INFLUENCE OF DRIVER ASSISTANCE SYSTEMS ON REPAIR COSTS

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ABSTRACT

The growing proliferation of driver assistance systems in vehicles has made an increasingly significant contribution to the reduction in the number of fatalities and severities in traffic accidents. Driver assistance systems, such as autonomous pre-crash braking systems can reduce the impact velocity (particularly the impact energy) or can even avoid the crash completely. Thus, by reducing the impact speed in order to decrease the number of serious accidents, the subsequent repair costs of the crashed vehicle can also be lowered.

In the following article, based on a crash test (following Euro NCAP with a frontal impact) the influence of driver assistance systems on repair costs after an accident are described and discussed. Particularly, the potential of an integrated safety approach regarding repair cost reduction is described, focusing on an autonomous emergency braking system. The system of an actual BMW 5 Series model will serve as an example.

The repair costs of two vehicles crashed with and without an autonomous pre-crash braking system are compared here. The relevant test results are described and discussed, quantifying the effect of the autonomous emergency braking system on the impact speed and, consequently, on the repair cost reduction. Furthermore, an estimate of the benefit of the system in real-world crashes is given.

One major result of the test was that with an autonomous emergency braking system, an impact speed reduction of up to 40% (based on the initial speed according to the Euro NCAP test procedure) can be achieved. The benefits generated concerning the damage to a BMW 5 Series are also described.

INTRODUCTION

So far systems that help to prevent accidents (active safety) and systems to minimize the consequences of accidents (passive safety) have clearly been separate fields. The isolated treatment of those two safety pillars became difficult with more and more components merging the borders established by the definitions. The integrated safety approach was born. Sensors, finding their way into the vehicle through active systems are simultaneously used for passive safety systems.

Automatic braking and pre-crash occupant positioning are systems offered by an increasing number of automobile manufacturers in their high class vehicles. Based on the experience with other safety systems the new systems will soon find their way into all vehicle classes. The benefit potential of passive safety systems like airbags or seat belts with their surrounding components is identified in crash tests.

The benefit potential of active safety systems like ESP is analyzed in driving maneuvers. To test active and integrated safety systems in a reproducible way requires crash tests allowing a pre-crash reaction on the part of the car. So far no test standard, neither for homologation nor for consumer testing, allows a reliable statement about the effectiveness of active and integrated safety systems. Their benefit potential has not been verified yet. To define test standards for driver assistance systems with a main focus on forward-looking systems, the vFSS working group was founded in 2009.

The first results of the vFSS working group (advanced Forward-looking Safety Systems) encouraged them cause to test the effectiveness of an autonomous braking system and the influence on the occupant load outcome. Therefore, the DEKRA Crash Test Center modified its hauling system to automatically react on the braking of the test vehicle by adapting the hauling speed. KTI and DEKRA carried out the first crash test with an automatic braking car.

This paper gives an overview of the frontal impact accident scenarios and describes the crash test with automatic braking and its results relating to vehicle damage and potential benefits on repair costs.

CRASH TEST

The tested vehicle was a BMW 530d, type F10, equipped with a prototypic collision imminent braking system. The test set up followed the Euro NCAP frontal impact configuration. This is an offset crash test with 40% overlap against a deformable barrier and Hybrid III 50_{th} percentile male dummies on the driver's and passenger's seats. The collision speed is given at 64 km/h. This speed was chosen as the initial speed for the autonomous braking. For comparison, a similar car was crashed without the activation of an active safety system. The test set-up is shown in Figure 1.

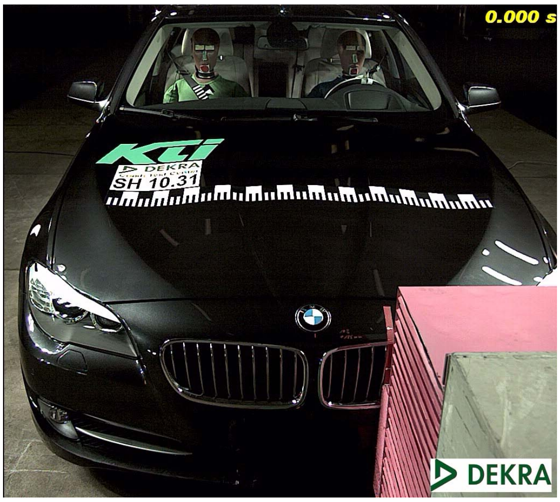

Figure 1. Impact position with 40% overlap.

Approaching the barrier the sensor detected the obstacle and the full braking power was automatically triggered 0.9 seconds before the impact. The collision speed was reduced to 40km/h. The collision energy was, thus, reduced far more than 50% from 343kJ to 133kJ. The different deformation patterns are shown in Figure 2.

Figure 2. Different deformations resulting from the 64 km/h impact (orange) and the 40 km/h impact (black).

The results showed the effectiveness of a pre-crash braking system. The vehicle damage could clearly be reduced due to the reduction of impact speed. The damages on both cars were analyzed. It turned out that the car at 64 km/h impact suffered additional damage, among other things, on the front bulkhead, A-pillar, windscreen, right side member and left front door (Figure 3).

The software "Audatex AudaPad" was used to calculate the damages on both vehicles. AudaPad is a special software used for calculating repair costs on vehicles. The comparison of these results with the ones of a similar crash test with deactivated systems and a collision speed of 64 km/h showed significant differences. The repair costs were reduced by more than 25% in the 40 km/h test.

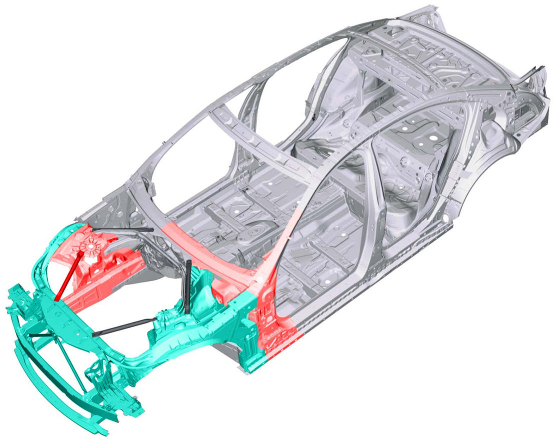

Figure 3. Comparison of damage on the body structure resulting from the 64 km/h impact (red) and the 40 km/h impact (green).

REPAIRS

Preliminary consideration

Steel-aluminium composite construction is used on the BMW 5 Series (F10), Figure 4. The BMW (F10) has a stiff passenger cell, increased use of high-strength multi-phase steel and hot-moulded ultra-high-strength steel, giving the safety passenger cell maximum stiffness on relatively low weight. The front side panels, bonnet, the doors and the front spring supports on the body of the new BMW 5 Series sedan are made of aluminium.

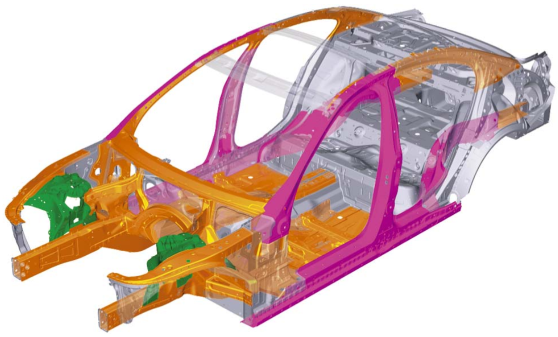

Figure 4. Aluminium (green), multi-phase steel (orange) and hot-moulded ultra-high-strength steel (pink) used for the BMW F10 body structure [Source: BMW]

The OEM’s introduction of new materials and production techniques in cars makes it increasingly important so that the repair of such vehicles is carried out with the appropriate techniques and quality [1]. Therefore, OEM information was used during the repair. The damaged car was repaired with an Inverter type welding machine with 10 kA maximum current and a variable pressure (maximum force 5 kN) to join the high-strength steel safely. Because of aluminium`s electrical flow characteristics, welding is not permitted anywhere on the front structure of the BMW F10; front end components are partially attached with rivets and a high-strength glue. Therefore, it is a requirement that appropriate technical equipment and parts are used, such as rivet insertion and extraction tool, factory-specified structural adhesive and silicon-coated rivets.

Repair after the impact at 40 km/h

Initially, for proper diagnosis an electronic measurement of the car body was carried out. After additional check with a tear test-spray-set, we found that the right aluminium front shock tower section was not damaged. After removal of exterior attachment parts (such as bumper, headlights, fender, bonnet), the car was fixed on a bench. The repair started with a raw reshaping of the car chassis on a universal straightening bench. During straightening, we measured the dimensions at reference points. The vehicle was then raised on a lift. Windscreen and dashboard were removed (access and front-seat passenger airbag had been deployed). The engine was also removed in order to properly access the damaged components. The engine and front suspension were then removed. The front end of the car was fully disassembled while mounted on the Car-O-Liner bench to ensure manufacturer`s tolerance would be met. To prepare the new parts, marked the cutting lines and then cut them at those points. We then made a rough cut of the brace (between firewall and strut tower), side member and inner fender apron near the installation area. Welded connections were open and wheel arch with engine support was removed. In order to replacement part correctly, we used alignment brackets to mount to the firewall. To preparation of new parts, were severance cut marked and cut. By repairing this vehicle on a bench, we were able to restore it to factory specifications. New components were attached with welding, adhesive and rivets. Thereby, to avoid contact corrosion, we grinded the new wheel arch part in the area of the bonding surfaces. The vehicle had to remain on the bench for 12 hours (at a temperature of 20°) after the structural adhesive was applied to allow it to set properly. The car was then taped and protected so that it could be primed. A factory-recommended seam sealer was then applied to all new joined seams and painted. Then, the engine and front suspension were installed as a single unit; all systems were installed and checked prior to painting. Finally the errors were deleted in the error memory.

Repair after the impact at 64 km/h

In comparison to the crash at 40 km/h, there was a substantial difference, with far more comprehensive deformation of the car body after the 64 km/h impact. The A-pillar was damaged, especially at the lower part at the connection with the sill and the roof side rail was deformed. Other differences were noticeable at the side member which displayed severe deformation on the front floor under reinforcement not seen in the first crash at 40 km/h. It was also noticed that the firewall was damaged in the second crash. The progress of repair was basically the same as the repair after the crash at 40 km/h. However, additionally it was necessary to repair the firewall, right front side member, right front spring supports and A-pillar. In order to do this, the interior up to the B-pillar area had to be removed. It was, different from the repair on the car at 40 km/h impact, carried out a roughly cut the side member and front shock tower near the installation area also on the right-hand side. In order to replace the A-pillar, the spot-welded adhesive joints were open and the side frame connection cut, Figure 5. At the A-pillar was the bonded connection with MAG weld seam was replaced and sealant was applied to the cavity sealing.

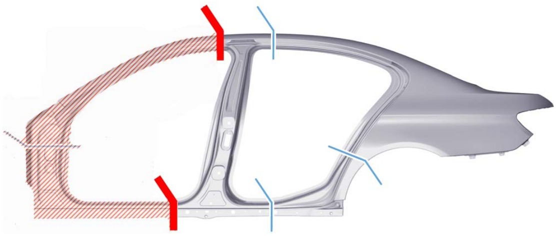

Figure 5. Red marked severance cuts at the side frame (blue marked: further preferred cuts) [2].

The new parts were in accordance with marked severance cuts and cut and adjusted with alignment brackets. Fundamentally, the complete front including some parts of the firewall were removed. The assembly was carried out again, similarly to the other BMW, which crashed at 40 km/h.

ACCIDENT OCCURRENCE

In the year 2009, 41 million cars were registered in Germany (79% of all motorized vehicles). In the same year the German police registered 2.3 million accidents. 73% of all accidents, occurred in urban areas, followed by 20% in rural areas (not on motorways) and 7% in motorways [3].

Furthermore, several of the accidents reported to insurance companies were not recorded by the police. On the other hand, certain cases were recorded by the police but not reported to insurance companies if no claim for compensation was expected [4]. In Germany for example, the number of accidents reported by insurers was about 3.371 million (of motor car liability insurance case, 2.656

million of them passenger cars) in 2009 [5]. The average loss per car accident in motor liability insurance amounted to 3,520 €.

The right parameter to estimate the benefit potential of active safety systems is the kind of accident. In the official statistics of road traffic accidents in Germany, 10 kinds of accidents can be distinguished. The distribution of the individual accidents (with severely injured people and severe accidents involving material damage) is shown in Figure 6.

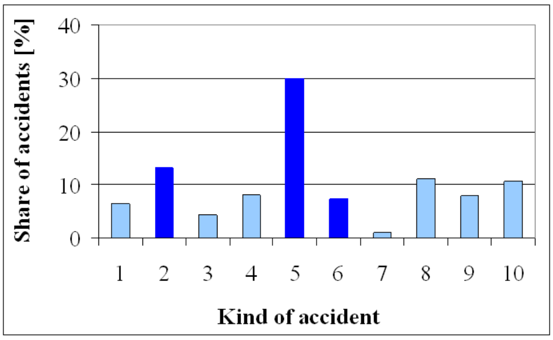

Figure 6. The share of accidents with severely injured persons and severe accidents involving material damage (n=310,810).

Three kinds of accidents were identified, which could potentially have been influenced by Collision Imminent Braking Systems (Type 2, 5 and 6). They are highlighted in dark blue in Figure 6. According to the German Federal Statistical Office, Type No. 2 "Collision with another vehicle moving ahead or waiting" describes accidents caused by a rear-end collision with a vehicle, which was either still moving or stopping due to the traffic situation. The kind of accident No. 5 includes collisions with crossing vehicles and with vehicles which are about to enter or leave from/to other roads, paths or premises. Collisions between vehicle and pedestrian belong to the No. 6 kind of accidents. More than half of all accidents belong to this three kinds of accidents (50.5%). For these crash types the automatic emergency braking systems can reduce the collision speed and can prevent the accidents or mitigate its effects.

Another important factor is the vehicle's braking before the impact. In most cases the vehicles are decelerated before the impact. Within the vFSS working package accident analysis was evaluated the GIDAS (German in depth Accident Study) data in regard to the pre-crash braking behavior in selected kinds of accidents (including the car-against-pedestrian accident). This current study is based on a total of 1,492 car accidents with frontal car impacts (single front or first impact of multiple collisions) against rear of 2-track-vehicles (a total of 13,433 of reconstructed accidents, years 2000 - 2007). In about 25% of the 1,492 cases the bullet vehicle was not decelerated before the impact. In another 23% of the cases the data did not contain information about the pre-crash braking behavior. In all other cases the cars were decelerated before the impact. About 30% of the cars braked with an average acceleration of less than 4m/s^2. This is only half of the possible braking acceleration under good conditions. In nearly 28% of the cases, the deceleration was greater than 6m/s², Figure 7. Further analysis of accident databases corroborated these results [DEKRA, GDV, AZT]. These results will help to estimate the real world effectiveness of automatic emergency braking systems.

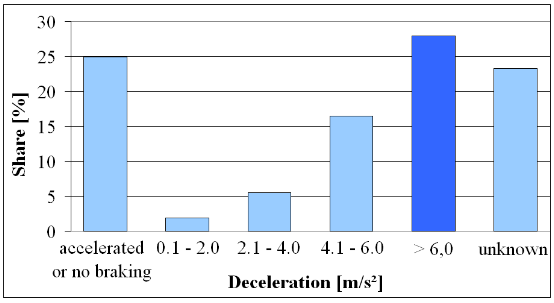

Figure 7. Deceleration of the bullet vehicle (n=1,492) [Source: vFSS].

POTENTIAL BENEFIT OF AUTOMATIC EMERGENCY BRAKING SYSTEMS

About 50% of all drivers braked with an average acceleration of less than 6m/s^2 [Source: vFSS]. In order to help drivers during braking maneuvers, cars can be fitted with a collision imminent braking system. In this respect, more than 50% of the accidents can be immediately addressed. We did not check the conditions on the spot. However, it is advisable to consider the road surface conditions in future analyses.

Certainly, there is less damage on the car with reduced collision speed. Figure 8 shows the known correspondence between the impact speed and the repair costs. The vehicles were crashed at 10 to 22.5 km/h over the front surfaces [6, 7, 8]. The RCAR speed test was used as this basis for these tests. The test conditions are shown in table 1.

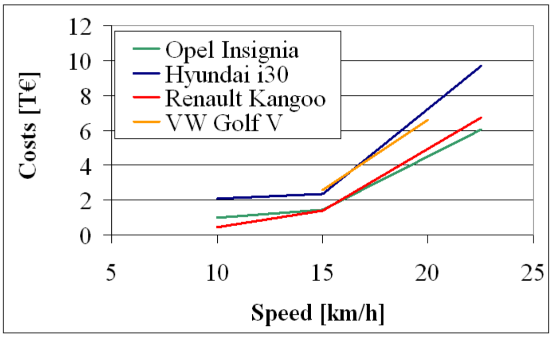

Figure 8. Correspondence between the impact speed and the repair costs [6, 7, 8].

Table 1.
Test conditions

Collision speed	slope	overlap
10 km/h	0°	100%
15 km/h	10°	40% left side
20 km/h	10°	40% left side
22.5 km/h	10°	40% right side

In the frontal impacts, there is a direct relationship between the impact speed and the repair costs. Moreover, the evolution in costs for frontal impacts is very similar in the vehicles. The crash management modern cars are the reason for this performance. New vehicle bumpers are designed to withstand minor impact without significant damage (except scratches, notches and the like). Energy-absorbing bumpers in some form, are capable of absorbing impact of up to 5 km/h. Then, is there very little difference in the vehicles between the impacts at 10 and 15 km/h. At this speed range most of the parts that were damaged were easy to replace. The repair costs increased with increasing collision speed, since the side beam was damaged, and the mechanical units had to be replaced. With regard to the restraint systems, the driver's airbag, the front passenger airbag, and the safety belt pretensioners were activated.

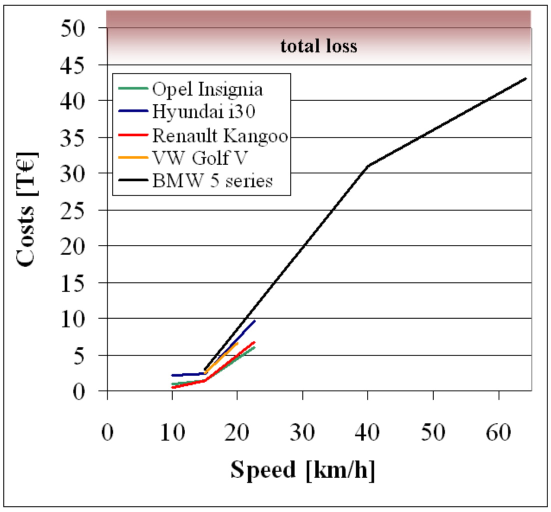

Figure 9. Correspondence between the impact speed and the costs for a speed range of 10 km/h to 64 km/h.

The repair costs as a result of the crash tests at 40 km/h and 64 km/h are also shown in figure 9, which shows an S-shaped (run of the) curve. This is largely due because the outer parts of the car (so called "crumple zones") controlled the weakening of this area, while strengthening and increasing the rigidity of the inner part of the body of the car. This turns the passenger cabin into a "safety cell", by using more reinforced beams and higher-strength steels to improve the resistance of the occupant compartment against mechanical loads in the event of a crash and which leads to less deformation.

In addition, it needs to be considered that repair costs not only occur on the bullet cars, but also on the target vehicles. The repair costs are limited by total loss. Nevertheless it is possible that the repair costs are lower, if according to the insurance company the current value of the vehicle goes below the repair costs (total loss).

The distribution of the driving speed of the car is of great interest. Figure 10 shows the distribution of the driving speed of the bullet vehicle. It is obvious that 40% of the cars have collision speeds of 40 km/h or below and the majority of impacts happen at initial speeds below 50 km/h.

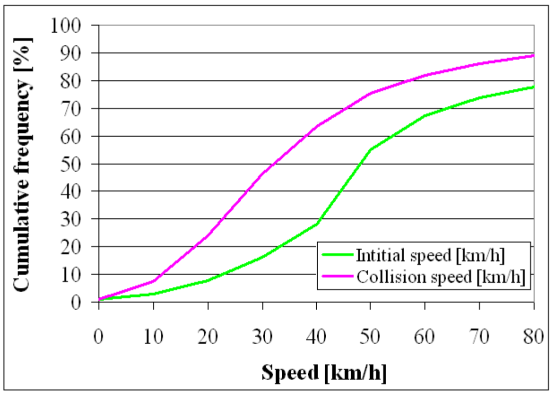

Figure 10. Initial speed and collision speed of the bullet car (unknown excluded, n ≈ 1,000) [Source: vFSS]

Assuming that all target vehicles were standing at the impact, the deceleration and resulting probable collision speed can be calculated when using an autonomous pre-crash braking system (in reality nearly 65% of the rear impacted vehicles were stationary at the impact). The speed reduction can easily be calculated as shown below:

$$v_c = \sqrt{v_i^2 - 2 \cdot a \cdot s} \quad (1)$$

Where:

$$s = v_c \cdot t \quad (2)$$

v_c = collision speed
v_i = initial speed
a = deceleration
t = time to collision

The reduction of speed is shown in Figure 11 for a braking deceleration of 3, 6 and 10m/s². 3 m/s² is a typical deceleration for an autonomous cruise control system and 10 m/s² are achievable under best conditions (dry road surface). The speed reduction in the test with autonomous braking of the BMW is highlighted in pink (6 m/s²). This deceleration can be achieved even on a wet road surface.

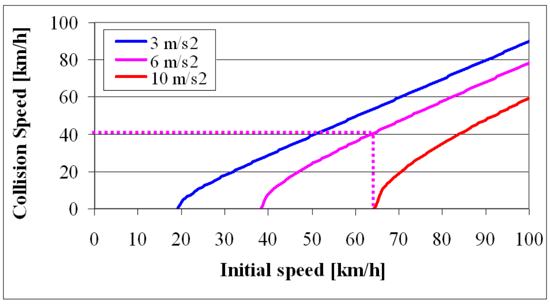

Figure 11. Speed reduction for a braking deceleration of 3, 6 and 10m/s² (rounded) and time to collision t = 0,9 s.

Figure 10 shows the distribution of collision speed and initial speed of the bullet car. The possible collision speed, under best conditions, is additionally shown in figure 12 provided that at all events the car decelerates by using an autonomous pre-crash braking system (for car accidents in the used database). Note: about half of all accidents are kinds of accidents with severely injured people and severe accidents involving material damage could potentially have been influenced by Collision Imminent Braking Systems (Figure 6). In reality, the benefit is dependent on a variety of parameters (such as road surface conditions, point of time when the system reacts and the intensity of reaction).

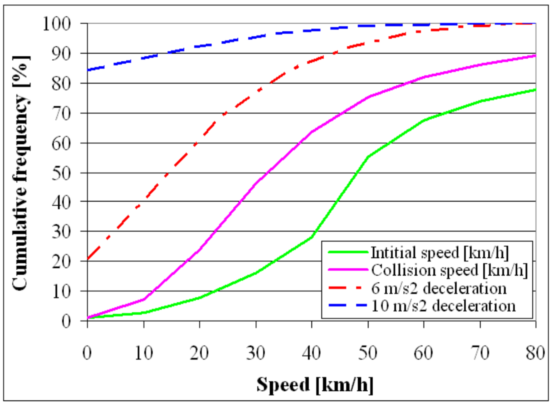

Figure 12. Possible collision speed deceleration at usage an autonomous pre-crash braking system (deceleration of 6 and 10m/s², time to collision t = 0,9 s, unknown excluded).

The curve moves toward lower collision speed, by means of better utilization of the road friction coefficient. The number of cars that come to a standstill before the impact is noticeable (v_c = 0 km/h). This is the share of accidents, where a collision could completely be avoided using an autonomous braking system at a low speed (in this example with the BMW at nearly 38 km/h initial speed, see Figure 11).

Figure 12 shows that nearly 40% from all accident cars (in this example cars they have initial speeds 44 km/h or below) the collision can speed reduced below 15 km/h as critical speed in respect of repair costs. In real accidents occurrence these succeeds only approximately 15% of all drivers. Thereby, the automatic full emergency braking system can speed reduced below 15 km/h (as critical speed) of up to additionally 35% of in this study investigated accidents is possible (nearly 15 to 20% of all accidents involving cars with severely injured people and severe accidents involving material damage). In this speed area where often only parts damaged, which are easy to replace and very rarely structure parts. Furthermore, an autonomous emergency braking system (with a deceleration no more than 6 m/s^2 and time to collision 0,9 s), could completely avoiding approximately 20% of accidents in this study (approximately 10% of all accidents involving cars with severely injured people and severe accidents involving material damage). If all cars were fitted with Collision Imminent Braking Systems, up to 80% (40% of all accidents involving cars with severely injured people and severe accidents involving material damage) of all car accidents in the current database could have been avoided under best conditions (dry road surface, deceleration 10 m/s^2, time to collision t = 0,9 s, optimal system reaction).

CONCLUSIONS

Apart from ESP systems, emergency braking systems and collision warning systems are those with the greatest safety potential in the field of active safety in cars.

In a recent study conducted by KTI, it was found that with the help of the Collision Imminent Braking Systems, ten to forty percent of car accidents could have been prevented in Germany alone. The benefit is established a variety of parameters such as road surface conditions and system reaction.

The findings were based on a crash test of a BMW 5 Series equipped with a prototypic pre-crash system and automatic full emergency braking.

Subsequent it was performed a predictive calculation of the usefulness of automatic full emergency braking system regarding repair cost reduction. Factors taken into account during the research included both official statistics and the analysis of the traffic accidents which have so far been studied within the framework GIDAS (German In-Depth Accident Study).

The automatic full emergency braking system is capable of braking the vehicle to a complete standstill. In the event the traffic following slows too rapidly, the system provides a warning and calculates the required brake pressure required to safely stop the vehicle which is then provided instantaneously by the emergency braking system system as soon as the brake pedal is depressed.

Approaching the obstacle the sensor detected the obstacle and the system warn the driver by illuminating a red light in the instrument panel and the Head-Up Display 2.1 seconds prior to the impact. 1.7 seconds before impact the system give an alarm by adding a warning signal. The full braking power to be automatically triggered 0.9 seconds before the impact. Should the driver disregard the warning, the emergency braking system performs an emergency partial braking maneuver, significantly reducing the severity of the impact. The systems reaction but varies from manufacturer to manufacturer.

The analysis of the real life accident occurrence potentially show the influenced of automatic full emergency braking systems: More than half of all accidents are kinds of accidents (50.5%, note: accidents with severely injured people and severe accidents involving material damage) which could potentially have been influenced by Collision Imminent Braking Systems. Furthermore, in the analysed accident data, a braking with an average acceleration of more than 6m/s^2 before the impact could be observed in only nearly 27%. These accidents immediately can be addressed with a Collision Imminent Braking System.

Assuming that all cars (100%) are equipped with an autonomous emergency braking system, speed could be reduced below 15 km/h as critical speed, in nearly 25 to 45% of all car accidents involving severely injured people and severe accidents involving material damage. If all cars were fitted with Collision Imminent Braking Systems, dependent on conditions, 10 to 40% of all car accidents in Germany could be avoided.

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