BENEFIT ESTIMATION OF ADVANCED DRIVER ASSISTANCE SYSTEMS FOR CARS DERIVED FROM REAL-LIFE ACCIDENTS

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ABSTRACT

Advanced Driver Assistance Systems (ADAS) are today becoming increasingly common in the market. The safety potential of these systems has been evaluated using different approaches in several studies. In order to quantify the effects of ADAS on accidents described by insurers` claim files, German Insurers Accident Research has performed a comprehensive study. The database used for the study was a representative excerpt from the German Insurers' data, covering 2,025 accidents. Statistical methods were used to extrapolate these accidents up to 167,699 claims.

The conclusions of the analyses are as follows: a Collision Mitigation Braking System (CMBS) which is able to gather information from the environment, to warn the driver and to perform a partial braking maneuver autonomously (CMBS 2), could prevent up to 17.8 % of all car accidents with personal injuries in the data sample. The theoretical safety potential of a Lateral Guidance System, consisting of Lane Change Assist and Lane Keeping Assist, was determined to be up to 7.3 %.

Hence, a car fleet equipped with CMBS 2 and Lateral Guidance could avoid up to 25.1 % of all car accidents in the data sample. This theoretical safety potential is based on the assumptions that 100 % of the car fleet is equipped with these systems and the driver reacts perfectly when warned.

DATABASE

German Insurers Accident Research (UDV) is a department of the German Insurance Association (Gesamtverband der Deutschen Versicherungswirtschaft e.V. - GDV) and has access to all the third party vehicle insurance claims reported to the GDV. For 2007, these amounted to 3.4 million claims, of which 2.6 million were claims involving cars. For the purposes of accident research, the UDV set up a database (referred to as the UDB), taking a representative cross-section (years 2002-2006) from this large data pool. The data collected is conditioned for interdisciplinary purposes for the fields of vehicle safety, transport infrastructure and traffic behaviour. The contents of the claim files from the insurers form the basis of the UDB. The depth of information provided by the UDB is significantly higher than that of the Federal German statistics [1] (see Figure 1). It is comparable with GIDAS [2, 3], although some attributes are less meaningful because no analysis is carried out at the scene of the accident. Around 1,000 new cases are added to the UDB each year.

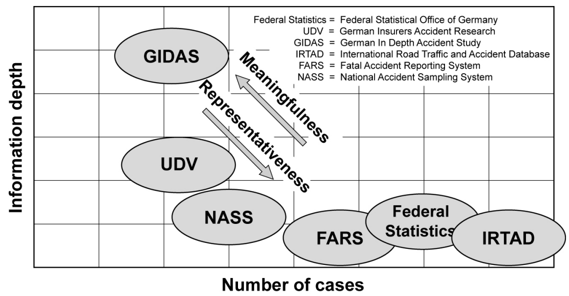


Figure 1. The UDV database compared with other accident databases.

Data set and representativeness

Only third-party vehicle claims involving personal injury and at least € 15,000 total claim value have been taken into account for the GDV accident database. Cases involving only damage to property and less serious accidents involving personal injury (total claim value < € 15,000) are not included in the UDB. Each year, a random sampling method [4] is used to collect stratified random samples that take into account the type of traffic involvement, the damage sum class and the time of year as stratification variables. Case-dependent extrapolation factors allow the sample in the UDB to be extrapolated to the target population of all claims in Germany. This ensures that the statements with respect to the safety potential of driver assistance systems refer to a representative sample of all claims dealt with by German insurers.

This current study is based on a total of 1,641 car accidents, which were extrapolated to a total of 136,954 cases. All types of traffic involvement were taken into account as the collision parties for the car (cars, trucks, buses, motorcycles, bicycles and pedestrians) as well as single car accidents. Single car accidents are, however, underrepresented, as cases in which there is no injury or damage to a third party are not brought to the attention of GDV.

METHOD

Analysis of the safety potential was carried out using a multi-step-approach (see Figure 2). Starting from the accident data stored in the UDB ("A – UDB database"), the accidents involving cars were selected in a first step ("B – Data pool"). In a second step, key aspects of the course of the accidents and groups of ADASs were defined ("C – Relevance pool 1") that could be expected to exert a positive influence on the key aspects of the accidents that had been derived (e.g. Intelligent Braking Assist, Lateral Support). In a third step, the system characteristics were derived for generic ADASs. Different stages of development of the systems were defined and evaluated ("D – Relevance pool 2"). It was of no significance for the analysis whether it is currently already possible to implement the technical system characteristics and whether the systems under consideration are already available on the market. It was also not the intention to carry out a comparison of specific products.

Fourthly, the theoretical safety potentials of the defined generic ADASs were determined by systematic case-by-case analysis ("E – Calculation of the theoretical safety potential"), and driver behaviour and HMI layout were additionally considered in the fifth step. ("F – Calculation of the achievable safety potential").

The cases were analyzed using the "What would happen if..." method. The prerequisite for this is that none of the vehicles involved in the accidents that were analyzed were fitted with an ADAS. This approach considers the course of the accident as it happened in reality and contrasts it with the course of the accident as it would have been with ADAS (see also [5]). This makes it possible to determine the influence an ADAS would have had on the course of the accident if all the cars had been fitted with the ADAS under consideration. Although a comparison between "cars with ADAS" and "cars without ADAS" would have been theoretically possible, this was not done,

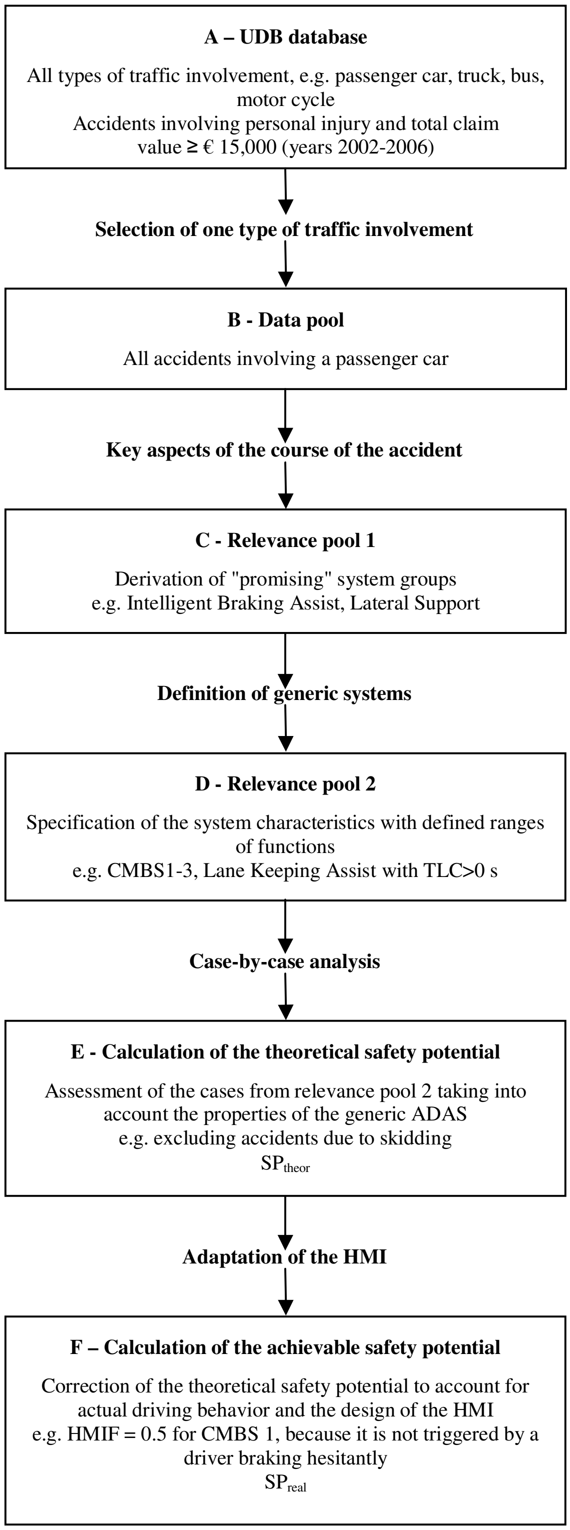


Figure 2. Multi-step-approach where A ≥ B ≥ C ≥ D ≥ E ≥ F with respect to the size of the data pool.

on the one hand because there are still too few cars fitted with modern ADASs in the overall total (and involved in the accidents) and on the other because it was not intended to compare specific products [6, 7].

The method of investigation selected initially assumes that a driver reacts ideally to the warnings issued by the system, which is generally not the case in reality. This means that the theoretical safety potential calculated in step four of the method represents an upper limit that is unlikely to be achieved under real driving conditions. Taking adequate account of driver behaviour is a huge challenge in accident research, in particular in the context of ADASs. The problem is approached in different ways in the various studies. Thus, it is for instance possible to divide drivers into groups and to characterize these groups with specific attributes such as braking behaviour [8]. A different approach was adopted in this study: In order to provide a quantitative description of the influence of the systems and their various development stages on driver behaviour, existing expertise based on the most recent information was used. The index derived from this ("HMIF") takes account of the following parameters: driver reaction, behaviour adaptation, and the design of the human-machine interface [9]. The HMIF can take a value between 0 and 1. This is multiplied by the theoretical safety potential in order to determine the safety potential that can be achieved when the aspects mentioned above are taken into account.

$$SP_{real} = HMIF \times SP_{theor}$$

$HMIF$ – Human Machine Interface Factor where $HMIF \in \{0...1\}$

SP_{real} – achievable safety potential

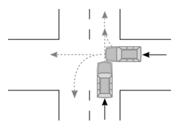
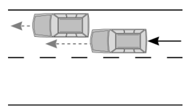
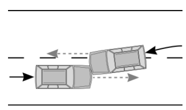
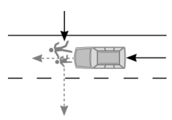
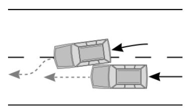
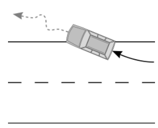
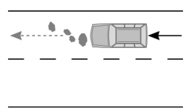
SP_{theor} – theoretical safety potential

A value of HMIF=0 means that there is only a theoretical safety potential that cannot, however, be exploited in practice because of poor interface design. One example would be an optical collision warning system that directs the driver's attention into the vehicle instead of onto the road. A value of HMIF=1 means that the potential that can be achieved in theory and in reality are identical. An example of such a system is the Electronic Stability Program (ESP): When the ESP intervenes, the driver's attention is not distracted, neither is there a risk of any negative behaviour adaptation associated with a different driving style.

APPLICATION OF THE METHOD TO SELECTED SYSTEMS

Using the method described, the car accidents in the UDB (n=1,641) extrapolated to n=136,954 were categorized on the basis of the attribute "kind of accident" and ordered by the frequency with which the different types occurred (see Table 1). The "kind of accident" attribute describes the directions in which the vehicles involved were heading when they first collided on the carriageway, or, if there was no collision, at the time of the first mechanical impact on a vehicle [1].

Table 1.
Most frequent accident scenarios for car accidents from the data pool

Most frequent accident situation ($n_{data\ pool}$=136,954) [100 %]		**Proportion**
(1) Collision with another vehicle which is turning into or crossing a road		34.5%
(2) Collision with another vehicle - moving forwards or waiting - which is starting, stopping or is stationary		22.2%
(3) Collision with another oncoming vehicle		15.5%
(4) Collision between vehicle and pedestrian		12.1%
(5) Collision with another vehicle moving laterally in the same direction		6.9%
(6) Leaving the carriageway to the right or left		6.3%
(7) Collision with an obstacle in the carriageway		0.1%

The list of typical accident scenarios in Table 1 can be used for preliminary selection of sensible ADAS groups (see Table 2). This list does not, however, provide the theoretical safety potential of generic ADASs. Instead, it is possible to identify potential promising ADAS groups in accordance with the stated methodology (relevance pool 1).

Table 2.
Ranking of possible ADAS groups on the basis of the data pool

ADAS group	Accident situation addressed	Data pool
Intelligent Braking Assist	(1) (2) (7)	56.8 % (n=77,775)
Rear-end collisions and all situations where the directions of travel of vehicles cross each other		
Pedestrian/Bicyclist Detection Assist	(1) (4)	46.6 % (n=63,865)
Also possible: All other situations where pedestrians/bicyclists interact with vehicles		
Junction/Intersection Assist	(1)	34.5 % (n=47,243)
Addresses all situations where the directions of travel of vehicles cross each other		
Lateral Support	(3) (5) (6)	27.7 % (n=37,895)
Covers situations where drivers leave the lane unintentionally or intentionally, e.g. overtaking and blind spots		

This reveals that intelligent braking systems that are, among other things, able to prevent rear-end collisions would be able to address the great majority of the accidents in the database, followed by an assistance system able to prevent accidents with vulnerable road users (pedestrians and cyclists). This study, however, only investigates intelligent braking systems and lateral support systems.

Collision Mitigation Braking Systems (CMBS)

Collision Mitigation Braking Systems are able to positively influence specific accident scenarios (see tables 1 and 2) [6]. For this study, three different development stages of a CBMS were investigated with the aim of revealing sensible directions in which development can be pursued and to assess these in terms of safety potential. The system properties selected have a direct impact on the accidents in which any influence can be exerted (see Table 3 to Table 5). To comply with the methodology, steps must be taken to ensure that the vehicles in the data pool are not fitted with a CMBS. This could not, however, be guaranteed in all cases for CMBS 1.

The first development stage of a CMBS (CMBS 1) virtually corresponds to the traditional braking assist systems as required in passenger cars by the pedestrian protection directive [13] that has been approved. The second stage already has the capability of collecting environment information and is able to detect double-track vehicles driving in front. On the systems currently available on the market, this is done almost exclusively with radar sensors. The third development stage describes a system that as yet does not exist in the form presented. As such, the system is based on the functionality provided by the second stage and is also able to detect potential collision parties crossing from the side. The system is not restricted to the detection of double-track vehicles. Instead, all motorized vehicles as well as pedestrians and cyclists are detected.

Table 3.
System properties and derived database attributes for the first development stage of a CMBS (CMBS 1)

CMBS 1	
System description	**Application to the UDB**
- Enhancement of the braking force up to the blocking threshold in the event that a driver initiates an emergency braking maneuver but does not actually carry it out	- Only those accidents in which the driver braked and in which the driving and collision speeds are known - The "case car" is the vehicle on which the primary impact is at the front
- Maximum deceleration that can be achieved: 9.5 m/s² (dry road surface); 7 m/s² (wet road surface)	- Sub-categorization of the accidents by the state of the road surface (dry/wet)
- No detection of the environment	- All accident scenarios

Taking account of the system characteristics of the CMBSs described in Table 3 through Table 5 we arrive at the case material collated in Table 6. Only cases from relevance pool 2 are used to determine the

Table 4.
System properties and derived database attributes for the second development stage of a CMBS (CMBS 2)

CMBS 2	
System description	**Application to the UDB**
- As for CMBS 1 plus:	
- Forward detection of the environment (sensor-independent)	- Rear-end collisions with double-track vehicles
- Detection of double-track vehicle driving in front (not stationary)	
- Speed range: 0-200 kph	All accidents in which the driving speed of the "case car" is known and:
- warning at TTC 2.6 s, i.e. 2.6 s before the calculated collision with the vehicle in front	
- automatic partial braking at 0.6 g by the system if there is no reaction from the driver at TTC 1.6 s	- the driver has not braked
- if the driver has reacted, a modulated braking maneuver or an emergency braking maneuver is performed	- the driver has braked

theoretical safety potential. Case-by-case analysis is used to determine those accidents from relevance pool 2 that could have been avoided by CMBS 1, CMBS 2 or CMBS 3. An analogous approach is used for all the other systems under investigation (see Table 8 and Table 11).

Taking CMBS 2 as an example, we shall explain the procedure used to form the individual pools: Starting from a data pool with 65,328 car accidents, all rear-end collisions are selected. These then form relevance pool 1. In a following step, these cases are further restricted on the basis of the specified system characteristics (see Table 4). For CMBS 2, this means that only rear-end collisions with moving, double-track vehicles are taken into account (relevance pool 2). This pool is finally used for case-by-case analysis.

Table 5.
System properties and derived database attributes for the third development stage of a CMBS (CMBS 3)

CMBS 3	
System description	**Application to the UDB**
- As for CMBS 2 plus:	
- Forward and lateral detection of the environment (sensor-independent)	- All accident scenarios
- Detection of all types of road users including pedestrians and stationary objects/obstacles	
- Automatic maximum braking by the system at TTC 1 s in the sense of a modulated braking maneuver	- All accidents in which the driving speed of the "case car" is known

Table 6.
Relevant extrapolated accident data for the three development stages of a CMBS

	Data pool	**Relevance pool 1**	**Relevance pool 2**
CMBS 1	52,226	29,365	14,318
CMBS 2	65,328	23,640	7,409
CMBS 3	83,524	46,628	46,628

There are significant differences between the CMBSs with respect to the HMIF: The HMIF for CMBS 1 is 0.5. The most important reason for this is that today's systems are parameterized for normal to sporty drivers. This does not account for apprehensive or hesitant drivers who would be in particular need of the system. This was confirmed by trials in a driving simulator, where the braking assist system only registered as having triggered in 47 % of cases [10].

In the case of CMBS 2 and CMBS 3, the HMIF is 1, since no behaviour adaptation is to be expected.

Lateral Guidance Systems

Overtaking accidents, accidents in the context of changing lanes and departure from the carriageway form a further important group of accidents (see Table 2). A Lane Keeping Assist system and a Lane Change Assist system were assessed for these accidents. The latter was divided into two subsystems: One system warns of oncoming traffic when overtaking and the second system warns of vehicles approaching from behind in the blind spot during a deliberate overtaking or lane change maneuver.

Table 7.
System characteristics and derived database attributes for the Lane Keeping Assist system

Lane Keeping Assist system	
System description	**Application to the UDB**
- Capturing of the lane marking(s) using sensors and cameras (range: approx. 50 m)	- Accidents caused by inadvertent departure from the carriageway (e.g. as a result of inattention, distraction, overtiredness) - The "case car" is the vehicle with the reference number 01 (party responsible for the accident)
- Detection of an impending inadvertent departure from the lane by comparing the current direction of travel with the course of the current lane	
- Active between 10 kph and 200 kph	
- Warning issued to the driver at TLC > 0 s (Time to Lane Change, speed-dependent) - No intervention in the steering by the system	
- Function is maintained even in bends provided that the radius is at least 200 m	
- Function is only available if at least one lane marking is available	- Assumption: At least one lane marking was present in all the accidents investigated
- Detection of all types of markings except overlaid lines (e.g. in the vicinity of roadworks)	- Accidents in the vicinity of roadworks are not taken into consideration
- Coupled to the indicator unit, i.e. the system is deactivated when the indicator is switched on	- Accidents resulting from a deliberate lane change maneuver are not taken into account

__Lane Keeping Assist__ **-** The functions of the Lane Keeping Assist system investigated here are based on systems already available on the market.

Taking account of the system characteristics described in Table 7, we arrive at the accident data shown in Table 8.

In the case of the Lane Keeping Assist system, relevance pool 1 is formed by the key aspect of the accident "departure from the lane/carriageway". For relevance pool 2, accidents in the vicinity of roadworks and in tight bends, etc. are filtered out, as it cannot be guaranteed that the system will function reliably in such cases. The case-by-case analysis was carried out on relevance pool 2 (7,207 cases).

Table 8.
Relevant extrapolated accident data for a Lane Keeping Assist system

	Data pool	**Relevance pool 1**	**Relevance pool 2**
Lane Keeping Assist system	136,954	17,848	7,207

An HMIF of 0.5 was determined in [9] for deriving the achievable safety potential of a Lane Keeping Assist system. The reason for this is that a low magnitude haptic warning tends to be selected in order to prevent frequent false warnings from being perceived as a nuisance. Acoustic warnings on the other hand are not sufficiently specific and direction-dependent acoustic warnings do not deliver any additional benefit [9].

__Lane Change Assist__ **-** A variety of studies and statistics [1, 11] provide evidence that rural roads represent the greatest safety problem in Germany with respect to fatal accidents. In this context, accidents involving oncoming traffic are conspicuous. In such situations, an Overtaking Assist system providing support to the driver would be desirable. However, such a system (see Table 9) is currently not available [12]. Theoretically, it would also be conceivable to implement a system such as this using car-to-car communication. Although such systems currently belong to the future, it nevertheless makes sense to analyze the safety potential, because it can provide insights into future development priorities.

Table 9.
System characteristics and derived database attributes for the Overtaking Assist system

Overtaking Assist system	
System description	**Application to the UDB**
- Monitoring of the area in front of the vehicle at a significant distance (assumption: at least 300 m; sensor-independent)	- Collisions with oncoming vehicles during overtaking (using accident types in the magnitude of hundreds and the attribute "direction of travel, vehicle 1"/"Collision with vehicle 2 which ...")
- Detection of oncoming double-track vehicles and motorcycles	
- Calculation of the theoretical collision time using the speeds and distance between the vehicles (without taking into account the course of the road, e.g. humps)	- The "case car" is the vehicle with the reference number 01 (party responsible for the accident)
- Warning issued to the driver when the indicator is set if the overtaking maneuver is judged to be critical	- Assumption: The driver had set the indicator for each overtaking maneuver

The Overtaking Assist system described in Table 9 was not assessed on the basis of the HMIF because there are currently no concrete, scientific findings with respect to such a system.

For the Blind Spot Detection system (see Tables 10 and 11), relevance pool 1 was formed by the key aspect of the accident "lane change", in other words those accidents in which a collision occurred when changing lane (7,403 cases). For relevance pool 2, only those accidents were taken into account, for example, in which the party changing lane was hit from the rear or side and was driving at least 10 kph. The accident material meeting this criterion is given in Table 11.

The HMIF for a Blind Spot Detection system is assumed to be 0.8 in accordance with [9]. The reason is that the system assumes that the driver looks in a particular direction, which does not always happen. This applies, for instance, for systems designed with a flashing signal on the wing mirror.

Table 10.
System characteristics and relevant accident data for a Blind Spot Detection system

Blind Spot Detection system	
System description	**Application to the UDB**
- Monitoring of the areas behind and to the side of the vehicle	- Collisions with approaching vehicles when pulling out or with overtaken vehicles when pulling in again (accident types in the magnitude of hundreds) - The “case-car” is the vehicle with the primary impact to the rear or to the side (right or left)
- Detection of approaching double-track vehicles and motorcycles that are between 20 kph slower and 70 kph faster.	
- System active as of 10 kph	- Accidents caused by changing lanes from stationary are not taken into account
- Warning issued to the driver when the indicator is set and when an approaching vehicle or motorcycle is in the blind spot area	- Assumption: Indicator is set on each overtaking maneuver

Table 11.
Relevant extrapolated accident data for a Lane Change Assist system

	Data pool	**Relevance pool 1**	**Relevance pool 2**
Overtaking Assist system	136,954	7,403	2,222
Blind Spot Detection system	136,954	7,403	3,582

RESULTS

This current study on the safety potential of selected ADAS systems is based on a total of 1,641 car accidents. Extrapolated to the total claims on the insurers, this corresponds to a total of 136,954 cases. Depending on the question being investigated and the ADAS under consideration, this number of cases is reduced because the information required is not always 100 % present in the database. For instance, in order to determine the safety potential of CMBS 1, only those cases are considered where it is known whether the driver braked before the collision, which means that all the accidents in which it is not possible to determine whether the driver braked must be filtered out. The same principle applies to the other ADASs considered here. This aspect is reflected in Tables 12 through 14.

A multi-step-approach was used for each ADAS under investigation (see Figure 2). Considerable differences in the magnitude of the safety potential can be observed for longitudinal guidance systems (CMBS 1-3) and lateral guidance systems.

Collision Mitigation Braking Systems (CMBS)

Table 12 indicates the fundamentally high safety potential for CMBS systems. It can be seen that even CMBS 1 has a significant positive impact on the accident situation. The configuration of the generic CMBS 1 corresponds to the braking assist system that will become mandatory when the pedestrian protection directive takes effect [13]. In this case, the achievable safety potential SP_{real} differs considerably from the theoretical safety potential SP_{theor}. Nevertheless, even if this is taken into account, it would be possible to avoid SP_{real}=5.7 % of all car accidents.

It can also be clearly seen that a significantly higher safety potential can be expected in future. If we assume that the generic CMBS 2 corresponds to the CBMS already available on the market, SP_{real}=12.1 % of all car accidents in the database could be avoided if 100 % of cars were fitted with the system.

On the basis of all the rear-end collisions in the database (n=23,640), the resulting safety potential is 28 % for CMBS 2.

Table 12.
Extrapolated numbers of accidents and theoretical and achievable safety potential of CMBSs

	Data pool [100 %]	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**	**SP_{real}**
CMBS 1	52,226	29,365	14,318	5,960 **11.4%**	**5.7%**
CMBS 2	65,328	23,640	7,409	4,213 (6.4%) **17.8%**	(6.4%) **12.1%**
CMBS 3	83,524	46,628	46,628	24,027 (28.7%) **46.5%**	(28.7%) **40.8%**

It can be expected that systems in the more distant future would closely resemble the characteristics of the CMBS 3. Such systems can be understood as "Junction/Intersection Assist systems". If vehicles were fitted with CMBS 3 type systems, SP_{real}=40.8 % of all car accidents could be avoided. Toyota have already presented initial attempts at such systems with their Front-side Pre-crash detection system [14].

Lane Keeping Assist

Systems that warn a driver when leaving a lane are becoming increasingly common in modern vehicles. Against this background, the safety potential determined here is extremely relevant, especially as the design of the generic Lane Keeping Assist system investigated here approximately corresponds to current systems. The achievable safety potential of a Lane Keeping Assist system is SP_{real}=2.2 % (see Table 13). As with the CMBS 1, this case clearly shows the considerable influence the human-machine interface has in respect of system design.

On the basis of all the accidents in the database resulting from inadvertent departure from the lane (n=17,848), the resulting safety potential for a Lane Keeping Assist system is SP_{real}=16.8 % (SP_{theor}=33.6 %).

Table 13.
Extrapolated numbers of accidents and theoretical and achievable safety potential of a Lane Keeping Assist system

	Data pool [100 %]	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**	**SP_{real}**
Lane Keeping Assist system	136,954	17,848	7,207	6,005 **4.4%**	3,003 **2.2%**

Lane Change Assist

Blind Spot Detection systems are also already available in many new vehicles. The design of the system investigated here approximately corresponds to that of currently available systems. The achievable safety potential SP_{real} is 1.4 % (see Table 14).

If the avoidable accidents (n=1,826) are considered in relation to all accidents where the driver deliberately changed lane (relevance pool 1, n=7,403), this results in a safety potential of SP_{real}=24.7 %.

Table 14.
Extrapolated numbers of accidents and theoretical and achievable safety potential of a Lane Change Assist system

	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
Overtaking Assist system	136,954	7,403	2,222	1,583 **1.2%**	------
Blind Spot Detection system	136,954	7,403	3,582	2,282 **1.7%**	1,826 **1.4%**

The Overtaking Assist system is intended to provide an insight into the future. The safety potential determined shows that despite the considerable technical outlay required to implement the function, only a relatively low theoretical safety potential of SP_{theor}=1.2 % can be expected.

However, if the avoidable accidents (n=1,583) are considered in relation to all accidents where the driver deliberately changed lane (relevance pool 1, n=7,403), this results in a safety potential of SP_{theor}=21.4 % for the Overtaking Assist system.

Human factor issues

This study underscores the importance of taking the human-machine interface into account when designing the system. It is only possible to derive realistic safety potentials when this aspect is taken into account. If this factor is ignored, any potential that is determined can at best be seen as an estimate. One of the challenges that will face accident researchers generally in the future will be to reveal solutions for integrating the aspect of HMI in analyses of safety potential.

CONCLUSIONS

After the ESP, CMBSs are the systems that deliver the greatest safety potential in the field of active safety. They should therefore be fitted to the car fleet as soon as possible. In Europe, a first step has been taken in the right direction with the Regulation concerning type approval requirements for the general safety of motor vehicles [15, 16].

Hence, a future car fleet equipped with CMBS 2 and Lateral Guidance (Lane Keeping Assist, Overtaking Assist and Blind Spot Detection systems) could avoid up to SP_{theor}=25.1 % of all car accidents in the data sample. Methodologically, it is correct to add up these safety potential figures, as they arise from independent subsets of accident data.

The study also reveals a further issue: Above all in first-generation systems, it is crucial that the human-machine interface is taken into account. Significant contributions to improving safety can be achieved even with systems that are already on the market (CMBS 1, Lane Keeping Assist systems and Blind Spot Detection systems): If all cars were fitted with these systems, SP_{real}=9.3 % of all car accidents in the current database could have been avoided.

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