

Method to estimate the field effectiveness of an automatic braking system in combination with an adaptive restraint system in frontal crashes

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ABSTRACT

Current passive safety standards have already achieved a very high level of occupant protection. This is confirmed year by year through declining numbers of traffic related fatalities. This trend is assumed to continue because more and more vehicles on the road are designed to fulfill strong safety requirements especially in high speed crashes.

In order to further improve frontal crash protection active safety systems like automatic braking systems are introduced to the market. These systems are designed to mitigate the crash severity and they are expected to have a great impact in further reducing the number of injured persons in traffic accidents.

This paper will discuss a method to estimate field effectiveness of an automatic braking system in combination with an adaptive restraint system in frontal crashes.

The method is based on the German In-Depth Accident Study GIDAS. Accidents are clustered in relevant car-to-car scenarios. In each scenario the effect of an automatic braking system and of an adaptive restraint system on the injury outcome is analyzed. The sum of all the injury risks is weighted with the relevance of each scenario and the expected value of MAIS3+ injured persons is calculated with and without the integrated safety system.

INTRODUCTION

In the year 2009 more than 35.000 fatalities occurred in the EU in traffic accidents and more than 1.5 million persons were injured. The cost for society of these accidents including physical and psychological damage to the victims and their families represent approximately 130 billion € in 2009. Based on that societal burden the European

commission proposes to continue with the target of reducing the overall number of road deaths by half in the European Union by 2020 starting from 2010. In order to achieve this strategic goal the European commission has identified seven objectives for the next decade. Two of these objectives are safer vehicles and promoting the use of modern technology such as advanced driver assistance systems [1].

During the last decades also in the U.S. a great success in increasing road safety was achieved as Figure 1 shows.

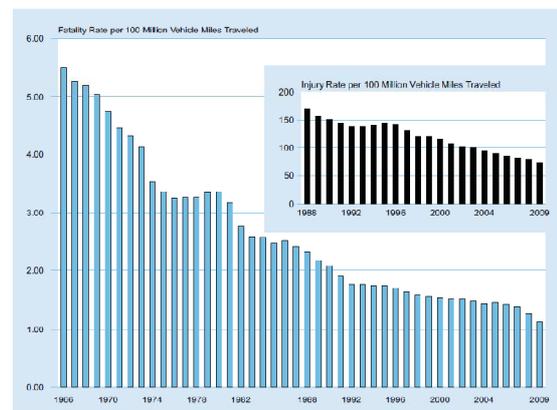


Figure 1. Motor Vehicle Fatality and Injury Rates per 100 Million Vehicle Miles Traveled, 1966-2009 in the US [2]

From 2008 to 2009 fatal crashes decreased by 9.9 percent, and the fatality rate reduced in 2009 to 1.13 fatalities per 100 million vehicle miles of travel. Furthermore, the injury rate per 100 million vehicle miles traveled decreased by 6.3 percent from 2008 to 2009. The decreased numbers of fatalities certainly are a result of common efforts in the fields of regulatory and traffic laws, enforcement, infrastructure, traffic education, post accident care and vehicle technology. Regarding vehicle technology a lot of new safety technologies within the last 50 years have contributed to this positive trend. Although passive safety systems are

nowadays well-engineered there is still room for improvements. Moreover, the trend in car safety is towards integrated and adaptive safety systems.

Active safety systems like automatic braking systems are designed to mitigate crash severity. These systems have already been introduced to the market, because they are expected to be very effective in reducing the injury outcome of traffic accidents. The most current efforts in development of restraint systems tend towards adapting the restraint performance to different crash parameters. In order to realize such an adaptive restraint performance new components like adaptive airbags and adaptive load limiters have been developed and already found their way to the market.

Therefore, the largest benefit for reducing the injury outcome in traffic accidents is expected by combining active and passive safety systems to an integrated system. Such an integrated safety system is not only effective during the accident. In general it assists the driver in the complete accident causation process (see Figure 2).

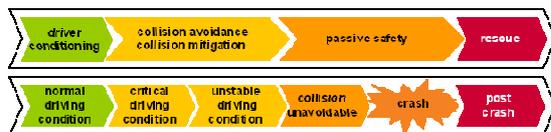


Figure 2. Process of accident causation and operating scheme of integrated safety systems [3]

In regular driving situations, condition safety of the driver should be assisted. That means that a good physical and psychological condition of the driver has to be assured. To this category belong all activities and systems supporting the reduction of the driver's workload and thus hold the probability for errors as low as possible. An example of such a system is driving comfort, air conditioning or seat design. In critical and instable driving situations, an integrated safety system helps to avoid an accident or to mitigate the accident severity via adequate countermeasures of the driver or an automatic system like an emergency braking system. If the collision cannot be avoided, passive safety measures will mitigate the accident outcome. The main issue is the evaluation of the efficiency of such an integrated safety system.

Benefits of passive safety systems can be evaluated by means of crash tests. These crash tests are

crucial and an indisputable method to develop cars which provide maximum protection for vehicle occupants as well as pedestrians and other road users. Repeatability is an important requirement in crash tests which can be achieved by standardized test configurations, the test itself and the instrumentation. Crash tests enable a view into higher accident severities compared to real world accident databases.

Active safety systems intervene before the collision and therefore modify the entire accident sequence.

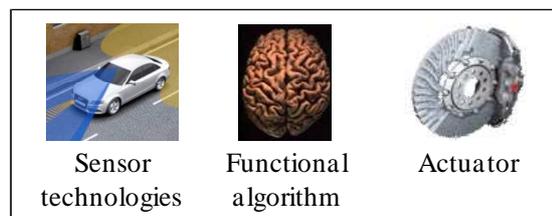


Figure 3. Components of an active safety system [4]

Figure 3 shows the components of an active safety system. An example of such a system is a crash imminent braking system. A sensor monitors the environment in front of a vehicle. If a critical situation occurs an algorithm determines whether a driver has already applied full braking power or not. If he has not and the collision is unavoidable, a braking actuator is activated and mitigates the accident severity. But how efficient is such an active safety system? Nowadays there are only a few methods available for evaluating the efficiency of an active safety system.



Figure 4. Estimated benefit of integrated safety systems [3]

Figure 4 shows the expected benefits of active and passive safety measurements. Passive measurements have already reached a very high level and a good market penetration. For the future active safety systems are expected to have a large

potential for improving safety system benefits, but their market penetration is still poor. So the maximum efficiency is expected through combining active and passive measurements in an integrated safety system.

Therefore, the objective of this paper is the presentation of a method enabling the computation of the efficiency of such an integrated safety system based on real accident data.

STATE-OF-THE-ART

Busch [5] developed an assessment methodology for the prediction of safety benefits of a driver assistance system such as brake assist or an emergency braking system. Figure 5 shows the schematic process of the automated individual case analysis.

The required data is taken from GIDAS (German In-Depth Accident Study) [6]. At first the real accident scenario sequence from GIDAS is simulated without any active safety systems. Second, a kind of virtual prototype is generated, i.e. accident scenarios are simulated with an active safety system. The simulation requires the change of each single scenario when an active system like an emergency brake is available. At first a safety benefit is calculated based on changes of physical measurements, e. g. reduced collision speed.

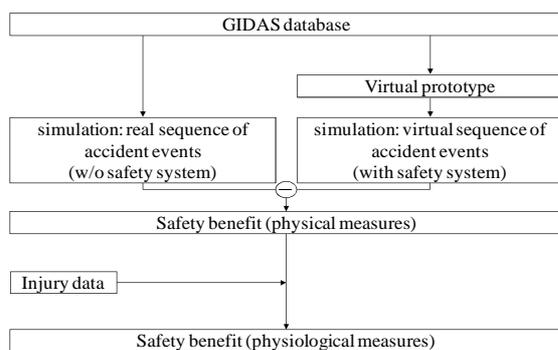


Figure 5: Schematic process of the automated individual case analysis [5]

Besides the information on accident circumstances, GIDAS also includes information on injuries of persons involved in the accident. These injury data are used to establish the so called injury-risk-functions. These functions describe the relationship of physical measurements such as collision speed and the injury risk. By using this relationship the

calculation of a safety benefit of an active system in terms of injury reduction is possible.

For the first time, this method provided an assessment of active safety systems based on real world accident data for all kinds of road traffic participants such as car occupants, vulnerable road users etc. This method is useful if the effects of an active safety system on the changes of a crash scenario outcome are easy to model. But if the complexity of an integrated safety system grows a new procedure to evaluate the effects has to be developed. That means that in each discrete time step the changes in the environment and in the decision making module of the active safety system is necessary to be analyzed. Therefore, the methodology from [5] had been revised and enlarged in [7].

The assessment method, PreEffect-iFGS, presents a procedure to assess the real-world safety benefit of integrated pedestrian protection safety systems (IPPSS). The schematic procedure is depicted in Figure 6. Initially, the real-world accident data from GIDAS are imported in a system simulation tool for reconstructing the original event of the accident into a simulation scenario. Next the changes to the original event of the accident in case of the existence of an integrated safety system is analyzed. For this each system component like sensor technology, algorithm or actuator is modeled. In an early stage of the system development general idealistic assumptions are made for these component models. Later on in the development process these component models are getting more and more realistic by using test data to validate the component models. The influence of various passive safety measures is implemented via modeling varying injury-risk-functions using the “Injury-Shift-Method” described in [8]. Depending on the location of the pedestrian impact on the vehicle, injuries will be reduced to minor injury if the passive safety system of the car shows good results at the point of impact. The effect of the safety system in the event of the accident is simulated based on the original scenario. Modified physical measures are also correlated to a risk of injury for each individual case allowing determination of the safety benefit of an IPPSS in terms of reduction of injured pedestrians for various active and passive components.

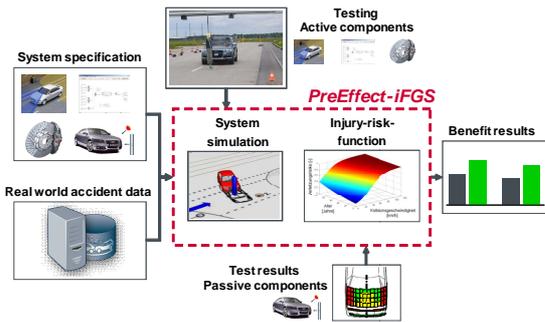


Figure 6. Method for assessment of integrated safety systems PreEffect-iFGS [7]

For the first time it is possible to model an integrated safety system for IPPSS with real components. Even real algorithms can be implemented and their effect on the real-world accident data can be determined.

The main focus of this method lies on injured pedestrians and not on occupants. However, effects of an automatic braking system on a driver or the effect of various adaptive restraint systems is not considered. Therefore, taking into account the safety benefit of integrated safety systems in car-to-car collisions, PreEffect-iFGS has to be extended.

In [9] a new method to determine the safety benefit of integrated safety systems in car-to-car collisions based on actual real-world accident data is presented. The schematic process of this method is shown in Figure 7, displaying an improved PreEffect-iFGS methodology shown in Figure 6.

The method is classified into two parts. In the first part, the database is updated to current safety standards, i.e. the reported benefit from a novel integrated safety system is achieved not only by taking into account current safety standards, but “on top” of these current standards.

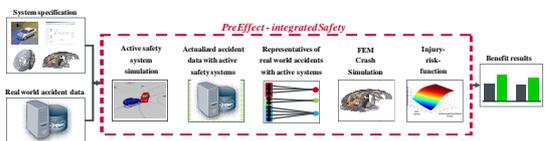


Figure 7. Method for assessment of integrated safety systems

In the second part, changes to the loads of an occupant because of the new integrated safety system are calculated via PC-Crash and occupant simulations.

METHOD

In this paper a first application of the method described in [9] on a subset of load cases with high relevance in real world accidents is demonstrated. In addition, an extension of the method towards material damage will be presented.

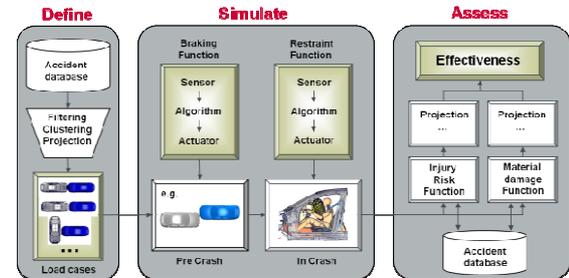


Figure 8. Three Steps to assess the effectiveness of an integrated safety system

The method is divided into three steps. First the load cases of interest are defined. Therefore, an accident database has to be chosen and analyzed for those scenarios being very relevant for real-world accidents. The major goal of this paper is the calculation of the effectiveness of an automatic braking system in combination with an adaptive restraint system in frontal crashes. Therefore, only frontal collided passenger cars will be considered. In the second step the implication of active and passive safety systems on the road users and the vehicles is simulated. To determine the changes to each impact because of an automatic braking system each scenario is simulated with PC-Crash. The effect of an adaptive restraint system in terms of changed occupant loads is simulated in an occupant simulation. In the third step for each simulated load case the changed risk of an AIS3+ injury to the occupants is calculated. Furthermore, the changed impact speed is used for estimating a reduction to material damage.

Step 1: Define

The method applies data from the In-Depth accident study GIDAS, which contains information about the accident, affected vehicles and people involved in the accident. GIDAS is the largest project on investigation of accident data in Germany. Since 1999 about 2000 accidents per year are collected in the greater areas of Hanover and Dresden according to a statistical sampling plan. GIDAS compiles only accidents with at least one injured person [6].

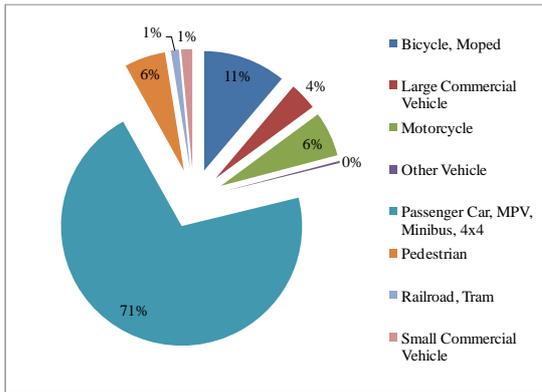


Figure 9. Distribution of the type of road users

For this study only accidents between passenger cars are relevant. In Figure 9 the distribution of the type of road users is shown. 71% of all accident participants in GIDAS are occupants of passenger cars, MPVs, Minibuses or 4x4.

The distribution of the collision opponents of these 71% involved people are shown in Figure 10. 54% of the opponents are passenger cars themselves. Another 10% of the opponents are objects like trees or road signs. For this study only the collisions between two passenger cars are considered.

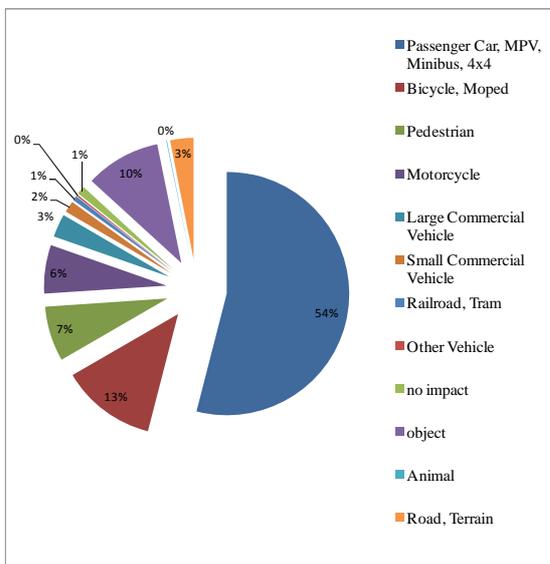


Figure 10. Distribution of collision opponents of passenger cars

Since several studies of real-world accidents have shown that accidents could be avoided if the car is equipped with an electronic stability program (ESP) the EU Parliament requires ESP system being obligatory in all new vehicles from 2013 on. In the considered database 10% of the passenger

car occupants are involved in a skidding accident. These accidents are removed from the database.

11% of the remaining occupants are involved in multiple collisions, i.e. collisions between more than two opponents. Such accidents are very complex and the effect of active and passive safety systems is limited by a lot of constraints and assumptions. In order not to overestimate the effect of such an integrated safety system only the first collision between two opponents is considered.

Figure 11 shows the distribution of the vehicle segments in the remaining database. The segments are chosen according to the coding of the German Kraftfahrtbundesamt (Federal Motor Transport Authority).

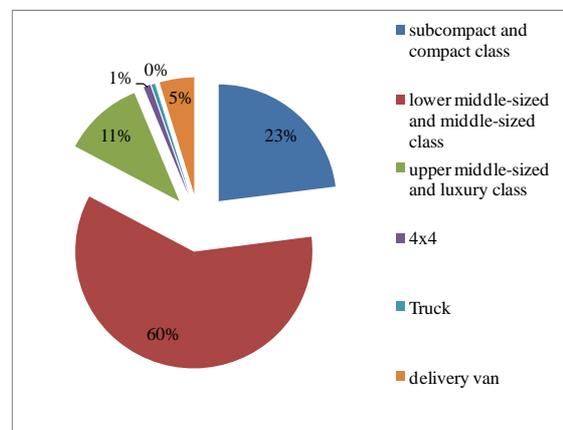


Figure 11. Distribution of the vehicle segments

In the chosen data from GIDAS about 94% of the vehicles belong to the subcompact, compact, lower middle-sized, middle-sized, upper middle-sized or luxury class. Only 6% of the persons involved in the accidents are occupants of a 4x4, Truck or delivery van. Therefore, for the following analysis these types of vehicles are no longer considered.

The distribution of the vehicle segments matches the homologation numbers of the Kraftfahrtbundesamt very well. That means that each vehicle has the same probability to collide with each other segment and therefore, no combination of vehicle segments exists, which has a larger probability of accident involvement.

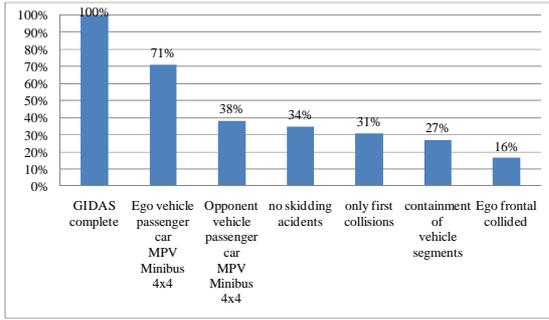


Figure 12. Summary of the filtering of the database

In Figure 12 a summary of the filter steps described above is shown. After all of these filter steps 27% of the people in the GIDAS database remain. This subset is considered for later analysis.

Next the database is analyzed concerning the impact constellations. Each impact constellation is described by the point of first impact and the angle between the longitudinal vehicle axes at the beginning of the crash.

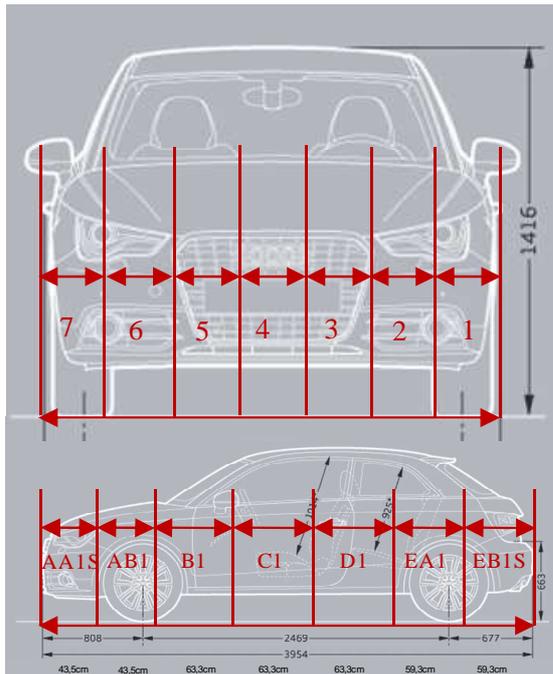


Figure 13. Clustering of the vehicle geometry

The point of first impact is defined as the distance from the foremost point of the car to the impact point towards the longitudinal vehicle axis and from the middle of the vehicle to the left or right. To determine generic impact points the width of the vehicles is sub-divided in seven equal sized parts (see Figure 13). The length of the vehicles also is divided in seven parts according to crash relevant

areas, for example A-pillar, middle of the driver's door or B-pillar.

In order to describe the point of first impact regarding the clustering as shown in Figure 13 some assumptions have to be made. The homologation statistic of the Kraftfahrtbundesamt lists all the vehicles, including make and type, and how many of this vehicle models are homologated. From each segment of interest about 50% of the homologated passenger cars are analyzed according to their geometrical partition. The segments are grouped as shown in Table 1.

Table 1. Summary of the segments

ID	Segment	Combined segment
A00	Subcompact class	Small
A0	Compact class	
A	Lower middle-sized class	Medium
B	Middle-sized class	
C	Upper middle-sized class	Large
D	Luxury class	

For each of the combined segments the mean value of the clustering shown in Figure 13 is calculated in terms of percentage of the length of the car (see Table 2).

Table 2. Clustering of the crash relevant impact areas

Cluster	Small	Medium	Large
AA	11%	11%	12%
AB	11%	12%	13%
B	17%	14%	12%
C	18%	14%	12%
D	17%	14%	12%
EA	13%	17%	19%
EB	13%	18%	20%

The combination of the points of first impact and the impact angle describes the impact constellation. Figure 14 shows an example of the clustered impact combinations. This combination describes a rear-end collision with an angle of 45° between the longitudinal vehicle axes.

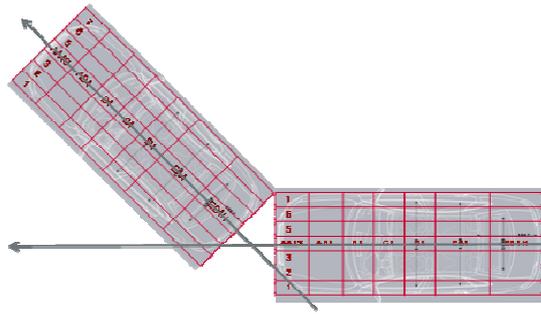


Figure 14. Generic impact constellation

This type of clustering generates 140 impact constellations which describe the selected database.

Each of these constellations can be assigned to an overall impact situation, e.g. rear-end collision.

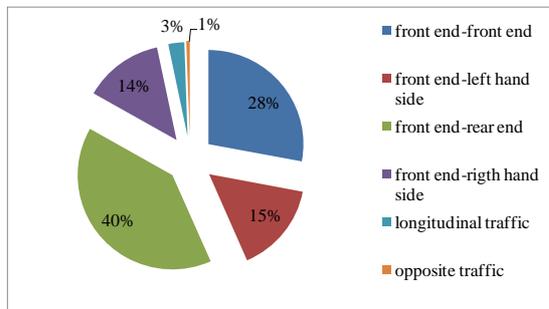


Figure 15. Distribution of overall impact types

Figure 15 shows the distribution of these overall impact types. About 40% of the selected occupants are involved in rear-end collisions. Another 28% are collisions between the front-ends of the opponents.

For the following analysis only collisions with at least one frontal collided vehicle are considered. About 61% of the involved occupants of the interesting database are passengers of frontal collided cars, i.e. 16% of all the persons in the GIDAS database according to Figure 12.

To determine the relevance of each scenario the distribution of the seat occupancy has to be analyzed (see Figure 16). 67% of the frontal collided occupants are drivers, 22% are passengers and 11% are sitting in the rear of the car.

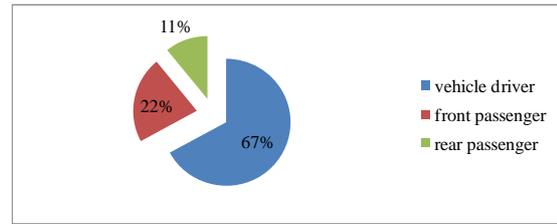


Figure 16. Distribution of seat occupancy

In order to select scenarios with a high relevance in the field, in this analysis only the driver of the frontal collided car is considered. About 66% of the drivers are male and 34% are female. In step 2 of the method (SIMULATE) the effect of passive safety systems on the occupant is simulated with HIII-dummies.

Table 3. Comparison of the GIDAS population and common dummy geometries

Percentile	Weight GIDAS	Weight HIII dummy	Height GIDAS	Height HIII dummy
5 th	52 kg	54 kg	158 cm	152 cm
50 th	74 kg	77.7 kg	173 cm	175 cm
95 th	100 kg	101 kg	188 cm	188 cm

For this, the size and weight of the occupants in the database have to be compared with the dummy geometry. Figure 17 and Figure 18 show the cumulative distributions of the height and weight of the occupants in GIDAS. In Table 3 the comparison between the occupants in GIDAS and the dummy geometries is listed. The dummy sizes and the GIDAS occupant sizes are matching very well.

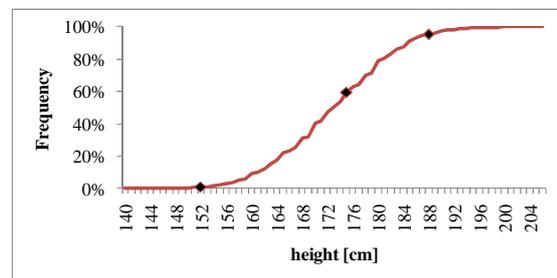


Figure 17. Cumulative distribution of the occupant height

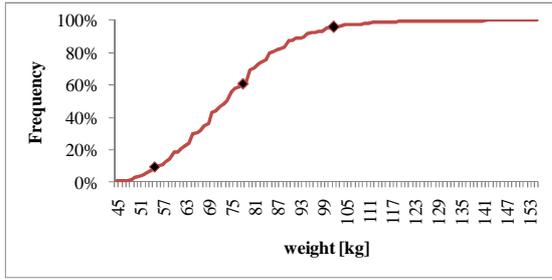


Figure 18. Cumulative distribution of the occupant weight

The goal of this paper is do determine the effect of an automatic braking system in combination with an adaptive restraint system based on real-world accidents. Therefore, different accident severities will be considered, to show the potential of the adaptive restraint system. As a measurement for the accident severity the change in velocity, Δv , due to the collision is used.

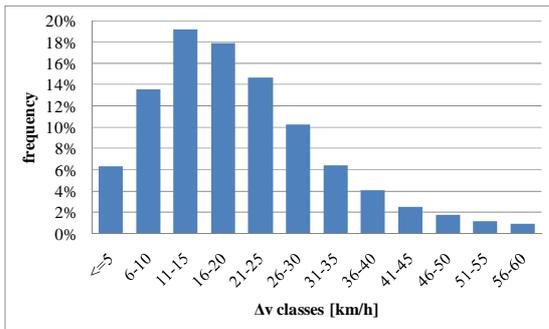


Figure 19. Distribution of the Delta-v classes

Figure 19 shows the distribution of Δv in the selected subset database. 20% of all frontal collided occupants suffered a Δv less or equal to 10km/h and another 37% of this occupants are involved in accidents with Δv between 11 and 20km/h. In summary about 57% of the frontal collided occupants are involved in relatively low accident severities.

In the next step representative accidents for all the accident severities are determined. For accident severities Δv less or equal to 40km/h (about 92% of the frontal collided cars) fully covered rear-end collisions with different relative collision velocities are chosen. The relative collision velocity v_{rel} is the velocity of the frontal collided vehicle minus the velocity of the rear end collided vehicle at the time of collision.

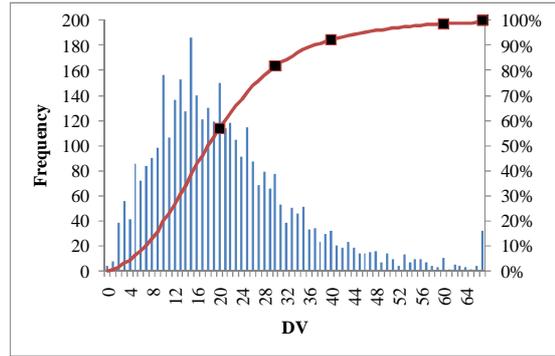


Figure 20. Cumulative distribution of Δv in the subset dataset

In Figure 20 the distribution of Δv is supplemented with the cumulative distribution. The first three black marked points are representatives for a mid-class crash severity. They are equivalent to completely covered rear-end collisions with a v_{rel} of 40, 50 and 60km/h.

As representatives for high-class crash severity with Δv greater than 40km/h two crash tests known as the Euro NCAP and the US NCAP frontal crash tests are selected (see Figure 21). These both tests cover about 99% of the accident severities in real life accidents.

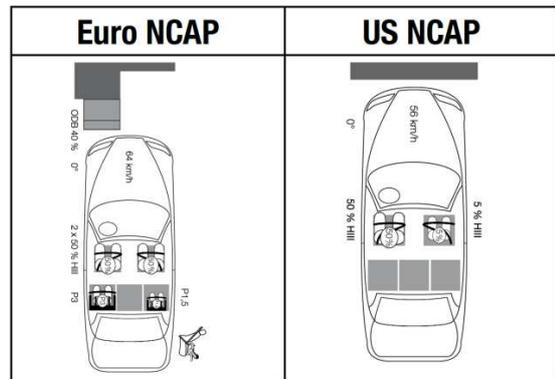


Figure 21. Load cases for $\Delta v > 40\text{km/h}$

Next the braking behavior of the driver has to be analyzed.

If the driver adjusted an average deceleration rate higher than 6m/s^2 the deceleration is boosted up by the brake assist system (BAS) to the maximum available deceleration dependent on the ground in each considered accident scenario. Because the EU decided to regulate the installation of BAS in new cars from November 2011 on, the effect of a 100% equipment rate of the BAS has to be accounted for.

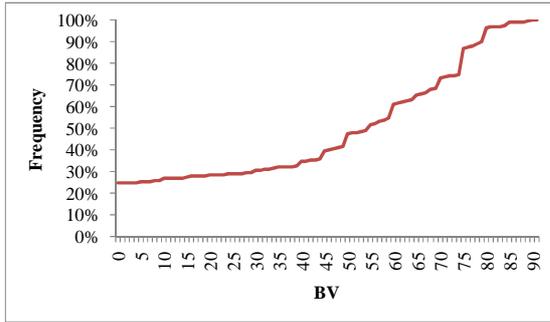


Figure 22. Cumulative distribution of the deceleration rate (BV) [$10 \cdot m/s^2$] in the subset dataset

In Figure 22 the cumulative distribution of the deceleration rate of the driver in the subset database is shown. About 25% of these drivers are not braking at all, another 30% of the drivers adjusted a deceleration rate less than $6m/s^2$. Therefore, in about 45% of the frontal collided accident scenarios a BAS is boosting up the deceleration to the maximum available deceleration rate. This maximum deceleration rate is only limited by the maximum transferable braking performance due to ground floor restrictions in each considered accident scenario. Based on this analysis an automatic braking system is able to reduce the collision speed in 55% of the subset database.

One possibility to account for the braking behavior of the driver in the method is to introduce weighting factors. Based on the analysis above for the automatic braking system a weighting factor of 0.55 is introduced, whereas for the adaptive restraint system a weighting factor of 1.0 is chosen, because it is able to be fully effective in each single accident.

In this section an exemplary filtering of the database towards load cases with high relevance in real life accident scenarios was conducted. In the next step the influence of an automatic braking system in combination with an adaptive restraint system on the selected load cases will be simulated.

Step 2: Simulate

Exemplarily for the mid-class crash severity accidents the influence of an automatic braking system is simulated based on three rear-end collisions from GIDAS (ANB1 - ANB3). For that these load cases are reconstructed in PC-Crash, one of the most common accident reconstruction software. In Table 4 the parameters of the original

scenarios and the changes to them, if an automatic braking system (ANB) is active, are listed.

Table 4. Parameters of the load cases ANB1-ANB3

Parameter	ANB1	ANB2	ANB3
V0	40km/h	50km/h	60km/h
BV	$0m/s^2$	$0m/s^2$	$0m/s^2$
available friction	$8.8m/s^2$	$8.8m/s^2$	$8.8m/s^2$
VK _{rel}	39km/h	50km/h	60km/h
VK _{rel} *	32km/h	39km/h	49km/h
Δ VK _{rel}	7km/h	11km/h	11km/h

Compared to the original relative collision speed VK_{rel} a reduction of 7-11km/h (Δ VK_{rel}) in these load cases is possible. Definitely, the amount of Δ VK_{rel} depends on the setting of relevant system parameters and environmental circumstances.

Next, the effect of an adaptive restraint system on the loads to the occupants is simulated. Such an adaptive restraint system consists of an adaptive belt and an adaptive airbag. The restraint behavior of these adaptive components is adaptable to specific parameters of real-world accidents. Several studies have shown that it is advantageous if the adaptive components are able to adapt their restraint behavior to the crash severity and to the anthropometry of the occupants [10].

The effect of such an adaptive restraint system on the loads on the occupants is simulated with specific simulation software, e.g. PAM Crash. Because current occupant compartments are designed for high crash severities it is assumed that the occupant compartment is still stable in the considered mid-class severity accidents. Therefore, only one occupant compartment model is used for the simulation of the different crash severities.

To determine the effect of an adaptive restraint system, the scenarios ANB1-ANB3 and both the load cases from Figure 21 are simulated three times.

First of all, the original scenario without any braking system and without an adaptive restraint system is modeled. In a second step, the scenarios, changed by a braking action, are simulated without the adaptive restraint system. In a final step, the changed scenarios with an adaptive restraint system are modeled. As a result from the occupant

simulation the different loads on the occupants are calculated.

In the second step (SIMULATE) of the method, the influence of an automatic braking system and an adaptive restraint system on the selected load cases was simulated. In the third step of the method, the effectiveness of these systems is estimated.

Step 3: Assess

In order to assess the effectiveness of an automatic braking system in combination with an adaptive restraint system the simulated changes of the load cases have to be transferred in terms of injury reduction or reduction of material damage.

For determining the influence of changed occupant loads on the injury outcome injury risk functions have to be used. In order to provide for comparability with legislation and consumerism at the best, the injury risk curves from the FMVSS 208 [11] are used. The considered injury level is the so called MAIS3+, i.e. all occupants with at least one body region injured more than AIS 2 (AIS stands for the Abbreviated Injury Scale). To calculate the overall risk of an MAIS3+ injury the assumption is made, that the injuries of each body region are independent. The combined MAIS3+ injury risk is calculated after the new US NCAP regulation for p_{joint} . For frontal collisions p_{joint} combines the injury risks for the head, the neck, the chest and the femur.

In this way a change of injury risk can be evaluated for each specific load case. The sum of all the MAIS3+ injury risks is the expected number of MAIS3+ injured persons in the specified load cases. The reduction of MAIS3+ injured occupants by a new system (like an automatic braking system and/or an adaptive restraint system) defines the field effectiveness of this system.

Besides the injury outcome also the changes to material damage are of interest.

The material damage of a vehicle in an accident depends on a lot of factors. In order to determine the influence of automatic braking systems on the material damage some assumptions have to be done. First of all, the material damage of each car is limited by the residual value of the car. An analysis of the Schwacke-list [12] suggests an exponential degeneration of the residual value over the age of

the car. Under the assumption that the residual value after three years amounts to half the original price, the residual value dependent on the age of the car can be calculated as

$$RV(t) = OV \times 2^{-\frac{t}{3}} \quad (1)$$

where RV is the residual value, t is the age of the car in years and OV is the original value of the car. Because the database contains a lot of different cars, for each combined segment an average OV is estimated (see Table 1).

Table 5.
Estimated average original value

Combined segment	Estimated average OV
Small	17.500 €
Medium	35.000 €
Large	75.000 €

In order to calculate the resulting cost of repairing depending on the crash severity several crash tests were analyzed. The analysis showed that the cost of repairing is more or less directly correlated to the crash severity Δv . Therefore, a regression analysis between Δv^2 and the cost of repairing damage (CORD) is conducted (see Figure 23).

$$CORD(\Delta v^2) = 208.82 \times \Delta v^2 - 1048.5 \quad (2)$$

Formula (2) describes the correlation of Δv^2 in m^2/s^2 and CORD in percentage of the OV.

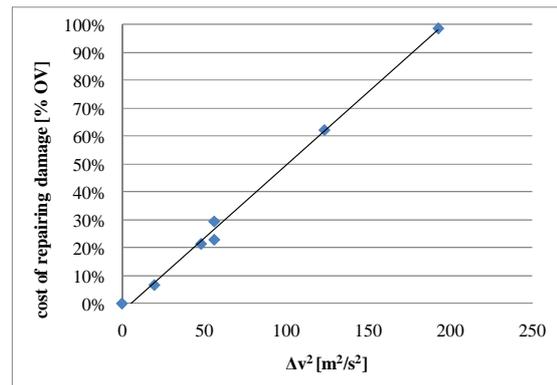


Figure 23. Regression of Δv over the cost of repairing damage

This function assumes that the cost of repairing damage does not depend on the segment of the car.

The material damage (MD) calculates out of a combination of formula (1) and (2).

$$MD(\Delta v^2, t) = \min_{\{\Delta v^2, t\}} (RV(t), \text{CORD}(\Delta v^2) \times OV) \quad (3)$$

The reduced cost of repairing is calculated out of the difference from the original MD without the braking system and the MD resulting from the reduced Δv .

As shown in this section the method allows an estimation of the changes to the injury outcome of occupants and the resulting material damage.

Summary and outlook

In this paper a method is described to calculate the effect of an automatic braking system in combination with an adaptive restraint system on the injury outcome of the occupants and on the material damage of the cars. The method is presented via some exemplary load cases with a high relevance in real-world accidents. The great advantage of this method is its modular composition.

The database can be replaced with other databases (e.g. U.S. accident statistics), whereby differences of vehicle populations or infrastructure can be accounted for. Therefore, the method allows estimating the effectiveness of integrated safety systems for arbitrary nations. For a worldwide prediction national accident databases have to be analyzed. In this regard harmonized accident databases with respect to representativeness, data structure and parameters according to the German In-Depth Accident Study GIDAS are required.

In the method the functions for determining the injury outcome and the material damage can be easily replaced by other functions. So the method is easily adoptable to the latest scientific findings, for example renewed injury risk functions. Also, the selection of the repairing cost function can depend on the specific realization of the automatic braking function components. Even if new types of dummies for the evaluation of vehicle safety are introduced into regulation and/or rating procedures the method is still valid because only the occupant simulation element and the injury risk function element have to be adjusted.

Although this method is very generic in the future a closer look to the robustness of the method is necessary. A further region of interest is the influence of the constitution of the load cases on

the calculated effectiveness. So the questions has to be answered how many and how detailed load cases must be chosen in order to get a valid prediction of the overall benefits. Also the sensitivity of the calculated effectiveness to the weighting of load cases is an interesting field of study.

Once the method is fixed in its constraints it can be applied to study the effect of integrated safety system parameters on the overall effectiveness of the system. Furthermore it is necessary to find out how strong are the relationships among relevant system parameters with respect to the largest achievable benefits and their limitations.

For example in order to study the benefits of an adaptive restraint system on the injury outcome new technologies for infinitely variable airbags and belts are desired because these components are expected to maximize occupant protection.

In the future an integration of additional elements to this method is planned to account for the latest developments in vehicle safety. Especially vehicle-to-vehicle or vehicle-to-infrastructure communication technologies are expected to have a great impact on further reducing fatalities and injured people. So we are looking forward to extend this method to assess also such kind of integrated safety systems.

Finally an extension of this method to all kind of road users has to be conducted in order to predict prospectively the changes to all the real-world accidents.

REFERENCES

1. European Commission, "Towards an European road safety area: policy orientations on road safety 2011 – 2020," Brussels, 20.7.2010
2. U.S. Department of Transportation, "Traffic Safety Facts 2009," DOT-HS-811-392
3. Gollewski, T., „Integrale Sicherheit - Herausforderungen, aktuelle Funktions- und Auslegungskonzepte aus Sicht eines OEMs,“ presented at Integrated Safety 2008, Germany, July 2-3, 2008.
4. Reßle, A., Schramm, S., Kölzow, T., „Generierung von Verletzungsrisikofunktionen für Fußgängerkollisionen,“ presented at 10th Crash.Tech, Germany, April 13-14, 2010.
5. Busch, S., „Entwicklung einer Bewertungsmethodik zur Prognose des Sicherheitsgewinns ausgewählter Fahrerassistenzsysteme,“ Ph.D. thesis, Technical University of Dresden, 2004.
6. Schramm, S., „Methode zur Berechnung der Feldeffektivität integraler Fußgängerschutzsysteme,“ Ph.D. thesis, Technical University of Munich, 2011.
7. Liers, H., „Benefit Estimation of the Euro NCAP Pedestrian Rating Concerning Real World Pedestrian Safety,“ ESV Technical Paper 09-0387, 2009.
8. Ressler, A., Fuerst, F., Heissing, B., Koelzow, T., Lienkamp, M., "Field Effectiveness Calculation of Integrated Safety Systems," 2011-01-1101 presented at the SAE 2011 World Congress, USA, April 12-14, 2011.
9. German In-Depth-Accident-Study (GIDAS), "accident investigation on the spot – Dresden and Hanover," <http://www.gidas.org/files/GIDAS.pdf>, Jan. 2011.
10. Schramm, C., Fuerst, F., Van den Hove, M., Gonter, M., „Adaptive Restraint Systems-The Restraint System of the Future,“ presented at 8th International Symposium Airbag 2006, Germany, December 04-06, 2006.
11. Department of Transportation, NHTSA, "Consumer Information; New Car Assessment Program," Docket No. NHTSA-2006-26555,
12. Schwacke, <http://www.schwacke.de>, March 2011.

1999, the GIDAS project has collected on-scene accident cases in the areas of Hanover and Dresden. GIDAS collects data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and its causation. The project is funded by the Federal Highway Research Institute (BAST) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist. Further information can be found at <http://www.gidas.org>.

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