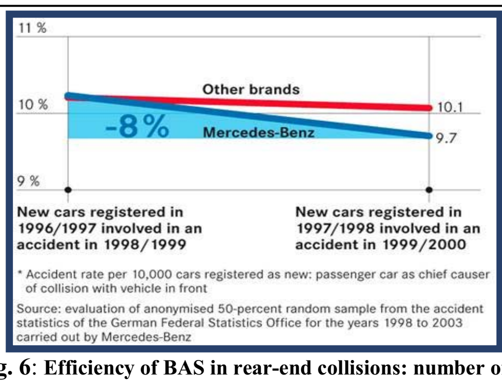

Fig. 6: **Efficiency of BAS in rear-end collisions: number of accidents down by 8 percent thanks to BAS**

10.000 newly registered passenger cars. The results show that the involvement of Mercedes-Benz cars dropped by eight percent following the installation of Brake Assist as standard equipment. By contrast, the rate for passenger cars of other brands remained relatively unchanged during this period (see figure 6).

Accidents with crossing pedestrians are among the most severe types of traffic accidents in Germany. In Germany nearly 13 percent of fatalities and 8 percent of injuries in traffic accidents result from this accident type in Germany in 2006 [16]. As well as the effective support in the case of a rear end collision BAS supports the driver in these accident situations. The evaluation of German accident statistics before and after the introduction of Brake Assist as standard equipment in all Mercedes-Benz automobiles showed that severe collisions between cars and crossing pedestrian dropped by 13 percent. For the passenger cars of other manufactures the share of pedestrian-related accidents resulting in fatalities or severe injuries decreased by one percent during the observed time period (figure 7).

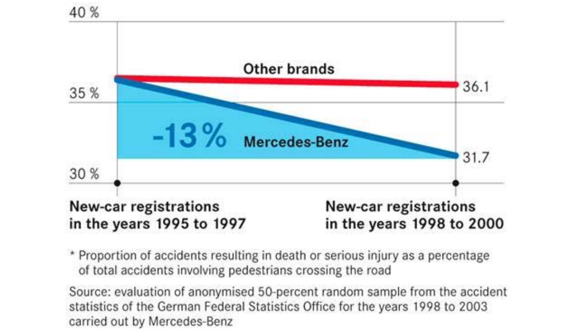

Fig. 7: **Efficiency of BAS in avoiding serious accidents with crossing pedestrians: down by 13 percent thanks to BAS**

Mercedes-Benz has extensively tested the function and operation of Brake Assist. Each test confirms the positive effect of BAS in increasing the braking power in emergency situations – an earlier initiation of the braking force and an operation at the maximum usable braking force. Both lead to shorter average stopping distances in sum. One result was a reduction of the stopping distance on a dry road for a velocity of 100km/h of 45 percent. A group of 100 drivers was therefore observed. Thanks to the usage of the Brake Assist they gained a reduction of their average stopping distance. In the investigated unforeseeable critical situation a reduction from 73 meters to an average stopping distance of 40 meters was achieved.

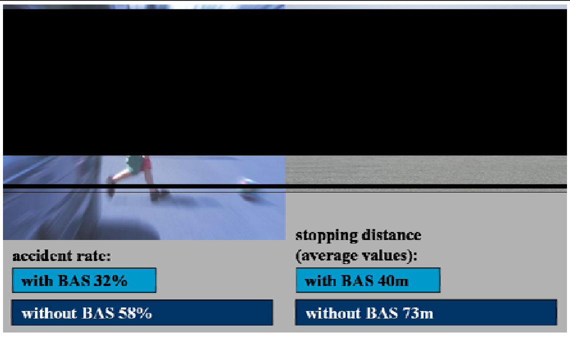

Fig. 8: Results from experimental tests concerning the function and operation of Brake Assist in the closed loop with the driver.

Another finding was based on an experiment in the driving simulator in Berlin [7]. In this study, 55 test-persons were driving on an urban road at a velocity of approximately 50km/h. While driving through a town suddenly a pedestrian (a child) crosses the road from the left to the right. In order to avoid the collision the test person had to perform a panic braking. In 45 percent for all situations a collision with the pedestrian occurred. The result was that drivers with vehicles equipped with BAS had an accident rate of 32 percent, where as drivers in the reference group using the same vehicles without am equipment of BAS had an accident rate of 58 percent. Fig. 8 shows this significant difference depending on whether the vehicle was equipped with Brake Assist or not. A closer look at the drivers of vehicle equipped with BAS reveals that all drivers who managed to activate Brake Assist could avoid the collision, accidents only occurred when BAS was not activated by the driver's actuation of the brake pedal. Brake Assist showed a benefit of reducing the accident rate by 26 percent in total or 55 percent relatively.

Supporting conclusions are drawn by LAB [23]. Here the system is called EBA (emergency brake assist) to specify the implemented strategy for assistance which is equivalent to the Brake Assist discussed here. Based on the French national injury accident census samples of BAS-relevant accident situations were identified. Via a logistic regression a risk for an involvement of an equipped and unequipped car was calculated. The evaluations result in a good effectiveness of Brake Assist: -7.5 percent of car occupant fatalities, -10 percent of pedestrian fatalities estimated by the used methodology versus in the national French census observed reduction of -11 percent overall injuries.

In a recent study carried out by the BASt [15] the safety impact of improved vehicle safety on the development of accidents of passenger cars on rural road were analyzed. Based on an evaluation of the German National Accident Statistics of the years 2000 to the year 2005 on rural roads, BASt estimated a disproportionate decrease of accident figures for newer vehicles in BAS-relevant situations compared to all situations. The equipment rate of cars with all kind of realization strategies and implementations of a Brake Assist System grows from 6 percent in 2000 to 20 percent in 2005. The involvement of cars younger than 2 year in BAS-relevant accident deceases by 41 percent, of older cars (in between 5 to 14 years old) decreases by 31 percent while the involvement in the comparable non-BAS-relevant accidents decreases by 20 percent only.

PRIMARY SAFETY MEASURES BASED ON ENHANCEMENTS IN ADVANCED CRUISE CONTROL TECHNOLOGY

FROM DISTRONIC TO DISTRONIC PLUS

Mercedes-Benz calls his advanced cruise control (acc) DISTRONIC (DTR). It was presented in 1998. The system combines the cruise control function with a 77 Gigahertz long-range radar sensor. For an intrinsic speed in the range between 30 to 180 km/h DTR can set a value for vehicle speed and another value for a time based distance maintaining to a vehicle in front. Below an intrinsic speed of 30 km/h DISTRONIC automatically switches off. Its maximum dynamic to decelerate is 2m/sec². The assisting System DISTRONIC tries to keep the vehicle at the desired speed until it detects a slower vehicle in front. In this case DTR reduces the intrinsic speed so that the planned distance to the car in front is kept. If DTR reaches its system limits the control task is handed over to the driver. DISTRONIC also contains optical and audible collision warning.

Selective further developments of DISTRONIC lead to DISTRONIC PLUS [1, 8] in 2005. The 77 GHz long range radar was combined with two 24 GHz short range radar sensors. The algorithms for situation perception and assessment were enhanced. This improvement enlarged the operating range from 0 km/h to 200 km/h. Furthermore the extend of the operating area of the proximity control widened, covering now a range between 0.2 m and 150 m. Last but not least an advanced dynamic range for deceleration was achieved, too (fig. 9). As such, automatic braking is now provided up to 4m/s² depending on the intrinsic speed.

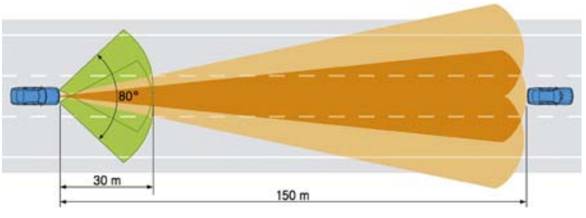

Figure 9: Short- and long range radar – filed of view (S-Class)

Where are the differences between DISTRONIC and DISTRONIC PLUS that are relevant for their ability to mitigate or if physically possible avoid rear-end accidents?

While the conventional DISTRONIC can not …

- automatically brake to a standstill, DISTRONIC PLUS can.
- “sense” a car standing still after braking to standstill DISTRONIC PLUS can.
- decelerate with more than 2 m/sec² DISTRONIC PLUS can decelerate automatically with 4m/sec² up to an intrinsic velocity equal 50 km/h, between an intrinsic velocity of 50-150 km/h with a deceleration in the range from 4 m/sec² to 2 m/sec², and above 150 km/h with 2 m/sec².
- control speed and distance in the range from 0-30 km/h for intrinsic velocity and in proximity up to 0.2 meters, DISTRONIC PLUS can.

Like all other advanced cruise control system DISTRONIC is an assisting system that increases the comfort of distance and speed control for the driver. The driver has to switch on this system to get this kind of assistance. It remains the same with DISTRONIC PLUS; it has to be switched on by the driver to get its functionality.

The advanced situation perception and assessment based on the use of 24-GHz radar, the extended dynamic and enlarged system limits cover the dynamic of more than 50% of rear-end accidents. In sum these additional features give DISTRONIC PLUS the opportunity to mitigate respectively avoid rear-end collisions.

FROM BRAKE ASSIST TO BRAKE ASSIST PLUS

Brake Assist, which was first introduced by Mercedes-Benz in 1996, has proven to be an effective primary safety measure. It provides assistance to the driver in avoiding accidents or mitigating their severity as we saw in a preceding section. But the triggering of the assistance - the power boost with all available brake pressure – stands or falls with two variables. On the one hand the identicalness of the individual speed has to be taken into account. On the other hand the pedal force applied by the driver is a decisive feature. Both variables employed during the pre-crash phase preceding an actual accident with its thresholds is taken as the basis for activation. The driver is “the sensor of the Brake Assist System for detecting emergency situations and triggering its assistance”. The driver can cancel the maximum brake support by releasing the brake pedal. The activation of the pressure boost is depending on the under lying characteristic diagram that has to warrant that an emergency braking is triggered in (objective) emergency situations only. The design of this diagram is on the horns of a (design) dilemma - faced with a choice between two evils. To decrease the thresholds to much might result in unintended assistances although it would trigger the assistance in more emergency situations. The way out of the dilemma was to increase the reliability of the interpretation of the brake reaction preformed by the driver for those situations whenever there is a vehicle in front. This new strategy has the ability to raise the rates of activation reported in [7, 26] for the case of rear-end collisions precisely. By this, it is able to prevent additional rear-end crashes in relation to the “classical” Brake Assist without environmental perception.

The results of an evaluation of over 800 representative brake reactions of driver in a pre-crash phase leading to a rear-end collision shows that these additional efforts pays off. More than 43 percent show a brake reaction in average (see fig. 10). The amount of 25 percent of driver that actually show no reaction is demanding for collision warning to initiate a reaction.

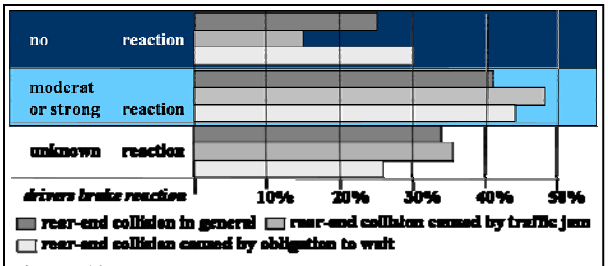

Figure 10: Reaction of the driver of the car that hits the car in front in the case of a rear-end collision (representative GIDAS evaluation of 839 accidents, 12-2006)

BRAKE ASSIT PLUS – A SENSOR BASED EXTENSION OF MERCEDES BRAKE ASSIST TO COLLISION WITH A VEHICLE IN FRONT

A stringent further development of BAS [8, 1] based on intensive work of the accident researchers was adding of "environmental sensing" i.e. the integration of (two) radar sensors systems to monitor and evaluate the traffic situation in front of the car. Design objective was to detect vehicles using the same lane in the same direction moving, starting or braking down to stand still.

The 77-GHz and two 24-GHz radar systems complement each other. The 77-GHz long-range radar is able to scan three lanes over a distance up to 150 meters with an angel of nine degrees. Two 24-GHz radar sensors monitor the immediate area in front of the vehicle from 0.2 up to 30 meter with an angle of 80 degree for each sensor (Fig. 9). With this radar-based environmental perception the situation evaluation algorithm of BAS PLUS can detect imminent rear-end collisions to identified obstacles. If there is currently one detected BAS PLUS does in parallel:

(1) BAS PLUS calculates continuously the actual braking assistance required to avoid a collision with a vehicle ahead by target braking (not necessarily a full braking). The calculated braking pressure is available as soon as the driver applies the brake.

While the conventional Brake Assist requires a (specific) reflex activation of the brake pedal, BAS PLUS only requires a pressure on the pedal that shows the clear intention for braking. (But it does not perform without a driver stepping on the brake – its remains a brake ASSIST.) This measure increases the number of activations considerably compared to BAS [14]. While the conventional BAS only can provide full braking pressure, BAS PLUS provides a situational depending braking pressure needed for a target braking.

(2) BAS PLUS warns the driver with an audible signal, prompting him to take action. *This warning sub function is an additional difference between conventional BAS and BAS PLUS. Thereby BAS PLUS is able to support drivers that misjudge criticality, react inert or got distracted. This warning increases the number of driver braking in these conflicts.*

The BAS PLUS system is an additional option working efficient especially in the case of rear-end collisions; naturally the (classical) BAS remains always available. Of course it continues to provide its efficient assistance in all accident situations. It proved itself especially helpful in those cases, in which the radar sensors failed to detect the objects or where an alert driver sticks to be a more efficient sensor than radar. As an extension of Brake Assist BAS PLUS is an "always-on" system like ABS or ESP. BAS PLUS is a component part of the DISTRONIC PLUS package not available as a stand-alone system. For this reason and since these systems are not standard equipments respectively their penetration rate is far below 100 percent it is not possible to determine their efficiency from a retrospect evaluation of the National Accident Statistics as it was done for BAS. A new method had to be utilized.

INCREASED EFFICIENCY OF INTER-CONNECTING SYSTEMS CAUSED BY IMPROVED ENVIORNMENTAL PERCEPTION

A representative study was carried out to answer one question in particular: how many real-life rear-end collisions could be prevented if all passenger cars were equipped with this radar-based interconnecting assisting systems?

This kind of evaluation is demanding for highly-developed simulation techniques. Each component like the primary and secondary safety measures, vehicle, driver and environment has to be modeled in detail taking their dynamic interactions into account. Especially the behavior of the mechatronical parts and control systems is challenging.

For a precise investigation of these components accident data were selected from GIDAS (database 12-2006). This category contains all rear end collisions with injuries, in which a passenger car collides with another vehicle in front, constituting a representative sample of rear-end collisions with injured persons in Germany. The resulting **AoA** consists of 839 in-depth evaluated accidents, especially containing reconstruction data. This data represent a picture of the conflicts. Fig. 10 and 11 were results of analysis them. Fig. 11 displays the distribution of the driver behavior in the pre-crash phase on motorways. Remarkable is the opposite behavior of the brake reaction in the existence of a traffic jam.

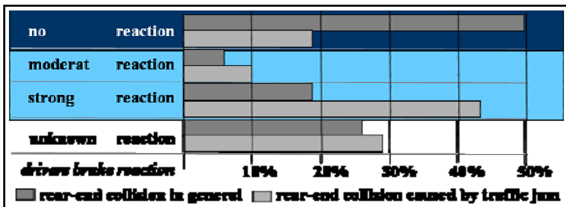

Figure 11: Driver reaction in rear-end collisions on freeways, motorways. (Basis: representative GIDAS evaluation, 12-06)

The assumptions on which the following efficiency analysis is based are very important; they are chosen to be very conservative:

DISTRONIC PLUS and BAS PLUS as well as DISTRONIC and BAS were emulated in detail as they were implemented in the cars on the road and tested virtually in assuming:

- the equipment rate of both systems is 100%,
- BAS PLUS is activated permanently,

- DISTRONIC PLUS as well as DISTRONIC is activated for 100% in extra urban driving on freeways and highways,
- Conservative assumptions with respect to the behavior of the driver during the accident:
  - Driver behavior remains unchanged,
  - A possible reaction of the driver to all kinds of collision warnings is not modeled.
  - A driver model for activating BAS is used.

With this conservatively defined scenario a lower limit for the efficiency of the combination of DISTRONIC PLUS and Break Assist PLUS in the case of rear-end collisions in Germany is gained. The results were taken from [24].

The safety potential of the interaction of DISTRONIC PLUS and BAS PLUS becomes especially evident extra urban on highways and freeways or motorways. Here the interacting system combination prevent over 37 percent of rear-end crashes in average. In another 31 percent of these collisions, the systems can help to greatly reduce accident severity. This is due to the large share of accidents in which drivers do not react. In much over 80% of these crashes were driver did not react a switched-on DISTRONIC PLUS is able to avoid the collision due to its implemented dynamic operating range. If not, the collision speed is reducing dramatically. Since the effect of an implied warning was ignored, this is all the more amazing. The importance of this is referred to the fact, that on German motorway about 57 percent of all fatalities and 62 percent of all serious injuries happened on this road category in 2006 [16].

In those accidents in which the driver brakes so far, DISTRONIC PLUS reduces energy in his car until the point in time when the driver applies the brake thus far. After this point BAS PLUS optimizes braking reaction of the driver to a target brake. This avoids many accidents or at least reduces their severity especially in the situations with traffic jam.

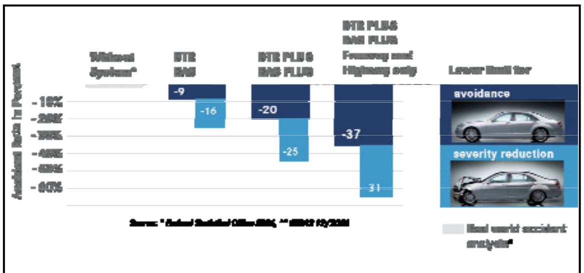

Figure 12: Effectiveness of the sytem combination DISTRONC and BAS respectively DISTRONIC PLUS and BAS PLUS in avoiding real life rear-end colisions or mitigating their severity

In the case of the interconnecting systems BAS and DISTRONIC the analysis shows that the number of rear-end crashes drops about 9 percent. A reduced severity is obtained additionally in another 16 percent.

In the case of the interconnecting systems BAS PLUS and DISTRONIC PLUS the share of avoided rear-end collisions is above 20 percent. The proportion of accidents with significantly reduced severity adds to it with 25 percent. The results were illustrated in fig. 12. The results show that DISTRONIC PLUS and Brake Assist PLUS complement one another in a perfect way, provided that DISTRONIC PLUS is switched on.

SIMPLIFIED ANALYSIS OF THE INFLUENCE OF THE DRIVER – INITIATING AND PREPONING THE BRAKE REACTION

The following assumptions about the driver were made in the previous efficiency analysis:

- Driver behavior remains unchanged.
- A possible reaction of the driver on all kinds of collision warnings is not modeled.

What's that suppose to mean against the background of efficiency? A warning can effect 2 basic reactions:

(1) If the driver does not react in the original accident without a warning, it is to be assumed that he would do so – with a certain probability.

(2) If the driver reacts in the original accident, two different cases had to distinguish:

(a) The reaction was before he could be aware of the warning, then it is to be assumed that the warning would have had no influence on the point in time of his reaction.

(b) The reaction was after the warning, and then it is to be assumed that the warning would have had influence on the point in time of his reaction. With a certain probability the collision warning will lead to a Preponing of the reaction – close(r) to the warning. In none of these cases the (observed) reaction point in time would have been regarded stable or preponed by the warning.

So the assumptions made are very conservative, but the consideration of a driver reaction on the warning would (only) improve but in no case impair the efficiencies.

Figure 13 shows simplified the efficiency resulting from a preponing of brake reaction in time for all drivers who already showed a break reaction in the reconstructed accidents taken from GIDAS. An average preponing period of 0.2 sec to 0.3 sec. for the brake reaction initialized by a warning seems to be

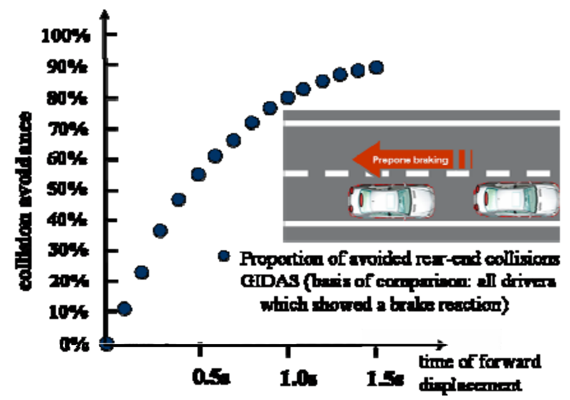

Figure 13: Prepone the driver's brake reaction in time - parameter study showing proportion of avoided rear-end crashes (Basis: Subset of those accidents in which driver actually braks)

realistic. Such a preponing would reduce the probability of a collision by 20-30 percent in the case of rear-end collisions. From a technical point of view Brake Assist is a situational adaptive boost initiated by the driver. This boost is able to decrease the build-up time of the break pressure to its maximum by 200 – 250 milliseconds. The difference to the observed 8 percent is what could be reached by intelligent triggering.
Adaptive Brake is the name of the Mercedes hydraulic braking system that is electronically controlled. It allows priming of the braking system. If the driver's foot removes rapid from the accelerator pedal as in an emergency situation the braking system is able to increase the pressure in the brake lines and therefore

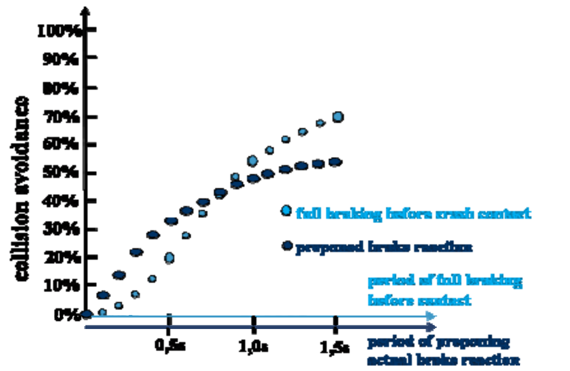

Figure 14: Parameterstudy preponing the driver's brake reaction in time versus triggering a full braking a certain period befor an unavoidable crash (keepin a fixed proportion reaction/no reaction)

brings the brake linings into light contact with the brake discs. This saves time for building up the brake pressure in the range from 20 to 100 milliseconds. Its effect could be estimated from fig. 13. Adaptive Brake is part of the standard equipment of the W221.
Beside preponing the brake reaction the idea of performing a full braking before an unavoidable crash

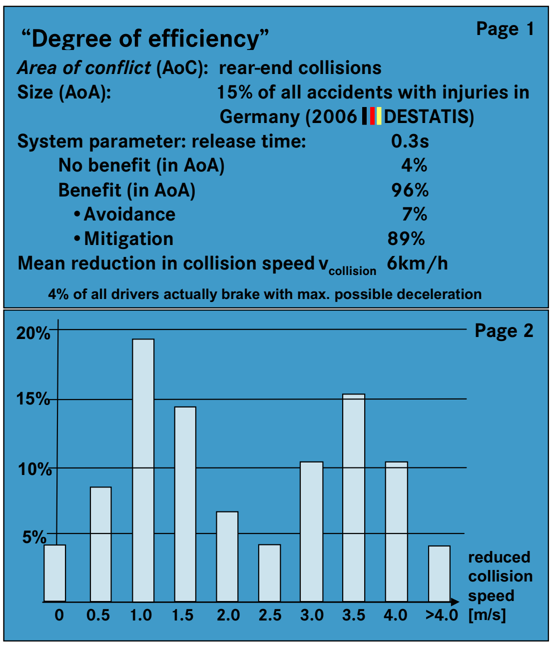

Figure 15: Parameterstudy efficiency of a pre-crash braking

is oblivious. The efficiency of both is given in figure 14. Here the proportion of brake and no brake reaction of the approaching driver is hold constant to the ratio that is contained in the GIADAS data. Fixing the parameter of the time the full braking is triggered before an inevitable crash we can determine the mean reduction of collision speed of the car colliding with the vehicle in front as well as its distribution (fig 15). The effect of an electronic crumble zone becomes apparent. 25 percent of all rear-ender profit on that.

PROVED EFFICIENY OF THE DISTRONIC PLUS SYSTEM PACKAGE - BASED ON DATAMINING OF SPARE- PARTS LOGISTICS

In this section we will present the results of the evaluation measuring the real-life safety efficiency of the so-called DISTRONIC PLUS assistance package, a special equipment option for the S-Class model W221. The assisting system DISTRONIC PLUS could only be ordered in form of this package. The DISTRONIC PLUS package as analyzed later on consists of:

- DISTRONIC PLUS
- Brake Assist PLUS (BAS standard equipment)
- PRE-SAFE® Brake (stage 1)

as well as

- Park Assist with Park Guidance

PRE-SAFE® Brake (stage 1) is an extension of Brake Assist PLUS that triggers an automatic partial braking and decelerates the vehicle at a rate up to 4m/s² if the driver has not respond to the warnings of Brake Assist PLUS resulting from an impending rear-end collision. In addition to the visual and acoustic warnings of Brake Assist PLUS its triggered partial braking provides the driver with a clear signal for acting. If the driver applies the brakes immediately, the maximum braking force is available thanks to Brake Assist PLUS. Depending on the driving situation the accident can be avoided at the last minute. If the accident is unavoidable, the PRE-SAFE® Brake reduces the severity of the impact and in turn, the risk of injury to the vehicle occupants. The strategy based on the interconnecting with Brake Assist PLUS and its warning is highlighted in fig. 16.

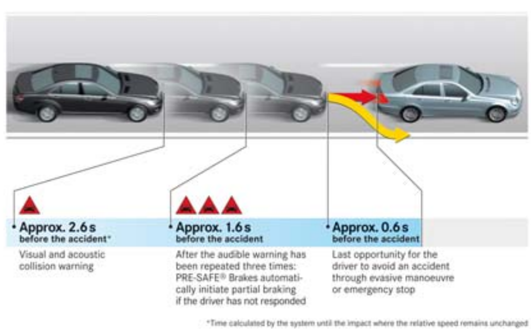

Figure 16: PRE-SAFE® Brake stage 1

DISTRONIC PLUS and its extended functionalities base on the enhanced technology of Adaptive Brake which is the name for hydraulic braking system that is electronically controlled and hence allowing advanced (comfort and) safety subfunctionallities like: brake drying and priming. Adaptive Brake is standard equipment in the W221.

This evaluation is based on the data of the spare parts for the S-Class model W221 delivered to all workshops or body shops in Germany in the period from launching the W221 model until the 31.10.2008. In this period about 40.000 cars were sold and registered in Germany. About 40 percent were equipped with the DISTRONIC PLUS package. The other 60 percent were equipped with parking assistance. The data base contains orders of nearly 2700 front and 3500 rear bumper.

The basic idea (fig. 17) is to follow the flow of the impact energy on its wave of destruction through the crash structure elements in the front respectively rear-end.

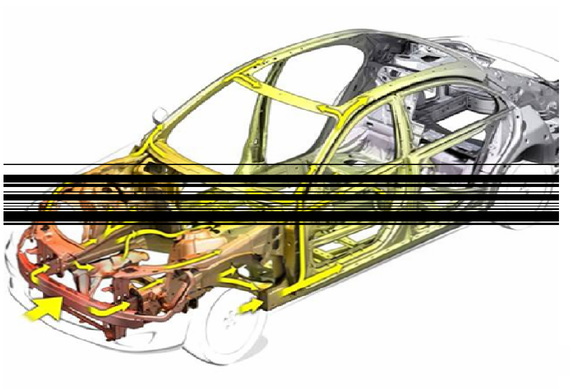

Figure 17: Direction and flow of impact energy through the front-end crash structurs

The body of a Mercedes-Benz passenger car provides impact protection in three stages. These stages are triggered progressively in the severity of the impact.

- At an impact speed up to approximately 4 km/h the plastic bumpers and their associated foam plastic components absorb the impact energy and then resume their original shape.
- In an impact up to 15 km/h, the energy is absorbed by the front cross member and the crash boxes in the front end module. Thus the structural members situated further aft (longitudinal members for example) are protected.
- At speed exceeding 15km/h, sturdy front end side members also share in the task of absorbing impact energy. The forces are transmitted in four directions: firstly along the cross members in the front end module, secondly along the longitudinal members behind the crash boxes; thirdly along the upper side members above the wheel arches and fourthly transferring via the front wheel into the side structures.

This crashworthiness is equal for front and rear crash structures. Therefore a first approximation of the collision speed as an indicator for the severity of the impact could be deduced by the passed threshold of these characteristic trigger points for plastic bumper, cross member, crash box and structural members behind the crash box. It is illustrated by figure 18. The collision speed helps to relate the order to a damage caused (probably) by a parking or a frontal accident.

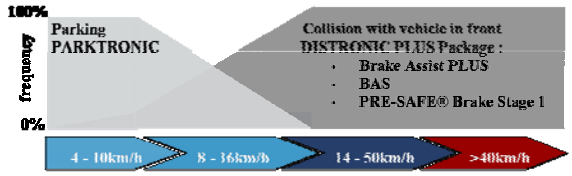

Figure 18: Different velocity ranges due to parking and front-end damages.

Coming back to the evaluation of the data, the first task is to identify those orders that belong to a repair that was caused by a frontal (or rear) crash. Simplified the task is to identify closed chains like:

- plastic bumper
- plastic bumper and cross member
- plastic bumper and cross member and side member
- and so on.

The second task is to match the chains to the ordered extras “DISTRONIC PLUS package”, “Park Assist”, “no extra”. A more principle task is to differentiate ordering resulting in repairs and in no-repairs (tuning reconstructions for example).

The results gained for the front-end side were contained in figure 19. The figures demonstrate that the rate of repairs for those cars which were equipped with the DISTRONIC PLUS package was reduced for all three ranges of energy equivalent collision speeds. The rate of repairs containing a front-end bumper were reduced by 5 percent, a front-end bumper in combination with a cross member dropped by 15 percent and repairs involving front-end bumper, cross and longitudinal member dropped by 25 percent.

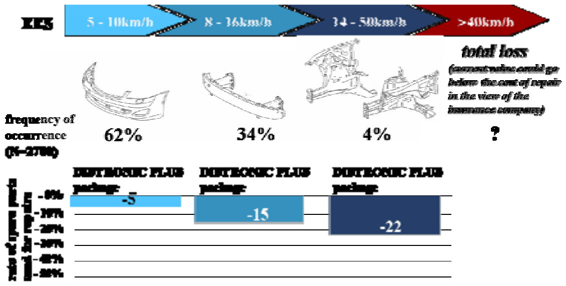

Figure 19: Reduction of front-end spare parts used for repairs due to the equipment with the DISTRONIC PLUS package in model W221 in Germany from lunch to 10-2008

The basis of this analysis is spare-parts used for repairs. In doing so, the damage of the front and rear of a S-Class is categorized in terms of the needed parts for the repair, not in categories of the collision leading to this damage. Below, we try to reduce this limitation by using representative accident data gained by analyzing GIDAS. Starting points for doing so, are the ranges of energy equivalent speeds (EES) corresponding to impacts that damage these spare-parts. The first step is to estimate the amount of total losses. This number could not obtained by a spare-part analysis; there is no repair of such cars. The collisions that correlate to such high energy impacts are generally accidents with injured persons. Especially a limit for an energy equivalent speed for a total loss is hard to determine. (Keep in mind that the impact energy is only one factor, a more determinant one is the age of the vehicle and its current value.) Figure 20 demonstrates the cumulative frequency of frontal damages of passenger cars in terms of their EES values (energy equivalent speeds). Following up collisions of one passenger car were considered by summing up energies. Fig. 20 shows that the damages corresponding to the EES range from 15 km/h to 45 km/h are 12 times higher than those corresponding to EES values greater than 45km/h. By this, a lower limit for total losses not contained in the data is 10% percent of the amount of the EES range from 15 to 45 km/h. Beyond that, figure 20 gives estimation for the proportion of the number of frontal collision with injuries and their severity corresponding to the defined and considered ranges for EES.

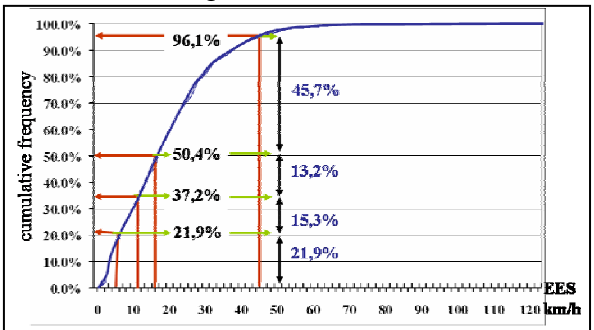

Figure 20: Cumulatative frequency of representative frontal demages described in terms of EES (energy equivalent speed). Databasis: passenger car with deamged hood, involved in a frontal collision with injured persons (GIDAS 12-2006; n=9520/6008)

The next task is to assign the observed efficiency of the DISTRONIC PLUS package in avoiding repairs to that kind of accident were it results from. We have to bear in mind that an avoided repair in one of the EES ranges does not mean that the corresponding collision is avoided. In general the damage is mitigated respectively shifted in another EES range. The radar sensors can detect only vehicles that were moving ahead in the same direction, waiting or starting. When manoeuvring or parking vehicles satisfy the above limitations, they might be detected as well. So we have to identify the fraction of rear-end collisions for each EES interval. The result is contained in figure 21.

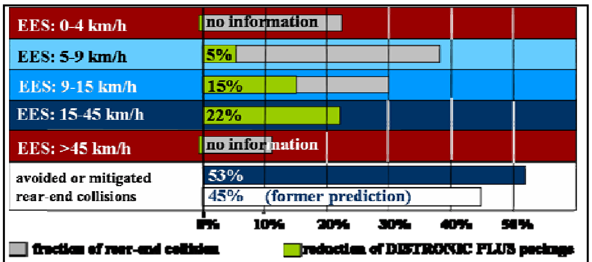

Figure 21: Fraction of rear-end collisions with injuries and front damages in different EES intervals (GIDAS evaluation, 12-06) and avoided repairs for cars equiped with DISTRONIC PLUS package.

The efficiency of avoiding or mitigating rear-end collision results from the reduced spare-parts in proportion of rear-end collisions summed up over all intervals. By doing so, we get an efficiency of the DISTRONIC PLUS package in avoiding 52 percent of all rear-end collisions with injuries. The efficiency that we obtained by this method is close to the efficiency of 45 percent we obtained by an alternative method presented in a former section for a sub package without PRE-SAFE® Brake stage 1. A most gratifying development is that the DISTRONIC PLUS package especially avoids accidents in the ranges of high EES values were the probability of an serious injury is substantial or, if that is not possible, reduces the dynamics of the vehicle to such an extent that the secondary safety measures are able to act best possible.

Now we will discus the results gained for the rear-end side. The figures for the reduction of spare-parts needed for repairs in the former discussed intervals for EES are contained in figure 22. The figures demonstrate that the rate of repairs for those cars which were equipped with the DISTRONIC PLUS package is reduced for all three ranges of damages. The rate of repairs containing a rear-end bumper is reduced by 3 percent, the need for a rear-end bumper in combination with a cross member dropped by 9 percent and repairs involving rear-end bumper, cross

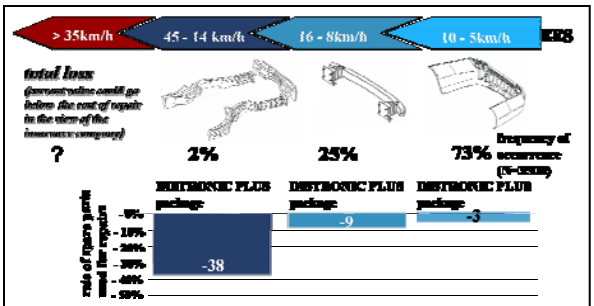

Figure 22: Reduction of rear-end spare parts used for repairs due to the equipment with the DISTRONIC PLUS package in model W221 in Germany from lunch to 10-2008

and longitudinal member dropped by 38 percent.

Again we analyzed GIDAS data to generate the cumulative frequency of rear-end damages in terms of their EES values. The graph is shown in fig. 23. For the rear-end damages we get a factor of 15 between the fraction of the EES interval from 15 km/h to 40 km/h and the range of EES values above 40km/h. By this, we can approximate the total losses not contained in the data by 10 percent of the fraction of the EES interval from 15 to 40 km/h. Again fig. 23 gives estimation for the proportion of the number of frontal collision with injuries and their severity corresponding to the defined ranges for their severity labelled by EES.

Interesting is the reduction of 38 percent thanks to the DISTRONIC PLUS package in the ordering of longitudinal members. The damage of these parts needs collision speeds above 15 km/h, which are not in the usual range of parking damages. Keeping in

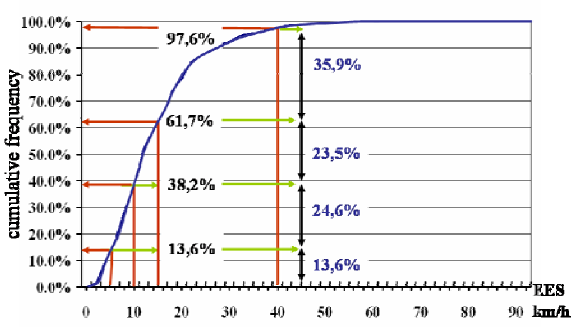

Figure 23: Cumulatative frequencies of representative rear-end demages described in terms of EES (energy equivalent speed). Databasis: passenger car with deamged rear, involved in a rear collision with injured persons (GIDAS 12-2006; n=2820/2015)

mind that both groups differ only by equipment with or without the DISTRONIC PLUS package, the reduced rate of spare parts can result only from an influence of it. Therefore a longitudinal member in the rear-end crash structure that is not broken can result only from an avoided collision with a car following behind. This proves that a system, which is originally designed to avoid or mitigate collisions with cars driving in front, can protect the driver from a crash with the succeeding car. The explanation for this phenomenon is that the components of the DISTRONIC PLUS package like collision warning, the target braking characteristic of the Brake Assist PLUS etc. are able to defang critical car following situations that might lead to a rear-end collision for the car equipped with this package as well as the car following behind. In general this will transfer a (panic) reaction that is fast-paced (late and hard reaction) to a preponed moderate one (effective by target-braking). Since the usually observable vehicle following distances require prompt and adequate reactions this damping behavior of the DISTRONIC PLUS package reduced the needed capability of the driver respectively the performance of the (closed) system driver and his vehicle. This increases the range of combination of response / reaction times and chosen intensities to avoid the collision. So, the probability that the driver behind reacts with a combination that can avoid the collision increases. Those critical situations appear especially in follow up collision situations. Fig. 24 shows that nearly each third rear-end collision is followed by another rear-end collision.

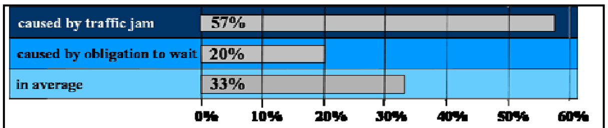

Figure 24: Amount of rear-end collisions with a following up or subsequent rear-end collision (Basis: GIDAS evaluation, 12-06)

In this case the vehicle that was the succeeding car in the first collision is now the preceding car with which a following vehicle collides. Therefore the DISTRONIC PLUS package is able to avoid or mitigate the collision with the following vehicle as well. We have to identify the fraction of rear-end collisions for each EES interval. The result is

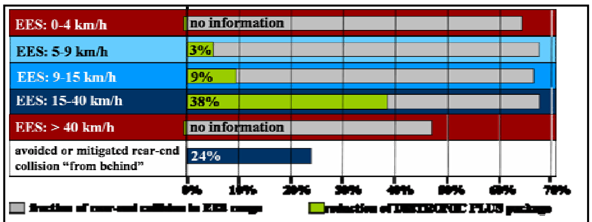

Figure 25: Fraction of rear-end collisions with injuries and rear-end damages in different EES intervals (GIDAS, 12-2006) and avoided repairs for cars equiped with DISTRONIC PLUS.

contained in figure 25. We observed a fraction of 24 percent in which rear-end collisions could be avoided or mitigated for the car in front thanks for its being equipped with the DISTRONIC PLUS package.

Reviewing the results, we can give a positive summary: the predicted efficiency in avoiding or mitigating rear-end collisions of the DISTRONIC PLUS package could be demonstrated in the event of real life accidents for a representative large-scale sample size. The proofed evidence of the DISTRONIC PLUS package in avoiding respectively mitigating rear-end collisions with the vehicle following in behind is the significant new result.

THE KEY SAFETY PROBLEM – PENETRATION OF THE MARKET

So far this paper deals with promising results:

- A normal driver is able to avoid a collision with a vehicle in front in 8 percent of all cases thanks to Brake Assist (classic).
- A normal driver is able to avoid a collision with a vehicle in front in 20 percent of all cases and to reduce the severity in an additional 25 percent thanks to DISTRONIC PLUS and BAS PLUS.
- A normal driver is able to avoid or mitigate each second collision with a vehicle in front respectively each fourth with a vehicle behind thanks to the DRISTONIC PLUS package.

The results demonstrate that an individual customer

Primary safety system	first offered S-Class	standard equipment Mercedes-Benz passenger car since	penetration in Mercedes-Benz passenger cars registered in Germany in 2007	penetration in passenger cars registered in Germany in 2007
ABS	1978	1992	96%	83%
BAS	1996	1997	75%	28%*
ESP	1994	1999	62%	43%
DISTRONIC PLUS package	2005	-	1%	-

* not comparable to BAS functionality of Mercedes-Benz in all other cars

Table 1: Market penetration of primary safety systems

can reduce considerably his risk of being involved in a rear-end collision for example by ordering a passenger car that includes this measures as standard or ordering it as an optional extra. They could be seen as milestones on the realization of an "individual" accident-free driving. In order to determine the contribution for the improvement in vehicle safety in

Germany or the EU it is important to consider the penetration rate of such a primary safety measure. Tab. 1 contains the rates for selected systems equipped in Mercedes-Benz passenger cars registered in Germany in 2008. The share of the market of Mercedes-Benz was 9.1 percent in 2008. Due to the decision of Mercedes-Benz to take ABS, BAS, ESP as standard equipment of their passenger cars in the last years, the equipment rates of theses systems in Mercedes cars is much higher than in the actual vehicle population.

Looking at the registration figures of passenger cars in Germany since 1991, it demonstrates that in nearly 7 years 50 percent of all passenger cars were renewed in average. Assuming a mandatory introduction of a safety measure, how long would it take for a penetration of the vehicle population to reach a rate of 65 percent? A general response to this question is contained in fig. 3. Keeping in mind that there will be extra time for standardization (3 years), legislation (3 years) and preparation for the OEM's (2 years) an extra of 8 years had to be added to the 9 years needed for market penetration for before a mandatory introduction.

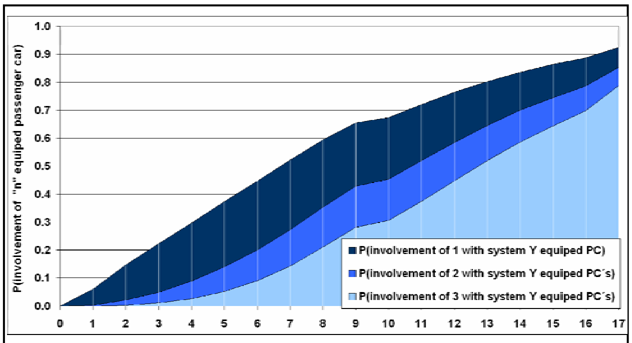

Figure 26: Probability of an involvement of n cars equiped with a system Y in an accident. – assuming a mandatory introduction of system Y in the year 0 on all new passenger cars. (Data base: registration numbers of Germany from 1991 to 2008)

CONCLUSION

The vision of *Accident-Free Driving* started as a research project in the DaimlerChrysler Research and became shortly after the vision of Mercedes-Benz. Both were rooted in the PROMETHEUS project (Program for European Traffic with Highest Efficiency and Unprecedented Safety) which was launched in 1986 by the then Daimler-Benz AG and was carried on as a cooperative venture of several European motor manufacturers, electronics producers and suppliers, universities and institutes for eight years. This cooperation resulted in numerous technologies with great benefits, which Mercedes-Benz translated into concrete technical products, among them the autonomous intelligent cruise control system DISTRONIC PLUS and the automatic PRE-SAFE® brakes – purchasable 20 years after the launch of PROMETHEUS. These and other technologies like Brake Assist and it enhancement with sensors and environment perception technologies play an important role in the vision of *Accident-Free Driving*.

In this paper we demonstrate the evidence of these systems in avoiding and mitigating the severity of longitudinal accidents in the event of real world accidents. Brake Assist, DISTRONIC PLUS and its sub functionalities collision warning, Brake Assist PLUS, PRE-SAFE® brake made a contribution to a significant reduction in the event of real life accidents.

If an accident is not avoidable these systems are interconnected so that they can made a contribution to stabilize respectively reduce the dynamics of the vehicle to such an extent that the secondary safety measures are able to act best possible. PRE-SAFE® is the interface to secondary safety measures. It is offering integrated safety by anticipating an impending accident based on data shared with primary safety measures and activating protective measures in advance [5, 29]. Networking (in the pre-crash phase) between primary and secondary safety measure with the objective of integrating the actual dynamics of vehicle and passengers into account for the behaviour of primary systems as well as preventive occupant protection and individualization of secondary measures to increase the integral protective effect [2].

Mercedes-Benz is now working on the next generations of assistance systems that will provide drivers with assistance in other types of critical situations. Expanded environmental assessment will afford new possibilities in the future for comprehensive enhancing vehicle safety. Next objectives are crossing pedestrian or vehicles, oncoming traffic and intersection assistance [3, 21]. Based on Daimler's philosophy of Real Life Safety, an over 40 years tradition in integration accident research results and in configuring systems on the basis of real life accidents, the work to realize the vision of *Accident-Free Driving* is continued in numerous research and engineering projects [22, 28].

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REFERENCES

[1] ATZ-Extra, Die neue S_Klasse von Mercedes-Benz, ATZ-Sonderheft 10/2005

[2] Baumann, K.-H., Schöneburg, R.: Fahrzeug-sicherheit in der Vorunfallphase, 24. VDI/VW-Gemeinschaftstagung Integrierte Sicherheit und Fahrerassistenzsysteme, Wolfsburg, 10.2008

[3] Baumann, K.-H., Fehring, M., Unselt, T.: Intersection accidents: an integrated safety approach, FISITA, Paper No. F2008-08-019, 2008, München
[4] Becker, H., Busch, S., Zobel, R.: Methods for the evaluation of primary safety measures by means of accident research, FISITA 2004 World Congress, F2004-V039,Barcelona, 2004
[5] Breitling, T, Schöneburg, R..: Enhancement of active and passive safety by future pre-safe systems, Paper No. 05-0080, ESV-Conference 2005, Nagoya, 2005
[6] Breuer, J., Eckstein, L., Frank, P.,Unselt, T.: Avoidance of „loss of control accidents“ through the benefit of ESP, FISITA 2004 World Congress, Barcelona
[7] Breuer, J. Eckstein, L., Unselt, T.: Fußgängerschutz durch Bremsassistenz, 1. Tagung „Aktive Sicherheit durch Fahrerassistenz“, TU München und TÜV Süd, 2004
[8] Breuer, J., Gleisner, S:, New Systems to avoid / mitigate rear-end collisions, VDI-Bericht Nr. 1960, p. 393 – 402, Düsseldorf, 2006
[9] Brühning, E.: Der Sicherheitsgewinn bisheriger Fahrerassistenzsysteme, Schriftenreihe Verkehrssicherheit, Band 13, DVR 2008
[10] Danner, M., Halm, J.: Technische Analyse von Verkehrsunfällen, Eurotax, 2nd edition, 1994.
[11] Erke, A.: Effects of electronic stability control (ESC) on accidents: A review of empirical evidence, AAP, Vol. 40, p. 167-173, 2008
[12] Fach, M., Baumann, F., Nüssle, M., u. a.: Objektive Bewertungsverfahren für radbremsenbasierte Systeme der Aktiven Sicherheit, 25. Int. μ-Symposium, p. 56-80, Darmstadt, 2005
[13] Farmer, C.: New evidence concerning fatal crashes of passenger vehicles before and after adding ABS, Acc. Ana. and Prev. 33, p361-369, 2001.
[14] Frank P, Reichelt, W.: Fahrerassistenzsysteme im Entwicklungsprozess, Ed. Timpe, p.71-78 Springer, Berlin, 2001
[15] Gail, J, Pöppel-Decker, M, Lorig, M, Eggers, A, Lerner, M, Ellmers, U,: Einfluss verbesserter Fahrzeugsicherheit bei Pkw auf die Entwicklung von Landstraßenunfällen, BAST Berichte, Reihe Fahrzeugtechnik, Band F70, 2008.
[16] German Federal Statistical Office: German Traffic Accident Statistics 2006, Fachserie 8, Reihe 7, Wiesbaden, Germany, 2007(available at www.destatis.de)
[17] www.GIDAS.org
[18] Gleissner, S., Heine, U., Hillenbrand, J.: Driver Assistance Systems for Active Safety in Mercedes-Benz Passenger Cars, FISITA-Congress 2008, F2008-08-047, 2008.
[19] Gottselig, B., Eis, V. Sferco, R.,: Entwicklung der Verkehrssicherheit - Potentialbestimmung von modernen Sicherheitssystemen, VDA-Kongress 2008, Leonberg, VDA
[20] Herrmann, R., Bakker, J.: Systematik zur Ermittlung der Wirksamkeit von Fahrzeugsicherheitsmaßnahmen auf der Grundlage von deutschen Unfalldatenbanken. Innovativer Kfz-Insassen- und Partnerschutz VDI – Gesellschaft Fahrzeug- und Verkehrstechnik, 2001.
[21] Justen, R.: New ways of safe driving, FISITA-Congress 2008, Paper No. F2008-08-056, 2008, München.
[22] Metzler, H-G,: The desperate steps towards “Intelligent Vehicles”, key note lecture IEEE IV-2008, Eindhoven, Netherlands.
[23] Page, Y., Foret-Bruno, J., Cuny, S. : Are expected and observed effectiveness of emergency brake assist in preventing road injury accidents consistent?, 19.ESV conference, Paper No.05-0268, 2005.
[24] Schittenhelm, H.: Design of effective collision mitigation systems and prediction of their statistical efficiency to avoid or mitigate real world accidents, FISITA Congress 2008, paper F2008-12-022, München, 2008
[25] Schittenhelm, H.: Predicting the efficiency of collision mitigation strategies with respect to real world accidents, 3.Tagung „Aktive Sicherheit durch Fahrerassistenz“, TÜV Süd, 2008 http://www.fahrzeugtechnikmuenchen.de/component/option,com_docman/task,cat_view/gid,37/Itemid,86/lang,de/
[26] Schittenhelm, H.: Fahrerverhalten und Fahrerreaktionen in kritischen Fahrsituationen, VDI-Tagung „Innovativer Insassen und Partnerschutz“, VDI-Berichte 1911, Berlin, 2005
[27] Schittenhelm, H., Ammon, D., Apel, A., Mitschke, M.; Driver behaviour model for longitudinal and lateral control in emergency manoeuvres, EAEC Congress 1995, Paper No. SIA9506C12, Strasburg
[28] Schöneburg, R.: Role of Technologies and Methods in Changing Unsafe Driver / Driving Behavior from an integrated Safety Approach, 20th ESV-Conference, Panel Session “Role of Technologies in Changing Unsafe Driver/Driving Behavior” Chair: Ronald Medford, NHTS Lyon, France, June 2007
[29] Schöneburg, R., Baumann, K-H., Justen, R., : PRE-SAFE – the next step in the enhancement of vehicle safety, paper 410, 18th ESV-Conference Nagoya, Japan, , 2003
[30] Seeck, A., Gail, J., Sferco, R., Otte, D., Zwipp, H., Bakker, J.: Development of the accident investigation and data handling methodology in the GIDAS project, paper 09-0282, ESV - 21. Conference, Stuttgart, 2009.