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Advanced Driver Assistance Systems

An investigation of their potential safety benefits based on an analysis of insurance claims in Germany

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Unfallforschung der Versicherer

GDV

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Abstract

The UDV (German Insurers Accident Research) worked on the Advanced Driver Assistance Systems project for the GDV Motor Insurance Loss Prevention Commission (Kommission Kraftfahrt Schadenverhütung) from 2007 to 2010. The aim of the project was to determine the potential safety benefits of selected advanced driver assistance systems. For the first time, car accidents involving damage but not personal injury were also investigated.

The findings were essentially that modern advanced driver assistance systems can have a positive effect on the damage, casualties and accidents examined (accidents involving personal injury and at least € 15,000 total claim value). For car accidents, the (generic) advanced driver assistance systems were found to have theoretical safety potential values ranging from 2% (for a blind spot detection system) to almost 45% (for an emergency brake assist system). For trucks the values ranged from 2% (for a lane departure warning system) to 12% (for an emergency brake assist system) and for buses from around 1% (for a lane departure warning system) to 15% (for an emergency brake assist system).

Car accidents involving damage to property only (third-party and fully comprehensive motor insurance) were investigated with respect to the benefits of parking assist systems and brake assist systems. The resulting analyses showed that 31% of third-party property damage claims could be avoided with an intelligent parking assist system and a further 22% could be avoided with a brake assist system. In the case of fully comprehensive claims, the potential safety benefits of the two systems were not as great but still considerable.

1 Introduction

Advanced driver assistance systems (ADASs), which improve the driving experience and/or safety, are now an integral component of modern vehicles. That applies not only to cars but also to trucks and buses. Considerable efforts are also being made to develop assistance systems for two-wheel motor vehicles to reduce the risk of accidents. However, it is a much more difficult challenge to develop such systems for single-track vehicles than for multi-track vehicles such as cars.

The aim of the Advanced Driver Assistance Systems project for the GDV Motor Insurance Loss Prevention Commission was to examine the potential safety benefits of selected ADASs for cars, trucks, buses and two-wheel motor vehicles. Car accidents involving damage to property but not personal injury (primarily parking accidents) were also investigated, and the potential benefits of parking assist systems were examined.

2 Methodology and subprojects

The first step taken was to make efforts to describe the current situation with regard to ADASs and store the information systematically in a knowledge database. This was done on the basis of two studies of the literature [1, 2]. The focus was on the benefits ascertained in the studies published thus far and the safety gains to be expected in practice.

2.1 Studies of the literature relating to advanced driver assistance systems

In an initial study of the literature [1], the technical functions of the various systems were described, and accident scenarios were identified in which the ADASs can be effective. In addition, an overview was provided of the systems that are either already available or will shortly be introduced. The following systems were examined:

- Brake assist systems
- Junction assistance systems
- Driver status monitoring systems
- Adaptive light control systems
- Blind spot warning systems
- Advanced ESC systems
- Lane departure warning systems
- Lane keeping assist systems with steering intervention
- Speed control systems
- Night vision systems.

The main aim of a further study of the literature [2] was to examine these ADASs from a traffic psychology perspective and both summarize the current state of knowledge and assess the quality of the various studies. This study of the literature was supplemented by a survey in which manufacturers were asked about the effects of ADASs. Finally, the system design of non-automatic ADASs (e.g. blind spot warning systems) was rated by an expert on a scale of 0 to 1 (see Section 2.4). The following parameters were taken into account: driver reaction, behavior adaptation and the design of the human-machine interface. It is thus possible to differentiate between the theoretical benefits and the benefits actually implemented and thus to give weightings to the results from the accident research (accident statistics) and in this way assess the improvements in safety brought by these systems.

2.2 Random sampling system and extrapolation methodology

In the course of the restructuring of the UDV (German Insurers Accident Research) from 2004 to 2006, a new tool was developed for entering and analyzing accident/loss files: the UDB (accident database). At the same time, the statistical and methodological foundations of the investigation and analysis system as a whole were improved. The aim was to ensure that, with regard to weighting, extrapolation and analysis of the data, the UDB complied with the methodological standards required of a nationally and internationally recognized accident sampling system. The results of this methodological development are described in [3]. In parallel with the development of the random sampling system, a method was developed of weighting and extrapolating the data in the UDB that ensures that the loss cases contained in the UDB provide a largely representative picture of **all** third-party motor insurance claims reported to the GDV. The potential safety benefits of ADASs described in Chapter 3, 4 and 5 below were determined using this newly developed extrapolation system. This ensures that the statements about the potential safety benefits of advanced driver assistance systems apply to a representative sample of all claims dealt with by German insurers.

2.3 Structure and description of the UDB and case material

In theory, the UDV (German Insurers Accident Research) has access to all the third-party motor insurance claims reported to the GDV. That amounted to 3.4 million claims in 2009 [4]. Annually stratified random samples of all the claims reported to the GDV are collected using the random sampling method described in [3]. These samples take into account the type of traffic involvement, the damage sum class and the time of year as stratification variables. An average of around 700-1,000 claims a year are entered in the UDB. All of these cases form the basis of this study.

However, only accidents involving personal injury and at least € 15,000 total claim value are entered in the UDB. Cases involving property damage but not personal injury and accidents involving personal injury and a total claim value of less than € 15,000 are not included in the UDB.

The level of detail of the information provided by the UDB is significantly greater than that of the Federal German statistics [5]. It is comparable with GIDAS [6, 7], although some aspects of the UDB information are less meaningful because no analysis is carried out at the scene of the accident.

2.4 Methodological approach

The retrospective analysis of the potential safety benefits or safety potential (SP) of advanced driver assistance systems can be carried out in different ways. For example, two accident groups can be compared: vehicles with ADASs and vehicles without them. This approach was not chosen here, however, both because there are still too few cars fitted with modern advanced driver assistance systems (and involved in accidents) and because we did not intend to compare specific products. Another option is to use the "What would happen if..." method. In this approach, the course of an accident as it happened in reality is examined and contrasted with what would have happened with an advanced driver assistance system. This makes it possible to determine the effect a particular advanced driver assistance system would have on the accident occurrence if all cars were fitted with the system.

To implement the "What would happen if..." method, both the accident circumstances (course of the accident) and the features (functions) of the system under investigation must be known. In addition, it must be ensured that the ADAS was not badly installed in any of the vehicles in the investigation. The circumstances of the accidents are an essential part of the UDB, and the functions of the generic systems (in some cases with different development stages) were derived from [1] and [2]. Thus, all the prerequisites for a differentiated analysis of the data using this method were met.

The analysis of the safety potential was carried out using a multi-step procedure (Figure 2.1). Taking the accident data stored in the UDB as the starting point, in an initial step the accidents involving a particular vehicle type (e.g. cars) were selected. This group of accidents formed the data pool for this vehicle type. The safety potential values obtained for advanced driver assistance systems are based on this pool of cases.

The second step was to determine the main kinds of accident. The "type of accident" or the "kind of accident" were used to do this. The three-digit type of accident developed by GDV [8] describes the initial conflict between two road users that caused the accident. The kind of accident [5], on the other hand, indicates the position of the vehicles involved in the collision in relation to each other immediately before the collision. The type of accident and kind of accident are independent of each other but provide a good way of grouping the accidents together in order to identify trends with regard to what may be key accident groups. To address the issue of how to prevent accidents, it was necessary to combine type and kind of accident in order to be able to take into account all accident scenarios with precision (e.g. all accidents resulting from lane changes).

The list of typical accident scenarios can be used to make a useful initial selection of groups of ADASs. However, this list does not indicate the theoretical safety potential of the generic ADASs. Instead, possible promising groups of ADASs can be identified. The accident scenarios form subsets within the data pool. These can be examined separately for each ADAS to be investigated (relevance pool 1). Relevance pool 1 (e.g. all rear-end collisions) indicates the initial relevance of the ADAS to the accident statistics without taking into account the specifics of particular systems (e.g. the system cannot detect stationary obstacles).

In a third step, sensor-independent generic system characteristics (functions) are obtained for the specified ADASs. Depending on the system, this was done assuming different development stages (e.g. emergency brake assist system 1, emergency brake assist system 2), with the highest development stage having the most advanced system characteristics and thus the greatest potential. It is of no significance to 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 intended to carry out a comparison of the products. Based on detailed knowledge of what the systems have to deliver, relevance pool 1 was further limited. The accidents that could be addressed only by means of the defined system characteristics (e.g. only rear-end collisions with moving vehicles) were removed from pool 1 to form relevance pool 2. Relevance pool 2 thus also takes into account the system limits and is a subset of relevance pool 1.

In the fourth step of the “What would happen if...” method, relevance pool 2 was subjected to a case-by-case analysis. For each case in the pool, a detailed investigation was carried out to ascertain whether the ADAS could have been expected to have a positive effect. Distinctions were drawn based on:

a) Whether the accident could have been avoided with the system
b) Whether the system would merely have had a positive effect on the accident

For the purpose of the investigation, an accident was considered to have been theoretically avoidable if it would not have happened with an ADAS. However, if the analysis showed that the accident would still have happened with an ADAS, but that the consequences of the accident would have been less serious, the accident was considered to be positively affected by the system (e.g. reduced speed on collision → less vehicle damage → less serious injuries to the vehicle occupants).

In the fifth and last step, which was carried out exclusively for ADASs for cars, the calculated theoretical safety potential was adjusted to take into account the human-machine interface.

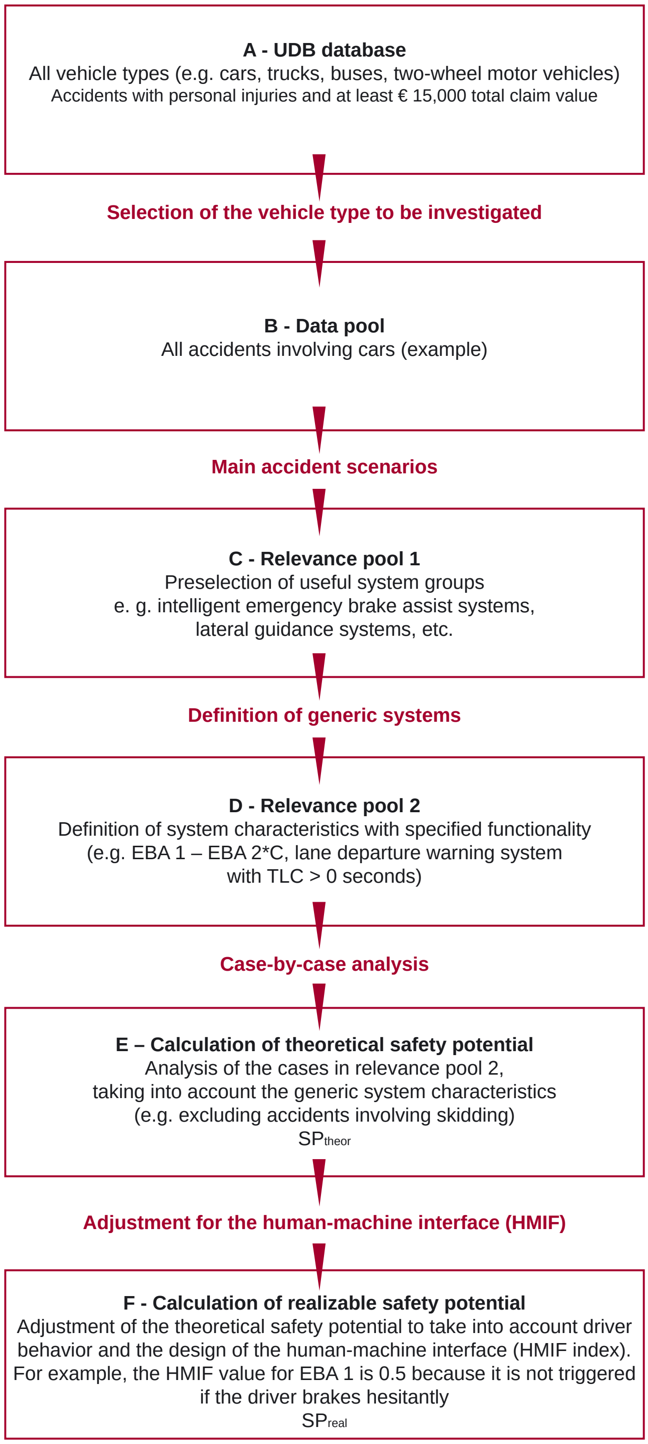


Figure 2.1:
Multi-stage method of analyzing the safety potential of ADASs

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 behavior is a huge challenge in accident research and in connection with ADASs, in particular. This problem is approached in different ways in the various studies. Thus, it is possible, for instance, to divide drivers into groups and to characterize these groups with specific attributes such as braking behavior. A different approach was adopted in this study: in order to provide a quantitative description of the effect of the systems and their various development stages on driver behavior, existing expertise was used [2], which is based on the latest information. The index derived from this (HMIF) takes account of the following parameters: driver reaction, behavior adaptation and the design of the human-machine interface. The HMIF can assume 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 with HMIF ε {0…1}

SP_{real} – realizable safety potential

SP_{theor} – theoretical safety potential

A value of 0 for HMIF means the safety potential is purely theoretical; it cannot 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's interior instead of onto the road. A value of 1 for HMIF means that the theoretical potential and realizable potential are identical. One example of this is an electronic stability control (ESC) system: when an ESC system intervenes, the driver's attention is not distracted, nor is there a risk of any negative behavior adaptation associated with a different driving style.

3 ADASs for cars

Using the extrapolation method mentioned in Section 2.2, the car accidents contained in the UDB for the years 2002 to 2006 (n = 1,641) were extrapolated to N = 136,954 cases. The breakdown of the other parties involved in the accidents with the cars in the extrapolated accident material is shown in Figure 3.1. Only the main other collision parties of the car are shown (i.e. those road users with which the car had the most serious collision involving the most personal injury). Cases involving cars not directly involved (e.g. minor subsequent collisions between a vehicle already involved in an accident and the car) are not shown in Figure 3.1. Collisions between cars account for the largest share of these accidents (around 47%), followed by collisions with motorcycles (14.7%), cyclists (13.5%), pedestrians (12.8%) and trucks (7.3%). Single car accidents account for only 4% of the accidents in the UDB and are thus clearly underrepresented compared with the official statistics [5]. This can be attributed to the fact that the UDB is fed third-party claims, and single car accidents only appear in the accident material when a third party is affected.

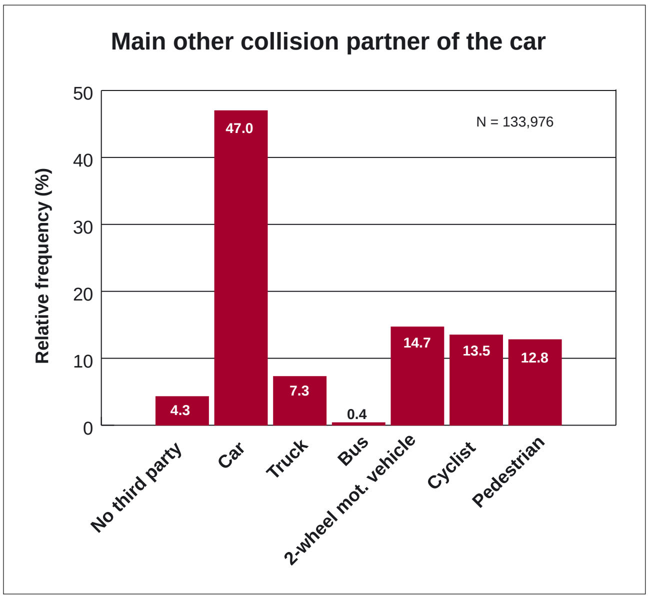


Figure 3.1:
Single car accidents and main other collision parties of the car in the accident material examined

The categorization of the case material by accident situation is shown in Figure 3.2. The different scenarios are shown in descending order by frequency of occurrence and can therefore be used to make an initial selection of useful ADAS groups. However, this list does not indicate the theoretical safety potential of the generic ADASs. Instead, the key ADAS groups can be obtained from it.

Intelligent braking systems, which are able to prevent rear-end collisions, for example, could have a positive effect on a large portion of the car accidents in the database. These are followed by an advanced brake assist system that can address accidents involving unprotected road users (pedestrians and cyclists). Intelligent braking systems, pedestrian/cyclist detection systems and lateral guidance systems are examined in detail in this investigation. A separate section is devoted to accidents with traffic coming from the opposite direction (see Section 3.3.2).

As already mentioned, the investigation of the safety potential of selected advanced driver assistance systems for cars is based on n = 1,641 car accidents (extrapolated to N = 136,954). Depending on the question being investigated and the ADAS under consideration, this number of cases may be reduced because the information required is not always 100% available in the database. For example, to determine the safety potential of emergency brake assist system 1 (see Section 3.1.1), only those cases are considered in which it is known whether the brakes were applied before the collision. If this information is not available, the corresponding accidents have to be filtered out. The same principle applies to the other ADASs examined here.

3.1 Brake assist system – description and safety potential

Brake assist systems can have a positive effect on accident scenarios (1), (2), (4) and (7) (see Figure 3.2) [9]. For this study, five different development stages of a brake assist system or emergency brake assist system were investigated with the aim of revealing current and possible future directions for development and indicating

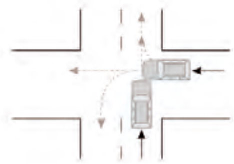
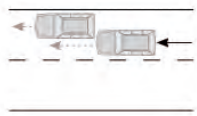
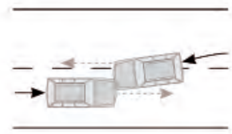
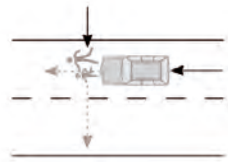
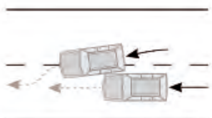
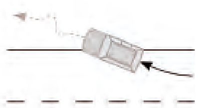
The most frequent accident scenarios $N_{data\ pool}$ = 136,954 [100 %]		**Percentage share**
(1) Collision with another vehicle that is turning into or crossing a road at an intersection		34.5
(2) Collision with another vehicle: ▪ which starts, stops or is stationary ▪ moving ahead or waiting		22.2
(3) Collision with an oncoming vehicle		15.5
(4) Collision between a vehicle and pedestrian		12.1
(5) Collision with another vehicle traveling in the same direction next to the first vehicle		6.9
(6) Coming off the road to the right/left		6.3
(7) Collision with an obstacle on the road		0.1

Figure 3.2:
Frequency of different accident scenarios in the car data pool

the safety potential of each system. For the sake of simplicity, all systems are referred to as emergency brake assist (EBA) systems:

- EBA 1 [a]
- EBA 2 [b]
- EBA 2* [c]
- EBA 2*P [d]; P = pedestrian
- EBA 2*C [e]; C = cyclist

3.1.1 EBA 1

An initial analysis of the car accidents (data pool of N = 136,954 accidents) showed that, in almost 60% of the cases, the first impact on the car primarily involved in the accident was at the front of the vehicle. These cars with a frontal impact form relevance pool 1. In almost half of the cases in relevance pool 1 (48.8%), the driver braked before the collision. In other words, the accident occurred despite the fact that the driver applied the brakes. Further analyses led to the conclusion that the driver either responded too late to the imminent collision or did not brake strongly enough. A brake assist system that helps the driver with emergency braking could have a positive effect on these accidents in which the driver applies the brakes before the collision (relevance pool 2). Relevance pool 2 was then analyzed on a case-by-case basis to clarify whether these accidents would have been avoidable with EBA 1.

The first step was to define a generic system (Table 3.1) with the first development stage [a] (EBA 1). This system is able to detect emergency braking situations from the way in which the brake and accelerator pedals are operated (but without any environment information) and then to apply maximum braking force within fractions of a second. EBA 1 thus reduces the stopping distance in emergency situations when the driver operates the brake pedal quickly but not forcefully enough. This functionality essentially corresponds to that of the conventional brake assist system, which the EC pedestrian protection directive [10] requires cars to have.

The case-by-case analysis of relevance pool 2 was carried out with the knowledge of these system characteristics of EBA 1. Only those cases were considered in which the driving and collision speed of the car and the condition of the road at the time of the accident were known. EBA 1 was applied in every case on the assumption that in the real accident the car driver did not exceed a defined average deceleration value when braking. Each case was then recalculated on the basis of two further assumptions:

Table 3.1:
System characteristics and derived database attributes for EBA 1

[a] EBA 1	
System description	**Application to the UDB**
▪ Increase of the braking force up to the blocking threshold in the event that the driver initiates emergency braking but does not follow through with it	▪ Only those accidents in which the driver braked and the driving and collision speeds are known ▪ The „case car“ is the vehicle with the primary impact at the front
▪ Maximum deceleration that can be achieved: ▪ 9.5 m/s² (dry road surface); 7 m/s² (wet road surface)	▪ Subcategorization of the accidents by the state of the road surface (dry/wet)
▪ No environment detection	▪ All accident scenarios

- As a result of the system intervention, the maximum possible deceleration would always be achieved (and thus greater deceleration than that achieved by the driver in the original accident).
- The other party involved in the collision would behave in exactly the same way as in the original accident (changing neither direction nor speed).

Table 3.1 shows the system characteristics of EBA 1 and how they are included in the analysis of the UDB.

To determine the safety potential of EBA 1 as a percentage, an adjustment had to be made to the original car data pool in order to establish the same basis for calculations as for relevance pool 2. Cases about which there was no information on the driving and collision speed or about braking before the accident were therefore excluded from both the data pool and relevance pool 1. The theoretical safety potential calculated was 11.4% (Table 3.2). The potential in terms of avoidable casualties is shown in Table 3.3. This shows that 1.8% of fatalities, 6.6% of all seriously injured and 17.2% of all slightly injured in car accidents could be avoided with EBA 1. This includes all those involved in the accident, not just those in the car with the advanced driver assistance system.

However, the specified safety potential (SP_{theor}) is only applicable assuming an ideal driver who operates the brake pedal quickly enough to reach the system's trigger threshold. Experiments [11] have shown, however, that in practice only around half of all drivers are able to activate a brake assist system (corresponding to EBA 1). Consequently, the HMIF value (see Section 2.4) for EBA 1 was set at 0.5, resulting in a more realistic safety potential (SP_{real}) in practice for EBA 1 of 5.7% (see Table 3.2).

In Table 3.2 and Table 3.3 (and in most of the subsequent tables as well), the 95% confidence interval [12] is specified as well as the calculated safety potential.

3.1.2 EBA 2

As already indicated (see Figure 3.2), rear-end collisions are a typical car accident scenario. Taking the data pool of N = 136,954 accidents as a starting point, all rear-end collisions were filtered to determine the safety potential of EBA (relevance pool 1). Relevance pool 1 contains all accidents in which a car had a rear-end collision with another road user (except for pedestrians). Within this group, rear-end collisions with double-track vehicles (cars, trucks, buses) were the dominant type. These

Table 3.2:
Car accidents that would have been avoidable with EBA 1

	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 1	52,226	29,365	14,318	5,960 **11.4 % ± 2.4 %**	**5.7 %**

Table 3.3:
Casualties in car accidents that would have been avoidable with EBA 1

	Number of casualties in the data pool	Avoidable casualties with EBA 1	
		Number	SP_{theor} [%]
Fatalities	5,139	90	**1.8 ± 3.1**
People with serious injuries	40,008	2,646	**6.6 ± 2.2**
People with minor injuries	44,282	7,636	**17.2 ± 3.2**

cases, which it would be possible to address with a more advanced emergency brake assist system than EBA 1 (EBA 2), form relevance pool 2.

The functions of the system applied here (EBA 2) thus describe a second development stage [b] of EBA (Table 3.4). This builds on the functions of EBA 1 and also offers environment detection. The system warns the driver about an imminent collision with the vehicle in front with a time to collision (TTC) of 2.6 seconds and initiates partial braking if the driver does not respond. In addition, from the time the warning is given, the maximum possible braking force is available in case the driver responds to the warning and brakes. However, stationary and single-track vehicles cannot be detected with EBA 2. This limitation was also taken into account in the formation of relevance pool 2. In addition, it was ensured that relevance pool 2 does not contain any rear-end collisions that would be avoidable with EBA 1. The potentials calculated for both these system types can thus be examined separately and added together.

The case-by-case analysis of EBA 2 was based on a calculation that includes, on the one hand, a warning from the system and, on the other, both the braking and non-braking driver. In cases in which the driver did not brake before the collision, only partial braking by the system was assumed. This assumption was made based on systems already in existence that initiate autonomous braking (i.e. without driver intervention) but not emergency braking. In the cases in which the driver braked before the collision, however, the maximum possible deceleration values were assumed. The recalculation of the course of the accident was based on the fact that all it takes to avoid an accident is for the car behind to reduce its speed to that of the vehicle in front of it; it does not have to be brought to a halt. If the vehicle in front had also braked, this was also taken into account. In some cases, information about the driving and collision speed of the vehicle in front was therefore also required for the calculation. The adjustment to the data pool required for this resulted in a database of N = 65,328 cases.

Taking into account the fact that EBA 2 is an enhancement of EBA 1, the theoretical safety potential is 17.8% in terms of avoidable accidents (11.4% + 6.4%) and 8.3% in terms of avoidable serious injuries (Table 3.5 and Table 3.6). The

Table 3.4:
System characteristics and derived database attributes for the second development stage of an EBA (EBA 2)

[b] as for EBA 1 plus:	
System description	**Application to the UDB**
▪ Detection of the environment in front (sensor-independent)	▪ Rear-end collisions with double-track vehicles
▪ Detection of double-track vehicles driving in front (not stationary)	
▪ Speed range: 0-200 km/h	▪ All accidents in which the speed of the “case car” is known and:
▪ Warning at TTC 2.6 seconds, i.e. 2.6 seconds before the calculated impact with the vehicle in front	
▪ Autonomous partial braking with 0.6 g by the system if there is no reaction from the driver at TTC 1.6 seconds	▪ The driver has not braked
▪ If the driver has reacted, a precision braking maneuver or an emergency braking maneuver is performed	▪ The driver has braked

real potential (SP_{real}) is 12.1% in terms of avoidable car accidents.

The theoretical safety potential of EBA 2 for accidents that are avoidable with EBA 2 in relation to all rear-end collisions is 28%.

The comparatively low increase in potential as far as casualties are concerned compared with EBA 1 can be explained by the fact that the existing case material available for analysis does not contain a single fatality in rear-end collisions in which a car collides with a moving double-track vehicle in front of it. Experience shows that serious/fatal injuries are less likely in rear-end collisions than in frontal or side-impact collisions [13, 14]; on the whole, minor injuries are to be expected.

3.1.3 EBA 2*

The EBA 2 system described in Section 3.1.2 is able to detect moving double-track vehicles but not stationary vehicles. However, about 14% of all rear-end collisions are with stationary double-track vehicles.

The third development stage [c] therefore adds a single parameter to the functionality of EBA 2 (EBA 2*). This puts the system in the position of being able to detect stationary double-track vehicles and trailers. To analyse relevance pool 2 on a case-by-case basis, the calculation method used for EBA 2 was adjusted to take into account braking the car to bring it to a halt.

The enhancement of the functionality of EBA 2 to bring it to the level of EBA 2* increased the theoretical accident

Table 3.5:
Accidents that would have been avoidable with EBA 2, using EBA 1 as a basis

Avoidable car accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 1	52,226	29,365	14,318	5,960 [a]	
				11.4 % ± 2.4 %	5.7 %
EBA 2	65,328	23,640	7,409	4,213 [b]	
				(6.4 %)	(6.4 %)
				17.8 % ± 2.9 %	**12.1 %**

Table 3.6:
Avoidable casualties with EBA 2, using EBA 1 as a basis

	Avoidable casualties with EBA 1	Additional benefit of EBA 2	SP_{theor}
Fatalities	1.8 %	-	**1.8 %**
People with serious injuries	6.6 %	1.7 %	**8.3 %**
People with minor injuries	17.2 %	13.8 %	**31.0 %**

avoidance potential by 1.8% to a total of 19.6% (Table 3.7); the real safety potential (SP_{real}) increased to 13.9%. There is also a slight increase in potential compared to EBA 2 in terms of avoidable casualties (Table 3.8). This can be explained by the rather conservative system concept. The group of rear-end collisions with stationary vehicles also includes collisions at the back of a tailback. Given the high speeds at which some of these cars approach, these accidents can only be avoided if the system intervention (and warning, in particular) takes place at a very early stage. Nevertheless, the detection of double-track vehicles together with a warning and autonomous braking increases the theoretical safety potential of emergency brake assist systems from 11.4% (EBA 1) to almost 20% (EBA 2*).

3.1.4 EBA 2*P

Accidents involving a car and unprotected road users (see Figure 3.1 and 3.2) also come up frequently in the car accident statistics (N = 136,954). These accidents are particularly critical because pedestrians and cyclists are unprotected in collisions with cars and thus often suffer serious or fatal injuries. Section 3.1.4 deals exclusively with accidents involving pedestrians, and Section 3.1.5 covers collisions between cyclists and cars. Accidents involving pedestrians make up around 14% of all car accidents and around 20% of all car accidents involving fatalities or serious injuries in the case material.

Table 3.7:
Accidents that would have been avoidable with EBA 2*, using EBA 1 and EBA 2 as a basis

Avoidable car accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 1	52,226	29,365	14,318	5,960	
				11.4 % ± 2.4 % [a]	5.7 %
EBA 2	65,328	23,640	7,409	4,213	
				(6.4 %) [b]	(6.4 %)
				17.8 % ± 2.9 %	12.1 %
EBA 2*	65,328	23,640	8,602	1,193	
				(1.8 %) [c]	(1.8 %)
				19.6 % ± 3.0 %	**13.9 %**

Table 3.8:
Casualties that would have been avoidable with EBA 2*, using EBA 1 and EBA 2 as a basis

	Avoidable casualties with EBA 2	Additional benefit of EBA 2*	SP_{theor}
Fatalities	1.8 %	0.4 %	**2.2 %**
People with serious injuries	8.3 %	1.1 %	**9.4%**
People with minor injuries	31.0 %	4.7 %	**35.7 %**

As with EBA 1, to calculate the potential of the new system (EBA 2*P), a data pool was used that contained only accidents in which the driving and collision speeds of the car were known (N = 52,226 accidents). Relevance pool 1 (only accidents in which the initial impact was at the front of the car) was used again, as for EBA 1. Relevance pool 2 contains only collisions between cars and pedestrians. Here, too, care was taken not to include those cases that were already avoidable with EBA 1. Also excluded were cases in which the collision with the pedestrian was the result of the car's previous collision with another road user. It can be assumed that pedestrian detection will no longer work reliably if the collision with the pedestrian is preceded by an initial impact with another road user or an obstacle.

In a similar approach to that used for EBA 1 to EBA 2*, a fourth EBA development stage [d] was defined. The additional functionality allows pedestrians to be detected and is referred to below as EBA 2*P, where P stands for pedestrian (Table 3.9). It was assumed that the system detects all kinds of pedestrians, does not warn the driver but executes emergency braking 0.5 seconds before the calculated impact with the front of the car (TTC = 0.5 seconds) and brings the car to a halt. However, if the driver reacts to the imminent collision independently, the maximum braking force is available from this point.

Due to the limits imposed on the case material in relevance pool 1 (only accidents where the initial impact was at the front of the car), collisions with pedestrians in which the pedestrian was hit by the side of the car (wing or wing mirror) or run over by a front wheel were not included. This can happen, for example, in turning-off accidents or when a child runs into the side of the car from between two parked cars at the side of the road. The figures specified below therefore do not indicate the full potential of pedestrian detection functionality. The case-by-case analysis resulted in two conspicuous findings. The first was that in most cases in which the driver managed to brake before the collision, little deceleration was achieved, an indication that the pedestrian was not perceived as being in a critical situation until very late. The second was that over 70% of all collisions between cars and pedestrians took place when the car was traveling at up to 30 km/h. This indicates that the potential for avoiding an accident is high with EBA 2*P, since, given emergency braking and maximum deceleration (spatial avoidability), half a second is generally enough time to come to a halt before the collision location.

Based on the data pool of 52,226 cases, the theoretical avoidance potential for EBA 2*P is a total of 13,909 cases. Table 3.10 shows the percentage shares of the four sets of functions examined thus far both separately ([a, b, c, d])

Table 3.9:
System characteristics and derived database attributes for the fourth development stage of an EBA (EBA 2*P)

[d] as for EBA 2* plus:	
System description	**Application to the UDB**
▪ Sensor-independent detection of all kinds of pedestrians (including those pushing bicycles and wheelchair users, for example)	▪ All car-pedestrian accidents
▪ Also works in the dark	
▪ All speed ranges	▪ All accidents in which the speed of the car is known and:
▪ Autonomous emergency braking at TTC = 0.5 seconds	▪ The driver did not brake
▪ Maximum increase of the braking force at TTC = 0.5 seconds	▪ The driver braked

and in total. With pedestrian detection, a further 4.9% of all car accidents could be avoided. Overall, an EBA system could prevent almost a quarter of all car accidents (24.5%) with the following development stages:

- EBA 1: braking assistance for the actively braking driver [a]
- EBA 2: as for EBA 1 plus detection of double-track vehicles driving in front [b]
- EBA 2*: as for EBA 2 plus detection of stationary double-track vehicles [c]
- EBA 2*P: as for for EBA 2* plus detection of pedestrians [d].

Since it is not meaningful to relate the number of avoided casualties in car-pedestrian accidents to the total number of casualties in all car accidents, the EBA 2*P potential was calculated in relation to car/pedestrian accidents only (Table 3.11). With a data pool of N = 9,615 cases (only those cases in which the driving and collision speeds of the car are known), there is a theoretical accident avoidance potential of 35.1%.

Table 3.10:
Accidents that would have been avoidable with EBA 2*P, using EBA 1, EBA 2 and EBA 2* as a basis – in relation to all car accidents

Avoidable car accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 1	52,226	29,365	14,318	5,960	
				11.4 % ± 2.4 % [a]	5.7 %
EBA 2	65,328	23,640	7,409	4,213	
				(6.4 %) [b]	(6.4 %)
				17.8 % ± 2.9 %	12.1 %
EBA 2*	65,328	23,640	8,602	1,193	
				(1.8 %) [c]	(1.8 %)
				19.6 % ± 3.0 %	13.9 %
EBA 2*FG	52,226	29,365	xxxxx	2,543	
				(4.9 %) [d]	(4.9 %)
				24.5 % ± 3.4 %	**18.8 %**

Table 3.11:
Car-pedestrian accidents that would have been avoidable with EBA 2*P, using EBA 1 and pure pedestrian detection as a basis – in relation to all car-pedestrian accidents

Avoidable car-pedestrian accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 2*P	9,615	-	-	3,383	
				35.1 % ± 8.3 %	**30.7 %**

Table 3.12:
Casualties that would have been avoidable with EBA 2*P, using EBA 1 and pure pedestrian detection as a basis – in relation to all car-pedestrian accidents

Avoidable casualties with EBA 2*P	Number of casualties in the data pool (car-pedestrian accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	1,345	282	**21.0 ± 19.4**
People with serious injuries	14,172	2,127	**15.0 ± 5.2**
People with minor injuries	3,309	1,472	**44.5 ± 15.0**

The potential with regard to casualties was calculated based on the same principle. 21% of fatalities and 15% of seriously injured were found to be avoidable (Table 3.12). The fatalities were exclusively pedestrians. However, just over 1% of the people with avoidable serious injuries (N = 2,127) and around 10% of those with avoidable slight injuries (N = 1,472) were car occupants. These injuries were mostly caused by subsequent collisions of the car (with parked vehicles, for example) after the collision with the pedestrian. Pedestrian detection thus has additional value in this respect because injuries to car occupants can be avoided as well as injuries to pedestrians.

3.1.5 EBA 2*C

The second group of accidents between cars and unprotected road users consists of car-cyclist accidents. These make up a considerable portion of the relevant data pool: almost 25%. The data pool and relevance pool were identical with those in Section 3.1.1 (EBA 1) and Section 3.1.4 (EBA 2*P). The car-cyclist collisions formed relevance pool 2.

The system investigated here was referred to as EBA 2*C (where C stands for cyclist), is the fifth development stage [e] of the emergency brake assist system and builds on the functions of EBA 1 to EBA 2*P (Table 3.13). It also

Table 3.13:
System characteristics and derived database attributes for the fifth development stage [e] of an EBA (EBA 2*C)

[e] as for EBA 2* plus:	
System description	**Application to the UDB**
▪ Sensor-independent detection of all cyclists	▪ All car-cyclist accidents
▪ Also works in the dark	
▪ All speed ranges	▪ All accidents in which the speed of the car is known and:
▪ Autonomous emergency braking at TTC = 0.5 seconds	▪ The driver did not brake
▪ Maximum increase of the braking force at TTC = 0.5 seconds	▪ The driver braked

enables cyclists to be detected. EBA 2*C does not give a warning; it executes emergency braking 0.5 seconds before the calculated impact with the front of the car (TTC = 0.5 seconds) and brings the car to a halt. However, if the driver reacts to the imminent collision independently, the maximum braking force is available from this point.

It should be noted here that because of the limits placed on the data pool (only accidents in which the initial collision is with the front of the vehicle), collisions in which the cyclist collided with the side of the car were not included. The figures specified below therefore do not indicate the full potential of cyclist detection functionality.

With the combined functionality of EBA 1, EBA 2, EBA 2*, EBA 2*P and EBA 2*C (Table 3.14), the safety potential of an emergency brake assist system in the fifth development stage [e], expressed as the percentage of all avoidable car accidents, is 43.4%.

It is impressive that – of all the car accidents with a known driving and collision speed (N = 52,226) – 18.9% (N = 9,889 accidents) were avoidable with cyclist detection alone and EBA 1 as a basis (see Table 3.14). The safety potential of EBA 2*C in relation to all car-cyclist accidents (N = 21,767) is 45.4% (Table 3.15).

Table 3.14:
Accidents that would have been avoidable with EBA 2*C, using EBA 1, EBA 2, EBA 2* and EBA 2*P as a basis – in relation to all car accidents

Avoidable car accidents	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 1	52,226	29,365	14,318	5,960	
				11.4 % ± 2.4 % [a]	5.7 %
EBA 2	65,328	23,640	7,409	4,213	
				(6.4 %) [b]	(6.4 %)
				17.8 % ± 2.9 %	12.1 %
EBA 2*	65,328	23,640	8,602	1,193	
				(1.8 %) [c]	(1.8 %)
				19.6 % ± 3.0 %	13.9 %
EBA 2*P	52,226	29,365	xxxxx	2,543	
				(4.9 %) [d]	(4.9 %)
				24.5 % ± 3.4 %	18.8 %
EBA 2*C	52,226	29,365	12,716	9,889	
				(18.9 %) [e]	(18.9 %)
				43.4 % ± 4.5 %	**37.7 %**

Table 3.15:
Accidents that would have been avoidable with EBA 2*C, using EBA 1 and pure cyclist detection as a basis – in relation to all car-cyclist accidents

Avoidable car-cyclist accidents	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
EBA 2*C	21,767	12,716	12,716	9,889	
				45.4 % ± 7.4 %	**45.4 %**

Table 3.16:
Casualties that would have been avoidable with EBA 2*C, using EBA 1 and pure cyclist detection as a basis – in relation to all car-cyclist accidents

Avoidable casualties with EBA 2*C	Number of casualties in the data pool (car-cyclist accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	166	0	**0**
People with serious injuries	14,464	6,850	**47.4 ± 9.1**
People with minor injuries	7,780	3,094	**39.8 ± 12.7**

As far as casualties are concerned, there is potential for avoiding only minor and serious injuries (Table 3.16). Almost half of all seriously injured and almost 40% of all slightly injured could be avoided with EBA 2*C. The case material did not include any casualties among car occupants. The relatively small number of fatalities among cyclists in the data pool (under 1%) occurred in dramatic cases involving cars with high collision speeds (>50 km/h). The defined system types would not be able to prevent these accidents, but they could have a positive effect. The recalculation of the course of the accidents revealed that EBA 2*C would have reduced the collision speed in some cases by up to 20 km/h and thus given cyclists who were killed a chance of survival.

3.2 Lane departure warning system – description and safety potential

Relevance pool 1 for the lane departure warning system consists of accidents in which a car departed from its lane or came off the road. For relevance pool 2, accidents in the vicinity of roadworks, tight bends, etc. are filtered out, since it cannot be guaranteed that the system would work reliably in such cases. The case-by-case analysis was carried out on relevance pool 2 (7,207 cases).

The functions of the lane departure warning system investigated here are based on systems already available on the market. Sensors detect the lane markings on the road surface on the left and right of the lane being used by the vehicle and provide a control unit with data on the vehicle's current course. If the vehicle deviates from the required course (i.e. if the vehicle crosses the lane marking or approaches it in such a way as to indicate that it is about to cross it), the system issues a visual, audible or haptic warning. Table 3.17 shows the system characteristics and their application in the UDB.

An HMIF value of 0.5 was specified in [2] for determining the achievable safety potential of a lane departure warning system as defined here. The reason for this is that a low magnitude haptic warning is selected in order to prevent frequent false warnings from being perceived as a nuisance. Acoustic warnings, on the other hand,

Table 3.17:
System characteristics and derived database attributes for the lane departure warning system

Lane departure warning system	
System description	**Application to the UDB**
▪ Detection of the lane marking(s) by means of sensors and cameras (range: approx. 50 m) ▪ 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 km/h and 200 km/h ▪ Warning issued to the driver at TLC > 0 s (TLC = time to lane change, speed-dependent) ▪ No intervention in the steering by the system ▪ Continues to work in bends provided that the radius is at least 200 m	▪ Accidents caused by inadvertently coming off the road (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)
▪ Only works if there is at least one lane marking	▪ Assumption: there was at least one lane marking 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 included
▪ 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 included

are not sufficiently specific, and direction-dependent acoustic warnings do not deliver any benefit according to [2].

Lane departure warning systems are being fitted increasingly in new vehicles, including in midrange and compact cars (i.e. vehicles that account for a high number of new registrations). Against this background, the safety potential determined here is highly significant, especially since the design of the generic lane departure warning system investigated here approximately corresponds to current systems. The realizable safety potential (SP_{real}) of a lane departure warning system is 2.2% (Table 3.18) but could theoretically be twice that given a system designed to optimum effect. It is clear – as in the case of EBA 1 – how important the human-machine interface is when it comes to system design.

The potential for avoiding casualties is relatively high. A theoretical potential for avoiding fatalities of up to 10% can be achieved, whereas for seriously injured the avoidance potential is 7% (Table 3.19). This can be

Table 3.18:
Accidents that would have been avoidable with a lane departure warning system

Avoidable car accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
Lane departure warning system	136,954	17,848	7,207	6,005	3,003
				4.4 % ± 1.0 %	**2.2 %**

Table 3.19:
Casualties that would have been avoidable with a lane departure warning system

Avoidable casualties with a lane departure warning system	Number of casualties in the data pool	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	10,768	1,087	**10.1 ± 4.6**
People with serious injuries	97,497	7,235	**7.4 ± 1.4**
People with minor injuries	130,075	7,410	**5.7 ± 1.2**

explained by the fact that accidents in which the vehicle comes off the road generally result in serious injuries or fatalities.

On the basis of all the accidents in the database that are the result of drivers inadvertently leaving their lane or coming off the road (N = 17,848), the safety potential that can be realized (SP_{real}) for the lane departure warning system is 16.8% (SP_{theor} = 33.6%).

3.3 Lane change assist system – description and safety potential

Overtaking accidents and accidents that occur in connection with intentional lane changes form a further important group of accidents (see Figure 3.2). A lane change assist system that was divided into two subsystems was assessed for these accidents. The first system warns of oncoming traffic when overtaking, and the second warns of vehicles approaching from behind in the blind spot during an intentional overtaking or lane change maneuver.

3.3.1 Blind spot warning system

To analyze the safety potential of a blind spot warning system, relevance pool 1 was formed by taking those accidents in which a collision occurred during or after a lane change (7,403 cases). For relevance pool 2, only those accidents were taken into account in which the party changing lane was hit from the rear or at the side and was driving at a speed of at least 10 km/h.

The system characteristics were defined, taking into account the fact that a blind spot warning system is already fitted in many new vehicles. The design of the system investigated here approximately corresponds to that of currently available systems. The system uses sensors to monitor the areas at the side of the vehicle. It detects existing or approaching road users (double-track vehicles and motorcycles) in the neighboring lane that are travelling up to 20 km/h slower or up to 70 km/h faster than its own vehicle (Table 3.20).

The case-by-case analysis of relevance pool 2 was carried out assuming an ideal driver and resulted in a theoretical avoidance potential (SP_{theor}) of 1.7% (Table 3.21). The HMIF value for a blind spot detection system is assumed to be 0.8 in accordance with [2]. The reason for this is that the system assumes that the driver looks in a particular direction, which does not always happen. This applies, for instance, to systems designed with a flashing signal on the wing mirror.

The analyses revealed a relatively low potential in terms of avoiding casualties (Table 3.22). As far as fatalities and serious injuries are concerned, the potential is 1-2%. For minor injuries it is 3%.

3.3.2 Overtaking assistant

The official statistics [5] show that roads outside built-up areas represent the greatest safety problem in Germany with respect to fatal accidents. In this context, accidents involving oncoming traffic loom large. In such situations,

Table 3.20:
System characteristics and derived database attributes for the blind spot warning system

Blind spot warning system	
System description	**Application to the UDB**
▪ Monitoring of the areas behind and to the side of the vehicle ▪ Detection of existing or approaching double-track vehicles and motorcycles that are up to 20 km/h slower or 70 km/h faster.	▪ Collisions with approaching vehicles when pulling out or with overtaken vehicles when pulling in again (accident types in the magnitude of hundreds) ▪ ADAS vehicle with primary impact to the rear or side (right or left)
▪ System active as of a speed of 10 km/h	▪ Accidents caused by changing lanes from a standing start are not taken into account
▪ Warning issued to the driver when the indicator is set if a lane change (overtaking maneuver) is judged to be critical	▪ Assumption: indicator is set for each lane change (overtaking maneuver)

Table 3.21:
Accidents that would have been avoidable with a blind spot warning system

Avoidable car accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
Blind spot warning system	136,954	7,403	3,582	2,282	1,826
				1.7 % ± 0.5 %	**1.4 %**

Table 3.22:
Casualties that would have been avoidable with a blind spot warning system

Avoidable casualties with a blind spot warning system	Number of casualties in the data pool	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	10,768	169	**1.6 ± 0.5**
People with serious injuries	97,497	1,173	**1.2 ± 1.6**
People with minor injuries	130,075	3,849	**3.0 ± 0.9**

an overtaking assistant would be desirable to help the driver. A start was made on this in the PRORETA 2 project [15].

Taking the data pool of N = 136,954 accidents as a starting point, relevance pool 1 was formed in the UDB (N = 7,403 cases). These were all the cases in which the accident occurred as a result of a lane change. All overtaking accidents caused by a car were selected from this pool, thus forming relevance pool 2 (N = 2,222 accidents). The system characteristics of the overtaking assistant are described in Table 3.23. Here, too, there is a critical assumption that the car driver reacts ideally to the system's warning and abandons an attempt to overtake. Under the assumed conditions, the course of each accident was examined to ascertain whether it would have been avoidable.

The analysis revealed that 71% of all accidents involving a car overtaking (relevance pool 2) could have been avoided with the generic system described here. In relation to all car accidents, this amounts to a safety potential (SP_{theor}) of 1.2% (Table 3.24). A greater benefit was ascertained for fatal accidents (see Table 3.25): 5% of all fatalities and 3% of serious injuries resulting from car accidents could have been avoided by an overtaking assistant.

The overtaking assistant is intended to provide pointers for the future here. The safety potential determined shows that despite the considerable technical outlay required to implement the function, only a relatively low safety potential can be expected. Moreover, the overtaking assistant described in Table 3.23 was not assessed on the basis of the HMIF because there are currently no concrete, scientific findings with respect to such a system.

3.4 Reverse assist system – description and safety potential

As indicated in Section 3.1.4, car-pedestrian accidents play a significant role in the car accident statistics. Collisions when a car is reversing are a special case. Taking a new data pool of 24,378 cases as a starting point (all car-pedestrian accidents), relevance pool 1 was formed (N = 3,867 cases). This consists of all collisions between cars and pedestrians caused by reversing. In the second step, all cases were selected in which the pedestrian was hit by the back of the car (relevance pool 2, consisting of N = 3,151 cases).

Table 3.23:
System characteristics and derived database attributes for the overtaking assistant

Overtaking assistant	
System description	**Application to the UDB**
▪ Monitoring of the area in front of the vehicle (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…") ▪ The "case car" is the vehicle with the reference number 01 (party responsible for the accident)
▪ Detection of oncoming double-track vehicles and motorcycles	
▪ Calculation of the theoretical collision time using the speeds and distances between the vehicles (without taking into account the course of the road, e.g. humps)	
▪ 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

Table 3.24:
Accidents that would have been avoidable with an overtaking assistant

Avoidable car accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
Overtaking assistant	136,954	7,403	2,222	1,583	-
				1.2 % ± 0.5 %	**-**

Table 3.25:
Casualties that would have been avoidable with an overtaking assistant

Avoidable casualties with an overtaking assistant	Number of casualties in the data pool	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	10,768	534	**5.0 ± 3.3**
People with serious injuries	97,497	2,772	**3.0 ± 0.9**
People with minor injuries	130,075	1,265	**1.0 ± 0.5**

Table 3.26:
Car-pedestrian accidents that would have been avoidable with a reverse assist system

Avoidable car-pedestrian accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}	SP_{real}
Reverse assist system	24,378	3,867	3,151	3,151	-
				12.9 % ± 4.1 %	**-**

Table 3.27:
Casualties that would have been avoidable with a reverse assist system in car-pedestrian accidents

Avoidable casualties with a reverse assist system	Number of casualties in the data pool (car-pedestrian accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	1,702	0	**0**
People with serious injuries	18,757	2,401	**12.8 ± 4.5**
People with minor injuries	6,889	780	**11.3 ± 6.9**

The generic system for accident avoidance defined here includes an advanced reversing camera with functionality that follows on from systems already under development. Sensors and a video camera scan the area behind the car. If there is a pedestrian in the defined area behind the stationary car, the system warns the driver when the reverse gear is selected and prevents the car from moving. If a pedestrian moves into the area behind the car during reversing and the system detects an imminent collision, the system emits an acoustic warning signal and initiates autonomous braking.

Due to the very low speeds of the cars when reversing, it was assumed in the case-by-case analysis that there was a high probability of all cases in relevance pool 2 (N = 3,151) being avoided with the reverse assist system defined here. This corresponds to an accident avoidance potential of almost 13% in relation to all car-pedestrian accidents (Table 3.26). As far as casualties are concerned, 12.8% of seriously injured pedestrians and 11.3% of pedestrians with minor injuries would not have been injured (Table 3.27). There were no pedestrian fatalities in relevance pool 2.

4 ADASs for trucks

The underlying case material consists of n = 443 truck accidents involving 570 trucks from 2002 to 2006. Using the method described in Section 2.2, these were extrapolated to N = 18,467 accidents involving N = 22,863 trucks. Only accidents involving at least one truck with a gross vehicle weight of at least 5 tonnes were included. Examples of such trucks are shown in the photographs in Appendix 1. The breakdown of the other parties involved in the accidents with the trucks in the accident material is shown in Figure 4.1. Only the main collision parties are shown (i.e. those road users with which the truck had the most serious collision involving the most personal injury). Cases involving trucks not directly involved (e.g. minor subsequent collisions between the truck and a vehicle already involved in a serious accident) are not shown in Figure 4.1. Collisions between trucks and cars account for the largest share of these accidents (around 63%), followed by collisions between trucks (16%) and with cyclists (7%), motorcyclists (6%) and pedestrians (6%). Truck accidents with no third-party involvement account for only 1% of the UDV's accident statistics and are thus clearly underrepresented compared with the official statistics [5]. This can be attributed to the fact that the UDB is fed third-party claims, and accidents with no third-party involvement only appear in the accident material when a third party is affected.

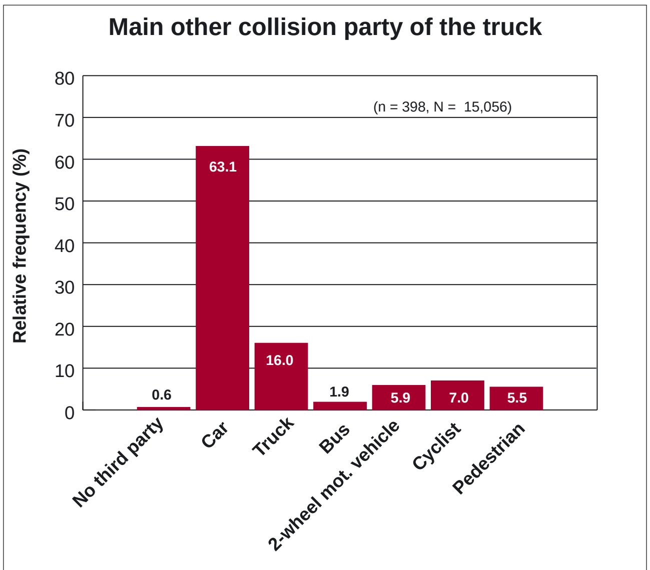


Figure 4.1:
Truck accidents with no third-party involvement and main collision parties of trucks in the available accident material

In the same way that the most common types of car accident were determined in Chapter 3, all truck accidents were categorized by accident situation and ranked (Figure 4.2).

The most common accidents in the truck accident statistics are rear-end collisions, which account for almost 32% of all truck accidents. These could be addressed with an emergency brake assist system. Scenarios (3) and (5) together account for the second largest share of truck accidents (23.6%). These are the scenarios in which a lane keeping assist system could have a positive effect.

The truck accident material was analyzed with regard to the safety potential of the following advanced driver assistance systems:

- Emergency brake assist system (EBA) 1 + 2
- Turning assistant (for pedestrians and cyclists)
- Lane departure warning system
- Blind spot warning system
- ESC
- Reverse assist system (for pedestrians)

4.1 Truck emergency brake assist system 1 (EBA 1) - description and safety potential

This part of the study examined only emergency brake assist systems that address rear-end collisions exclusively and are thus based very much on the emergency brake assist systems already available on the market [20]. Two development stages were defined: emergency brake assist system 1 responds only to double-track vehicles driving in front of the truck, while emergency brake assist system 2 can also detect stationary double-track vehicles.

4.1.1 Truck emergency brake assist system 1 (EBA 1)

Taking the truck data pool as a basis (N = 18,467 accidents), the first step was to select all rear-end collisions in which a

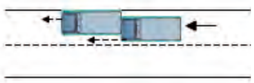
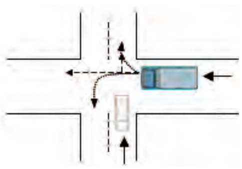
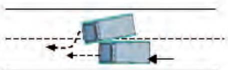
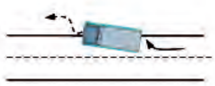
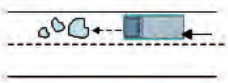
The most frequent accident scenarios $N_{data\ pool} = 18{,}467$ [100 %]		Per-cent-age share
(1) Collision with another vehicle that is: ▪ driving or stationary in front ▪ pulling away, stopping or standing in stationary traffic		31.6
(2) Collision with another vehicle that is turning into or crossing a road at an intersection		22.3
(3) Collision with another vehicle travelling in the same direction and at the side of the first vehicle		18.5
(4) Collision with an oncoming vehicle		14.3
(5) Coming off the road to the right/left		5.1
(6) Collision between a vehicle and pedestrian		4.4
(7) Collision with an obstacle on the road		0.4

Figure 4.2:
Frequency of different accident scenarios in the truck data pool

truck collided with the rear end of another vehicle without a preceding collision with another road user (relevance pool 1). This pool was then further reduced in size by selecting accidents in which trucks collided with moving double-track vehicles (relevance pool 2). A case-by-case analysis was then carried out on these to ascertain the potential of emergency brake assist system 1.

The system investigated here is an emergency brake assist system of the current generation. It is a fully automatic system that warns the driver when there is acute danger, initiates partial braking and, if the driver does not react, emergency braking to bring the vehicle to a halt. It responds only to moving vehicles. The system characteristics of EBA 1 are summarized in Table 4.1.

The case-by-case analysis was carried out based on a simplified, conservative calculation on the assumption that the driver did not react to the system's warning in any of the cases. Each case was then recalculated and only categorized as avoidable if, taking into account a warning and partial braking time of a second in each case and, where necessary, emergency braking, the truck would have braked to the speed of the vehicle in front and avoided a collision with it. This calculation was thus carried out purely theoretically and on the assumption that any adaptive cruise control (ACC) system was switched off, because the ACC uses the same sensors as the emergency brake assist system in practice and would normally intervene before it and initiate partial braking. For this reason, and due to the assumption that the driver did not react, the figures shown below represent the lower limit for the maximum avoidance potential to be expected for emergency brake assist system 1.

With an adjusted data pool of N = 12,273 cases (only accidents in which the truck's driving speed is known), the safety potential of EBA 1 was calculated as 6.1% in terms of avoidable accidents (Table 4.2) and 4% in terms of both avoidable fatalities and avoidable serious injuries (Table 4.3). 26.5% of all truck rear-end accidents (relevance pool 1: N = 2,815 cases) were found to be avoidable.

Table 4.1:
System characteristics and derived database attributes for the truck emergency brake assist system of the current generation (EBA 1)

EBA 1	
System description	**Application to the UDB**
▪ Environment detection for the road ahead (use of the radar sensors of the adaptive cruise control system)	▪ Rear-end collisions with double-track vehicles
▪ Detection of double-track vehicles driving in front (not stationary)	
▪ Maximum deceleration that can be achieved: 7 m/s² (dry road surface); 6 m/s² (wet road surface)	▪ Subcategorization of the accidents by the state of the road surface (dry/wet)
▪ Speed range: from 15 km/h; minimum speed of the vehicle in front: 10 km/h	▪ All accidents in which the speed of the truck that collides with the rear end of the vehicle in front is known
▪ Does not work when vehicles suddenly pull in immediately in front of the truck	
▪ The system warns the driver at TTC 3.3 seconds	
▪ Additional partial braking with 30% of the maximum braking force at TTC 2.3 seconds	
▪ Emergency braking with maximum braking force at TTC 1.3 seconds	

Table 4.2:
Truck accidents that would have been avoidable with EBA 1

Avoidable truck accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
EBA 1	12,273	2,815	1,239	746
				6.1 % ± 2.7 %

Table 4.3:
Casualties that would have been avoidable with EBA 1

Avoidable casualties with EBA 1	Number of casualties in the data pool (all truck accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	2,509	88	**3.5 ± 4.8**
People with serious injuries	8,635	345	**4.0 ± 2.5**
People with minor injuries	14,927	1,112	**7.4 ± 2.6**

4.1.2 Truck emergency brake assist system 2 (EBA 2)

A glance at relevance pools 1 and 2 in Table 4.2 shows that collisions with the rear end of stationary vehicles account for a large share of all truck rear-end collisions (56%). A new relevance pool 2 (N = 1,576 cases) was therefore formed from the existing relevance pool 1. This consists of all cases in which a truck collided with the rear end of stationary double-track vehicles. This pool was further investigated to ascertain the effect of an advanced emergency brake assist system 2 (EBA 2).

In addition to having all the functions of EBA 1, the EBA 2 system also detects stationary double-track vehicles. The calculation method for the safety potential of EBA 1 was therefore adjusted so that, in order to avoid an accident, it was necessary to brake and bring the truck to a halt without colliding with the vehicle in front.

Because it also detects stationary vehicles, the accident avoidance potential of EBA 2 is significantly higher than that of EBA 1; the safety potential is doubled to 12% (Table 4.4). There is a potential of 4.9% in terms of avoidable fatalities (Table 4.5) and 8.4% for avoidable serious injuries. The greatest impact of EBA 2 is on minor injuries, which are reduced by 17.5%. Over half (52.3%) of all truck rear-end accidents were found to be avoidable with emergency brake assist system 2.

Table 4.4:
Accidents that would have been avoidable with EBA 2, using EBA 1 as a basis

Avoidable truck accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
EBA 1	12,273	2,815	1,239	746
				6.1 %
EBA 2	12,273	2,815	1,576	725
				(5.9 %)
				12.0 % ± 3.8 %

Tabelle 4.5:
Casualties that would have been avoidable with EBA 2, using EBA 1 as a basis

Avoidable casualties with EBA 2	Number of casualties in the data pool (all truck accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	2,509	123	**4.9 ± 5.6**
People with serious injuries	8,635	723	**8.4 ± 3.6**
People with minor injuries	14,927	2,614	**17.5 ± 3.8**

4.2 Turning assistant – description and safety potential

A further analysis of the accident material (N = 18,467 cases) revealed that around 13% of truck accidents happen when the truck is turning into another road. 80% of these cases involve a collision between the truck and a cyclist (C) or pedestrian (P). Cyclist and pedestrian collisions account for a total of around 10% of all serious truck accidents in the UDB. In order to analyze a suitable advanced driver assistance system for turning maneuvers, all turning-off accidents of trucks were grouped together (relevance pool 1). Collisions with cyclists (N = 641 cases) and pedestrians (N = 170 cases) were selected from this pool to form relevance pool 2.

The generic system characteristics are the characteristics of the prototype turning assistant already launched by MAN [18]. However, additional functions were also assumed (Table 4.6). By means of sensors the system monitors the areas in front of and at the side of the truck (Figure 4.3) and warns the truck driver if a pedestrian or cyclist is approaching the truck when it is pulling away or turning into another road. The turning assistant prevents the truck from pulling away if there is a pedestrian in front of the truck at the time (e.g. at a traffic light).

Table 4.6:
System characteristics and derived database attributes for the truck turning assistant for cyclists and pedestrians

Turning assistent (C + P):		
	System description	**Application to the UDB**
	▪ Environment detection in front (sensor-independent)	▪ Turning-off accidents with cyclists and pedestrians
Detection of...	▪ Cyclists cycling slowly on the right (i.e. nearside) of the vehicle that are overtaken by the truck with little clearance at the side	▪ All truck turning-off accidents with pedestrians and cyclists, accidents with pedestrians who cross in front of a truck that is stationary or pulling away and accidents in which a cyclist is overtaken by a truck
	▪ Cyclists coming towards the truck from behind when the truck is turning off into a road on the right (i.e. nearside)	
	▪ Cyclists who take up a position on the right (i.e. nearside) of the stationary truck	
	▪ Pedestrians who approach a stationary or turning truck from the side	
	▪ Pedestrians who are in front of the truck when it pulls away	
	▪ No potential when trucks turn off into a road on the left (i.e. the offside)	

Figure 4.3:
Typical accident scenarios that could be avoided with the truck turning assistant for cyclists and pedestrians

An ideal driver who reacts to the warning and brakes accordingly was again assumed for the purpose of the case-by-case analysis. The course of each accident was reexamined, and it was assessed whether, given the assumptions made (e.g. driver initiates emergency braking, system prevents pulling away), the accident was avoidable. Avoidability was also analyzed in terms of whether or not the driver made any mistakes. If the accident occurred, for example, because the cyclist swerved while being overtaken and fell after contact with the truck/trailer (i.e. the truck driver could have done nothing to stop it), the accident was considered to be unavoidable.

In relation to all truck accidents, the theoretical avoidance potential for the turning assistant is 4.4% (Table 4.7). These accounted for 42.8% of all accidents between trucks and cyclists/pedestrians (Table 4.8). As far as casualties are concerned, 31.4% of fatalities, 43.5% of serious injuries and 42.1% of minor injuries in these accidents would have been avoidable (Table 4.9). This gives a clear indication of the great benefits of the

Table 4.7:
Truck accidents that would have been avoidable with the turning assistant for trucks in relation to all truck accidents

Avoidable truck accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
Turning assistant	18,467	2,414	811	811
				4.4 % ± 1.9 %

Table 4.8:
Truck accidents that would have been avoidable with the turning assistant for trucks in relation to all accidents involving trucks and pedestrians/cyclists

Avoidable accidents involving trucks and pedestrians/cyclists with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
Turning assistant	1,892	854	811	811
				42.8 % ± 13.2 %

Table 4.9:
Casualties that would have been avoidable with the turning assistant for trucks in relation to all accidents involving trucks and pedestrians/cyclists

Avoidable casualties with the turning assistant	Number of casualties in the data pool (all accidents involving trucks and pedestrians/cyclists	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	369	116	**31.4 ± 25.2**
People with serious injuries	1,512	658	**43.5 ± 15.2**
People with minor injuries	171	72	**42.1 ± 43.3**

system, particularly given that over 90% of the cyclists and pedestrians involved in these accidents were killed or seriously injured. 4% of the fatalities and 5% of all serious injuries resulting from all truck accidents would have been avoidable with the turning assistant.

4.3 Lane change assistant/blind spot warning system – description and safety potential

In order to analyze a lane change assistant or lane departure warning system (see Section 4.4), all truck accidents caused by changing lane were identified. These accidents are shown in scenarios (3) and (5) in Figure 4.2. For further analysis, however, a relevance pool (relevance pool 1) was formed, which describes these accident scenarios in a more concrete form. It contains only cases in which a collision was caused by the truck driver changing lane either intentionally or unintentionally. Relevance pool 1 (N = 2,297) accounts for 12% of the underlying data pool (N = 18,467). In this section, the potential is determined for the first group of cases, which occurred as a result of an intentional change of lane. These cases (N = 1,452) form relevance pool 2 and could be addressed by means of a suitable blind spot warning system.

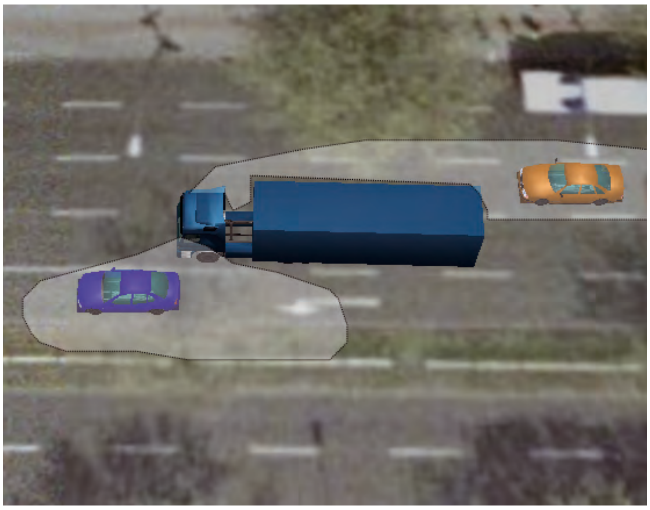


Figure 4.4:
Schematic view indicating how a blind spot warning system for trucks works

Table 4.10:
Accidents that could be addressed with the truck blind spot warning system

Truck accidents that could be addressed with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
Blind spot warning system	18,467	2,297	1,452	1,452
				7.9 % ± 2.6 %

Table 4.11:
Casualties that could be addressed with the truck blind spot warning system

Casualties that could be addressed with the blind spot warning system	Number of casualties in the data pool (all truck accidents)	Addressable casualties	
		Number	SP_{theor} [%]
Fatalities	2,766	0	**0**
People with serious injuries	11,959	172	**1.4 ± 1.4**
People with minor injuries	22,194	2,100	**9.5 ± 2.6**

The blind spot warning system considered here is a purely generic system that is not yet available in this form for trucks. This blind spot warning system monitors the neighboring lanes to the left and right of the truck and detects all kinds of road users (Figure 4.4). If the driver indicates an intention to change lane by setting an indicator, and the system detects an impending collision with one of the neighboring vehicles, the driver receives a warning. This generic blind spot warning system for trucks has the same functions as the blind spot warning system that is already available for cars.

The analysis of relevance pool 2 showed that accidents resulting from an intentional lane change generally do not have serious consequences. This is often the case when the vehicles involved only touch each other at the side and neither of them starts to skid or is forced off the road. Even the few rear-end collisions caused by a lane change rarely have serious consequences. However, the case-by-case analysis also made it clear that truck accidents caused by a lane change cannot be analyzed adequately because the course of the accident and accident location rarely allow reliable statements to be made about their avoidability. In some collisions with cars, for example, the truck driver did not immediately notice there had been an accident and drove on. On account of conflicting statements from witnesses and missing information at the accident location, it was no longer possible to work out retrospectively when and under what circumstances the lane change or collision took place. As a result of this uncertainty, the avoidance potential could not be determined for the blind spot warning system for trucks. However, an estimate of the positive influence of the system was made.

The number of cases on which the system could have a positive effect constitutes relevance pool 2, accounting for 7.9% of all truck accidents (Table 4.10). As far as casualties are concerned, the finding that these accidents rarely cause serious injuries was confirmed (Table 4.11); only 1.4% of the serious injuries could have been addressed with the system, and the number of fatalities would not have changed at all.

4.4 Lane departure warning system – description and safety potential

The second group of accidents caused by changing lane (relevance pool 1: N = 2,297) consists of accidents caused by drivers leaving their lane unintentionally (relevance pool 2: N = 845 cases). The analyses revealed that these cases are generally attributable to the truck driver being overtired, distracted or inattentive. These accidents could be addressed with a lane departure warning system.

The functionality of the ADAS considered here is based on that of the lane departure warning systems already available on the market [19]. It works in almost the same way as the systems already available for cars. A video camera behind the windshield detects the course of the lane. The system evaluates the lane markings and warns the driver if he is about to leave the lane unintentionally. It thus helps drivers to stay in lane on freeways or roads with good markings outside built-up areas even if they are being inattentive.

In the course of the case-by-case analysis, the course of each accident was analyzed, assuming an ideal driver and a system working to optimum effect. The case material was mostly well documented, and it was therefore possible to make an assessment as to avoidability. If there were sufficient indications to permit the assumption that the truck would not have left its lane if the system had been in operation, the accident was considered to be avoidable.

In relation to all truck accidents, this amounts to an avoidance potential of 1.8% for the lane departure warning system (Table 4.12). The picture for casualties is similar, with only 1% of serious injuries and 2% of minor injuries assessed as avoidable (Table 4.13).

If the accidents that would have been avoidable with the lane departure warning system (N = 329) are taken in relation to all accidents in which the truck left its lane unintentionally or came off the road (N = 845), the safety potential (SP_{theor}) is 38.9%.

Table 4.12:
Accidents that would have been avoidable with the lane departure warning system for trucks

Avoidable truck accidents with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
Lane departure warning system	18,467	2,297	845	329
				1.8 % ± 1.2 %

Table 4.13:
Avoidable casualties with the lane departure warning system for trucks

Casualties that would have been avoidable with the lane departure warning system	Number of casualties in the data pool (all truck accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	2,766	0	**0**
People with serious injuries	11,959	210	**1.0 ± 1.2**
People with minor injuries	22,194	404	**1.8 ± 1.2**

4.5 ESC – safety potential

Accidents caused by trucks skidding and/or rolling over are rare in the truck accident statistics (5% of all truck accidents), but their consequences are often serious. An analysis of the UDB revealed that there was at least one fatality or serious injury in around 60% of these cases.

Relevance pool 1 (N = 1,035 cases) was formed from the data pool of N = 18,467 cases. This pool consists of all accidents in which a truck became involved in an accident as a result of being in an unstable state in terms of driving dynamics. There are a number of possible causes of the truck being in an unstable state. These include:

- An evasive maneuver (the truck may have gone into a skid as a result of an evasive maneuver while overtaking with traffic coming in the other direction, for example)
- Skidding after a minor collision
- Skidding/tipping in a bend (coming off the road as a result of driving at an excessive speed)
- Skidding on a straight stretch of road (lane departure as a result of fatigue or inattentiveness and subsequent corrective steering).

Relevance pool 1, which is also relevance pool 2, was used to investigate the positive effects of an advanced driver assistance system. The system used for this was an electronic stability control (ESC) system. Such systems are already available as an option in some new trucks and will be mandatory for all newly registered trucks in the EU from 2013 [21]. The system uses sensors to monitor the vehicle's driving dynamics. If there is a risk of the tractor unit or trailer skidding or tipping, the system intervenes with selective braking of individual wheels to stabilize the truck-trailer combination.

Due to the complex processes involved in ESC intervention and the fact that there is little information available on the course of the skid, it was not possible to do a calculation to assess avoidability in the same way as was done for the emergency brake assist system. Instead, an assessment was merely made as to whether ESC would have had a positive effect.

Table 4.14:
Truck accidents that could be addressed with ESC

Truck accidents that could be addressed with	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
ESP	18,467	1,035	1,035	1,035
				5.6 % ± 2.1 %

Table 4.15:
Casualties that could be addressed with ESC for trucks

Casualties that could be addressed with ESC	Number of casualties in the data pool (all truck accidents)	Addressable casualties	
		Number	SP_{theor} [%]
Fatalities	2,766	57	**2.1 ± 3.5**
People with serious injuries	11,959	605	**5.1 ± 2.5**
People with minor injuries	22,194	1,169	**5.3 ± 1.9**

In relation to all truck accidents, the theoretical safety potential for ESC, in terms of accidents where it would have had a positive effect, is 5.6% (Table 4.14). There would have been a positive effect on around 2% of the fatalities and 5% of the serious injuries (Table 4.15). In other words, either the severity of the injuries would have been reduced, or the accidents would not have happened and there would thus have been no injuries.

4.6 Reverse assist system – description and safety potential

Taking the truck data pool of N = 18,467 cases as a starting point, collisions between trucks and pedestrians (scenario 6 in Figure 4.2) were investigated more closely with a view to assessing the potential of advanced driver assistance systems. A very high proportion of injuries to pedestrians sustained in collisions between trucks and pedestrians (N = 833) were found to occur when trucks were reversing. The extent to which an ADAS that monitors the area behind a truck could have a positive effect on these accidents was therefore examined.

The characteristics of the generic system for trucks are based on the functionality of the reversing camera for cars. The system monitors the space behind the truck and displays it on a monitor. If the engine is running and there is a pedestrian in the critical area behind the vehicle, an acoustic warning is emitted. The system prevents the vehicle from pulling away or brakes autonomously if the driver does not react.

In the case-by-case analysis, each course of each accident was reexamined and an assessment was made as to whether the collision would still have happened under the assumed conditions. As expected, the safety potential for the truck reverse assist system was relatively low (1.2%) in terms of avoidable accidents in relation to all truck accidents (Table 4.16). However, 27.1% of truck-pedestrian accidents were found to be avoidable (Table 4.17). A glance at the number of avoidable casualties (Table 4.18) makes the benefits of a truck reverse assist system even clearer: 18.1% of the fatalities and 25.9% of the serious injuries resulting from all truck-pedestrian accidents could have been avoided with a reverse assist system.

Table 4.16:
Truck-pedestrian accidents that would have been avoidable with a reverse assist system for trucks in relation to all truck accidents

Avoidable truck-pedestrian accidents with a	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
Reverse assist system	18,467	833	226	226
				1.2 % ± 1.0 %

Table 4.17:
Truck-pedestrian accidents that would have been avoidable with a reverse assist system for trucks in relation to all truck-pedestrian accidents

Avoidable truck-pedestrian accidents with a	Data pool [100 %]	Relevance pool 1	Relevance pool 2	SP_{theor}
Reverse assist system	833	226	226	226
				27.1 % ± 11.8 %

Table 4.18:
Casualties in truck-pedestrian accidents that would have been avoidable with a reverse assist system for trucks in relation to all truck-pedestrian accidents

Avoidable casualties with the reverse assist system	Number of casualties in the data pool (all truck-pedestrian accidents)	Avoidable casualties	
		Number	SP_{theor} [%]
Fatalities	226	41	**18.1 ± 26.7**
People with serious injuries	632	164	**25.9 ± 22.9**
People with minor injuries	57	21	**36.6 ± 66.8**

4.7 Relevance of ADASs for different truck categories

This section examines the question of whether the ADASs investigated above have the same relevance or safety potential for different truck categories. The following truck categories were considered (see Appendix 1):

- Single-unit truck
- Truck with trailer
- Tractor unit with semitrailer

Table 4.19 shows the percentage of accidents involving trucks of each of the three categories that could have been avoided with or positively affected by different ADASs. An example should make things clearer: 2,890 single-unit trucks were involved in the truck accident statistics, and 64 accidents could have been avoided if these single-unit trucks had been fitted with EBA 1, resulting in a safety potential value of 2.2%. Since accidents here are specified in relation to the vehicles involved, the safety potential values calculated are

Table 4.19:
Safety potential values of ADASs in different truck categories

ADAS	Safety potential (SP) [%]		
	Single-unit truck	Truck with trailer	Tractor unit with semitrailer
EBA 1 (a*)	2.2	6.1	5.1
EBA 2 (a)	7.9	10.7	9.5
Turning assistant (cyclists) (a)	4.2	0.6	2.9
Turning assistant (pedestrians) (a)	0.5	0.9	0.8
ESC (pa)**	1.5	4.6	6.1
Blind spot warning system (pa)	6.8	5.2	6.4
Lane departure warning system (a)	1.6	1.8	1.3
Reverse assist system (a)	3.0	0.5	-

*** a = could have been avoided**
**** pa = could have been positively affected**

not directly comparable with the values calculated in previous sections. However, they can be compared with the other values in Table 4.19.

The two most important ADASs with the greatest potential in all three truck categories are emergency brake assist system 2 (EBA 2) and the blind spot warning system. ESC is the third most important system in both the truck and trailer and the tractor unit and semitrailer categories, while a turning assistant is considerably more beneficial for single-unit trucks than an ESC system. Table 4.19 also shows that a reverse assist system has a much greater safety potential for single-unit trucks than for trucks with trailers or for tractor units with semitrailers.

5 ADASs for buses

The safety potential of ADASs for buses has been investigated in a separate project carried out for the GDV Motor Insurance Loss Prevention Commission. Consequently, only the key results need be summarized here for the sake of completeness (Table 5.1 and 5.2).

Please refer to the relevant report [17] for further information and detailed results.

Table 5.1:
Percentages of bus accidents that could have been positively affected or avoided with selected advanced driver assistance systems (N = 3,596)

ADAS	Safety potential SP_{theor} [%]	Effectiveness
Emergency brake assist system 1 [a]	8.9	pa**
Emergency brake assist system 2 [b]	15.1	pa
Turning assistant (for P and C) *	2.3	a***
Lane departure warning system	0.5	a
Blind spot warning system	3.8	pa
ESC	3.4	pa

* P = pedestrians, C = cyclists
** pa = could have been positively affected
*** a= could have been avoided
[a] Detection of double-track moving vehicles in front
[b] Detection of moving and stationary double-track vehicles in front

Table 5.2:
Percentages of casualties that could have been positively affected or avoided with selected advanced driver assistance systems (N = 3,596)

ADAS	Casualties that could have been positively affected or avoided - SP_{theor} [%]			Effectiveness
	Fatalities	SI****	MI****	
Emergency brake assist system 1	16.6	0.7	9.6	pa**
Emergency brake assist system 2	16.6	4.3	15.4	pa
Turning assistant (for P and C) *	-	4.1	-	a***
Lane departure warning system	-	1.9	1.7	a
Blind spot warning system	-	4.4	4.5	pa
ESC	-	3.5	15.6	pa

* P = pedestrians, C = cyclists
** pa = could have been positively affected
*** a= could have been avoided
**** SI = serious injuries, MI = minor injuries

6 Accidents involving two-wheel motor vehicles

There are still very few advanced driver assistance systems available for two-wheel motor vehicles – unlike for cars, trucks and buses. They are limited to anti-lock braking systems (ABSs) and traction control systems (TCSs) [16]. Consequently, rather than determining the safety potential of advanced driver assistance systems for motorcycles, this chapter describes the kind of accidents in which motorcycles are involved and the scenarios that lead to motorcycle accidents. Based on this knowledge, it may be possible in the future to specify the requirements to be met by ADASs and assess their effect in theory.

The underlying accident material from the years 2002 to 2007 consists of a total of 880 accidents involving two-wheel motor vehicles (all types, including mopeds, scooters and motorcycles). These were extrapolated to N = 38,386 accidents using the method described in Section 2.2. For the sake of simplicity, the two-wheel motor vehicles are generally referred to in Chapter 6 as motorcycles. Although this is taken to mean all types of two-wheel motor vehicle, they are not differentiated any further (due to the small number of cases). The breakdown of the other parties involved in the accidents with the motorcycles in the extrapolated accident material is shown in Figure 6.1. Only the main other parties involved in the collision are shown (i.e. those road users with which the motorcycle had the most serious collision, involving the most personal injury). Cases involving motorcycles not directly involved (e.g. minor subsequent collisions between the motorcycle and a vehicle already involved in a serious accident) are not shown in Figure 6.1. Motorcycle collisions with cars account for the largest proportion of these accidents (85%), followed by collisions with trucks (7%), cyclists (3%) and pedestrians (3%). Car accidents with no third-party involvement account for only 2% of the accidents in the UDB and are thus clearly underrepresented compared with the official statistics [5]. This can be attributed to the fact that the UDB is fed third-party claims, and accidents with no third-party involvement only appear in the accident material when a third party is affected.

Over 90% of the motorcycle accidents were collisions with multi-track vehicles (e.g. cars, trucks, buses), and 2% were without third-party involvement. Only these two groups (motorcycle collisions with multi-track vehicles and motorcycle accidents without third-party involvement) are considered below.

6.1 Accidents involving collisions between two-wheel motor vehicles and multi-track vehicles

The available accident material contained 34,646 motorcycle collisions with multi-track vehicles. In 21% of these accidents (7,217 cases), the motorcyclist was the main party responsible for the accident; thus, in 79% of them (27,429 cases) the motorcyclist was not primarily responsible. These two subsets are described separately in Section 6.1.1 and Section 6.1.2 below.

6.1.1 Accidents in which the motorcyclist was the main party responsible

Figure 6.2 shows the key accident scenarios for the motorcyclists (N = 7,217) who were the main cause of an accident. It also shows the percentages of killed or

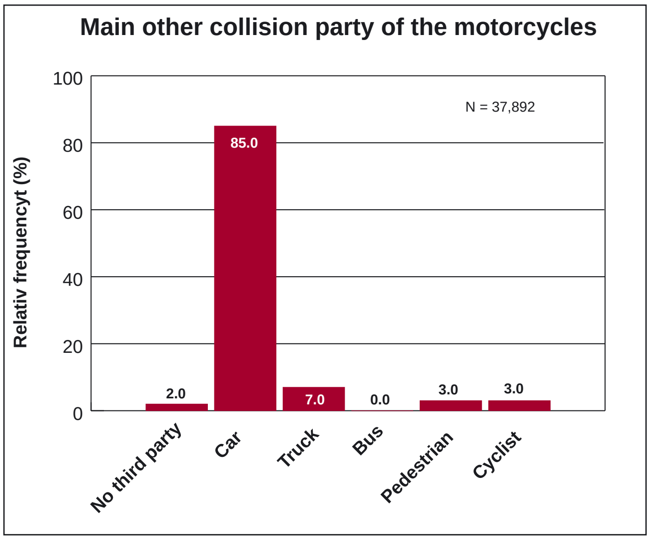


Figure 6.1:
Motorcycle accidents with no third-party involvement and main other parties involved in collisions with motorcycles in the available accident material

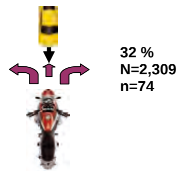
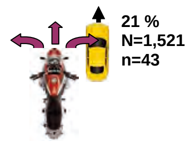
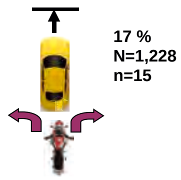
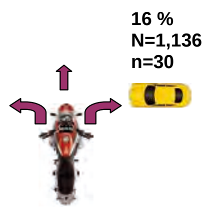
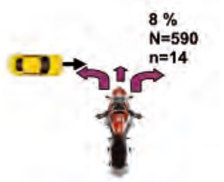
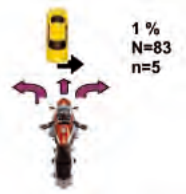
Scenario		Percentage of accidents accounted for by the scenario	Percentage in/outside built-up areas [%]	Percentage of fatalities accounted for by the scenario (N = 504 ≙ 100 %)	Percentage of serious injuries accounted for by the scenario (N = 5,214 ≙ 100 %)
	I: Collision with an oncoming vehicle	32 %	35/65	58 %	29 %
	II: Collision with a vehicle traveling in the same direction	21 %	48/52	6 %	25 %
	III: Collision with a vehicle that is stationary, parking or stopping for traffic	17 %	87/13	19 %	17 %
	IV: Collision with a vehicle coming from the right (nearside)	16 %	64/36	12 %	18 %
	V: Collision with a vehicle coming from the left (offside)	8 %	47/53	-	11 %
	VI: Collision with an oncoming vehicle turning left across oncoming traffic	1 %	23/77	6 %	0.5 %

Figure 6.2:
Accident scenarios with frequency of occurrence and consequences; motorcycle collisions with multi-track vehicles in which the motorcyclist is the main party responsible (N = 7,217)

seriously injured motorcyclists accounted for by each scenario. In 32% of the cases considered, the motorcycle collided with an oncoming multi-track vehicle; a typical example was when a motorcycle ended up on the other side of the road because the motorcyclist had taken a right-hand (i.e. nearside) bend too fast. This accident scenario was particularly life-threatening; 58% of all fatalities of motorcyclists who were primarily responsible for an accident occurred in this scenario. 65% of the instances of this scenario occurred outside built-up areas. Accident scenario VI is even more dangerous. Although it accounted for only 1% of the accidents, 6% of the fatalities occurred in this scenario. Here, too, a high proportion of the accidents occurred outside built-up areas (77%). Typical for this scenario is an oncoming vehicle turning across the traffic (i.e. left in Germany and most other countries) into another road and colliding with a motorcycle traveling at excessive speed. Scenario V is very different in terms of fatalities (what typically happens here is that the motorcyclist fails to take into account that the vehicle coming from the left has priority): although this scenario accounted for 8% of the accidents, none of them involved fatalities. There is a further interesting result for scenario III, in which a motorcycle collides with the rear end of a multi-track vehicle that is stationary, parking or stopping for traffic. This scenario accounted for an unexpectedly high proportion of motorcycle accidents (17%) and 19% of the motorcyclist fatalities involved in these rear-end collisions. A high proportion (87%) of them occurred in built-up areas, very often as a result of inattentiveness on the part of the motorcyclist.

6.1.2 Accidents in which the motorcyclist was not primarily at fault

Although it can be assumed in principle that motorcycle ADASs could only have a positive effect on or prevent those accidents caused by the motorcyclist (Section 6.1.1), it is possible to conceive of cases in which an ADAS could help a motorcyclist to avoid an accident that would otherwise occur through the fault of another road user (for example, by warning the motorcyclist: "Watch out, the car coming from the left is going to ignore that you have priority!"). The corresponding accident scenarios (in which the motorcyclist is not at fault) are shown in Figure 6.3.

The most frequent scenarios in the accident material were a) (30%, with a typical example being another motorist ignoring the priority of the motorcyclist when turning left into another road) and b) (29%, with a typical example being a driver wanting to turn off to the left (offside) and failing to see an oncoming motorcycle or seeing it too late), followed by accident scenarios c) (motorcycle traveling in the same direction) and d) (motorcycle coming from the right, i.e. nearside), which each accounted for 17% of these accidents. Scenarios e) and f) played only a minor role in the accidents in which motorcyclists were not at fault. The most dangerous scenario with the most fatalities in both absolute and relative terms was scenario c), in which 29% of the fatalities occurred although the scenario accounted for only 17% of these accidents.

6.2 Two-wheel motor vehicle accidents with no third-party involvement

There were a total of 64 accidents (n = 64) with no third-party involvement in the accident material. These were extrapolated to 731 cases (N = 731). Motorcycle accidents with no third-party involvement thus accounted for only 2% of the accidents considered here. The accidents with no third-party involvement considered below are thus clearly underrepresented compared with the official statistics [5]. This can be attributed to the fact that the UDB is fed third-party claims, and accidents with no third-party involvement only appear in the accident material when a third party is affected.

Figure 6.4 shows the five key accident scenarios for motorcycle accidents with no third-party involvement. The most frequent, accounting for 43% of the accidents, were falls when traveling straight ahead (scenario A1, a typical example being loss of control of the motorcycle on an uneven, wet or contaminated road surface), followed by coming off the road to the right, which is the nearside (scenario A2; 34%), and coming off the road to the left, which is the offside (scenario A3; 13%). The latter two scenarios were associated with excessive speed in bends and unfavorable weather conditions. Coming off the road to the right is much the most dangerous scenario, accounting for 62% of all motorcyclist fatalities in accidents without third-party involvement. The rest of the fatalities (38%) occurred in scenario A1 (fall when traveling straight ahead). There were no fatalities in any of the other scenarios without third-party involvement.

6.3 Key emphases for the development of ADASs for motorcycles

Measures to reduce the frequency of accidents involving two-wheel motor vehicles should thus theoretically focus on the following scenarios:

- **I:** collision with an oncoming vehicle (see Figure 6.2)
- **III:** : collision with a vehicle that is stationary, parking or stopping for traffic (see Figure 6.2),
- **A1:** fall when traveling straight ahead (see Figure 6.4)
- **A2:** coming off the road to the right (see Figure 6.4).

From the perspective of the authors, only an emergency brake assist system that issues a warning in critical situations and/or brakes autonomously appears to be feasible in practice (and will primarily affect scenario III). The EU project PISa (Powered Two Wheeler Integrated Safety) has already shown what form an ADAS like this might take once implemented [22]. Other ADASs are likely to be very expensive to implement because influencing the driving dynamics of a single-track vehicle in complex critical situations is highly complicated.

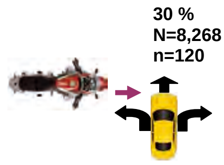
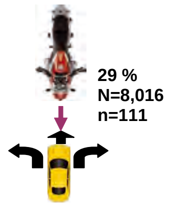
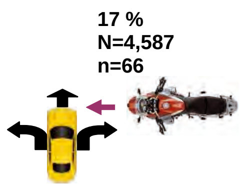
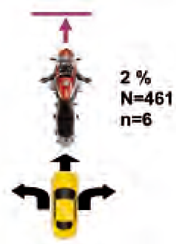
Scenario		Percentage of accidents accounted for by the scenario	Percentage in/outside built-up areas [%]	Percentage of fatalities accounted for by the scenario (N = 1,077 ≙ 10, %)	Percentage of serious injuries accounted for by the scenario (N = 20,057 ≙ 100 %)
	a) Collision with a motorcycle coming from the left (offside)	30 %	69/31	23 %	33 %
	b) Collision with an oncoming motorcycle traveling straight ahead	29 %	70/30	23 %	31 %
	c) Collision with a motorcycle traveling in the same direction	17 %	54/46	29 %	14 %
	d) Collision with a motorcycle coming from the right (nearside)	17 %	58/42	23 %	17 %
	e) Collision with a motorcycle that is stationary, parking or stopping for traffic	2 %	94/6	-	2 %

Figure 6.3:
Accident scenarios with frequency of occurrence and consequences; motorcycle collisions with multi-track vehicles in which the motorcyclist was not at fault (N = 27,429)

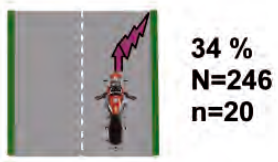
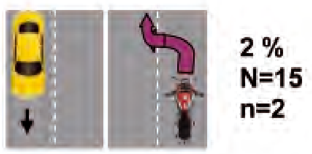
Scenario		Percentage of accidents accounted for by the scenario	Percentage in/outside built-up areas [%]	Percentage of fatalities accounted for by the scenario (N = 59 ≙ 100 %)	Percentage of serious injuries accounted for by the scenario (N = 335 ≙ 100 %)
	A1: Fall when traveling straight ahead	43 %	26/74	38 %	29 %
	A2: Coming off the road to the right (nearside)	34 %	30/70	62 %	29 %
	A3: Coming off the road to the left (offside)	13 %	49/51	-	12 %
	A4: Fall when changing lane to the right (nearside)	6 %	-	-	12 %
	A5: Fall when changing lane to the left (offside)	2 %	-	-	-

Figure 6.4:
Accident scenarios with frequency of occurrence and consequences for motorcycle accidents without third-party involvement (N = 731)

7 Car accidents involving property damage but not personal injury

Car accidents involving property damage alone were analyzed in this ADAS project as well as accidents involving casualties – with the focus on the benefits of parking assist systems for cars. For this purpose, car accident material was used that was completely independent of the UDB. This chapter describes the key benefits of an intelligent parking assist system (which assists with both parking and leaving parking spaces), but also considers and discusses other assistance systems that suggest themselves in order to combat the main accident scenarios. In addition, the possible theoretical impact of specific ADASs on accidents covered by third-party motor insurance (property damage only) and fully comprehensive motor insurance– is described, assuming a situation in which all cars in Germany are equipped with these ADASs.

7.1 Description of the property damage case material

Random samples of 187 third-party motor insurance claims and 155 fully comprehensive motor insurance claims were taken from SBS's standard records of damage claims from 2004 to 2006 and analyzed. The precise selection criteria are shown in Table 7.1. All types of damage (cases) in which a parking assist system, by definition, could not be expected to have an effect (e.g. fire/explosions, vehicle theft, flooding) were excluded from the case material in advance.

The total of 342 cases of very heterogeneous accidents and types of damage were initially divided up into specific accident scenarios in order to provide some structure. These are shown separately for third-party insurance and fully comprehensive insurance in Table 7.2. In third-party insurance damage claims, the most common scenarios are accidents that occur when parking and leaving parking spaces and rear-end collisions. In fully comprehensive insurance damage claims, there are many cases of glass damage so the relative frequencies of the various scenarios are significantly lower. They also have a different level of significance compared with third-party insurance.

7.2 Analysis of damage in third-party insurance claims

In a detailed case-by-case analysis, it was investigated for each accident scenario (see Appendix 2 for examples) whether the damage could have been avoided or mitigated with a (generic) ADAS. The ADASs shown in Table 7.3 were thus considered.

Table 7.1:
Cases selected

	Third-party insurance	Fully comprehensive insurance
WKZ*	112	112
Damage type**	16	51, 56, 74
SBS	2004 to 2006	2004 to 2006

*** WKZ = Wagniskennziffer (German insurance industry risk category); 112 = car**
**** Damage type 16 = damage to property alone**
51 = damage from collisions between vehicles
56 = other cases covered by fully comprehensive insurance
74 = glass breakage

Table 7.2:
Frequency of different accident scenarios in third-party and fully comprehensive insurance

	Third-party insurance		Fully comprehensive insurance	
	Number	%	Number	%
Parking and leaving a parking space	55	29.4	17	11.0
Rear-end collision	49	26.2	9	5.8
Sideswipe	10	5.3	3	1.9
Coming off the road/lane departure	9	4.8	6	3.9
Lane changing	9	4.8	3	1.9
Failure to concede priority	9	4.8	4	2.6
Glass damage	2	1.1	89	57.4
Other	37	19.8	19	12.3
Not clear	7	3.7	5	3.2
Total	**187**	**100.0**	**155**	**100.0**

The functions assumed for the different ADASs are described in Appendix 3. It was assumed that the parking assist system (or an ideal driver together with a proximity warning system) would execute parking maneuvers flawlessly to both enter and leave parallel or perpendicular parking spaces by moving forwards or reversing. Table 7.3 shows the maximum percentage of avoidable accidents for the parking assist system. For the other assistance systems it is specified whether damage could have been avoided or mitigated. It should be noted here that each type of damage was assigned to a single ADAS. This allows the theoretically possible safety potential values to be added up, since there is no overlapping.

A parking assist system, as described in Appendix 3, would thus have been able to prevent 31% of all damage to cars in third-party insurance claims, and an intelligent brake assist system could have had a positive effect on a further 27% of the damage claims. The information provided in the claim files is in some cases sparse, making it impossible to reconstruct the course of the accidents exactly. Nevertheless, it can be assumed that around 80% of the cases discussed here could have been prevented by a brake assist system designed to prevent accidents. Compared to the first two ADASs, all of the other systems described here have relatively low safety potential values of 6% or less. The ADASs listed in Tabelle 7.3 would not have any influence at all on almost 18% of all the damage in third-party insurance claims.

7.2.1 Detailed analysis for the parking assist system

Table 7.4 shows the different parking maneuvers in which damage occurred that could have been avoided using the

Table 7.3:
Damage in third-party insurance damage claims that could have been avoided or mitigated (positively affected) with ADASs

ADAS overview	Number	%	Effectiveness
Parking assist system (for parking and leaving a parking space)	58	31.0	a*
Brake assist system	51	27.3	pa**, a (80 %)
Blind spot warning system	12	6.4	pa
Junction assistance system	10	5.3	pa
Safe distance support system (side)	7	3.7	pa
Assistance system for pulling out (rear)	7	3.7	a
ESC	3	1.6	pa
Curve assistance system	3	1.6	pa
Assistance system for pulling out (front)	2	1.1	a
Driver status detection system (alcolock)	1	0.5	a
Total	**154**	**82.4**	
ADASs have no effect or effect not clear	33	17.6	
Total	**187**	**100.0**	
***a = damage that could have been avoided **pa = damage that could have been mitigated (positively affected)**			

parking assist system. By far the most damage occurred when drivers were leaving perpendicular parking spaces, which accounted for 47% of the damage claims, followed by leaving parallel parking spaces, which accounted for 10%. Damage occurred much less often during parking. It is conspicuous that many more problems occurred in perpendicular parking, both when leaving a parking space (46.6%) and when parking in a space (6.9%), than in parallel parking. These findings should be taken into account in the specification and development of an intelligent parking assist system.

The driving status of the vehicles parking or leaving a parking space immediately before the damage occurred is shown in Table 7.5. The great majority of cases of damage occurred during reversing (79.3%); drivers clearly have most problems with this.

Table 7.6 shows the associated driving status for each parking maneuver. The combination of these two characteristics makes it absolutely clear that most damage incurred in parking occurs when reversing out of perpendicular parking spaces: 26 of the total

Table 7.4:
Percentages of all parking damage claims accounted for by different parking maneuvers

Cases of damage that would have been avoidable with the parking assist system (n = 58)		
Maneuver	Number	%
Leaving a perpendicular parking space	27	46.6
Leaving a parallel parking space	6	10.3
Leaving a parking space (type not clear)	5	8.6
Parking in a perpendicular parking space	4	6.9
Parking in a parallel parking space	3	5.2
Parking in a parking space (type not clear)	1	1.7
Other/not clear	12	20.7
Total	**58**	**100.0**

Table 7.5:
Driving status of the car before the damage occurred

Cases of damage that would have been avoidable with the parking assist system (n = 58)		
Driving status	Number	%
Moving forward (<10 km/h)	4	6.9
Starting to move forward	3	5.2
Rolling forward at walking pace	2	3.4
Reversing	46	79.3
Not clear	3	5.2
Total	**58**	**100.0**

Table 7.6:
Cases of damage occurring when parking or leaving a parking space depending on driving status

Cases of damage that would have been avoidable with the parking assist system (n = 58)						
Driving status / Parking maneuver	Moving forward (<10 km/h)	Starting to move forward	Rolling forward at walking pace	Reversing	Not clear	∑
Leaving a perpendicular parking space	-	-	-	26	1	27
Leaving a parallel parking space	-	2	-	4	-	6
Leaving a parking space (type not clear)	-	-	-	4	1	5
Parking in a perpendicular parking space	2	-	-	2	-	4
Parking in a parallel parking space	1	-	-	2	-	3
Parking in a parking space (type not clear)	-	-	-	1	-	1
Other / Not clear	1	1	2	7	1	12
Total	**4**	**3**	**2**	**46**	**3**	**58**

of 58 cases of damage that could have been avoided with a parking assist system occurred during this maneuver. Damage was much rarer in all other parking situations.

7.2.2 Detailed analysis for the brake assist system

As shown in Tabelle 7.3, a brake assist system could have had a positive effect on up to 27% of the damage cases in third-party insurance claims, of which, as indicated in Section 7.2, approximately 80% would have been avoidable. For cases of damage that would have been avoidable with a brake assist system, Table 7.7 shows the driving status of the two vehicles involved when the collision happened. Both vehicles braked in 16 cases, and in 10 cases the liable party (LP) drove into the (already) stationary claimant (C). All other driving situations were much rarer. In 49 cases, the liable party drove into a car, and in two cases into a van.

For the cases of damage considered here that could have been avoided with a brake assist system, it is not possible to specify the driving speed and speed relative to the vehicle of the damaged party with precision. Nevertheless, these speeds (Table 7.8) can be estimated approximately based on the information and documentation in the claim files. It can thus be seen that although the number of cases in which the car was traveling at less than 40 km/h was roughly equal to the number in which the car was traveling at more than 40 km/h (12 cases as opposed to 13), high relative speeds (20 – 30 km/h) were very infrequent (only two cases). In all other cases, the relative speed was lower than this. Low relative speeds between the two vehicles of under 10 km/h were found in over half of the cases (26 of 51 cases).

Table 7.7:
Driving statuses of the two vehicles involved in the accident

Cases of damage that would have been avoidable with the brake assist system (n = 51)					
LP* / C**	Pulling away	Braking	Driving	Rolling	Not clear
Turning off	-	3	-	-	-
Pulling away	-	-	-	-	1
Braking	-	16	1	1	1
Driving	-	1	-	-	-
Reversing	1	-	-	-	-
Stationary	1	10	-	2	2
Not clear	-	6	1	-	4

* LP = liable party
** C = claimant

Table 7.8:
Driving speed of the liable party (LP) and relative speed of the vehicles involved in the accident

Cases of damage that would have been avoidable with the brake assist system (n = 51)						
Driving speed / Relative speed	-20 [km/h]	20 - 40 [km/h]	> 40 [km/h]	Not clear	Total	
					Number	%
- 10 km/h	5	3	5	13	26	51.0
10 - 20 km/h	-	4	5	11	20	39.2
20 - 30 km/h	-	-	2	-	2	3.9
Not clear	-	-	1	2	3	5.9
∑	**5**	**7**	**13**	**26**	**51**	**100.0**

7.2.3 Effect of the parking and brake assist systems on cases of damage in third-party insurance – property damage only

As shown in Table 7.3, 31% of the cases of damage to cars in third-party insurance could have been avoided with an intelligent parking assist system. When this percentage is applied to all of the accidents in the GDV statistics (see Table 7.9), the annual avoidance potential obtained is 710,662 cases of damage (as applied to the year 2008) – if all cars were equipped with an intelligent parking system.

As far as damage costs are concerned, 23% of the costs for the damage to cars in third-party insurance claims could be avoided with a parking assist system in all cars; which corresponds to damage costs of €1,182,122,440 a year.

A brake assist system for rear-end collisions would have had a positive effect on around 27% of the cases of damage to cars in third-party insurance claims, as shown in Table 7.3. If this percentage is applied to all of the accidents in the GDV's statistics, the result is a positive effect on 618,963 cases of damage. In other words, they could be avoided or their damage costs could be reduced. Rear-end collisions cause more damage than the average accident, which is why the brake assist system would be able to address around 35% of the total damage costs of €5.2 billion. That amounts to damage costs of around €1.8 billion. If it is assumed that around 80% of the addressable damage could be avoided, a brake assist system would be able to reduce the annual damage costs in third-party motor insurance by around €1.4 billion.

If all cars in Germany were equipped with both a parking assist system and a brake assist system, the damage costs in third-party insurance would be reduced by around €2.6 billion a year (based on 2008).

7.3 Analysis of damage in fully comprehensive insurance claims

In the same way as for the cases of damage in third-party insurance claims, as described in Section 7.2, the cases of damage in fully comprehensive insurance claims were analyzed on a case-by-case basis to ascertain whether they could have been avoided or positively affected (Table 7.10). For the types of damage considered here (fully comprehensive insurance, damage types 51, 56 and 74), an intelligent parking assist system has the highest

Table 7.9:
Extract from the GDV statistics for 2008 – third-party insurance damage claims (3P)

	No. of cases of damage	Damage costs
3P, all risk categories (WKZ), all types of damage (11 + 16)	3,296,278	11,724,523,000
Of which damage type 11	321,436	4,886,597,000
Of which damage type 16	2,974,842	6,837,926,000
3P, risk category (WKZ) 112, all types of damage (11 + 16)	2,564,207	9,215,949,000
Of which damage type 11	271,750	4,010,243,000
Of which damage type 16	2,292,457	5,205,706,000

Table 7.10:
Damage in fully comprehensive insurance damage claims that could have been avoided or positively affected with ADASs

ADAS-overview	Number	%	Effectiveness
Parking assistent system	24	15.5	a*
Brake assist system	8	5.2	pa**
Junction assistance system	4	2.6	pa
Blind spot warning system	3	1.9	pa
ESC	3	1.9	pa
Curve assistance system	3	1.9	pa
Safe distance support system (side)	2	1.3	pa
Assistance system for pulling out (rear)	1	0.6	a
Total	**48**	**31.0**	
ADAS have no effect	107	69.0	
Total	155	100.0	
***a = damage that could have been avoided** ****pa = damage that could have been positively affected**			

theoretical safety potential (15.5%). A brake assist system would have had a positive effect on around 5% of the cases of damage. The other ADASs considered have only very low safety potential values. On account of the high number of cases of glass damage (n = 89), the percentage of cases that cannot be positively affected by any of the ADASs considered here is comparatively high (69%).

7.3.1 Detailed analysis for the parking assist system

For all of the analyses involving the parking assist system, it was assumed that the system was able to prevent all relevant damage. In order to do that, it would have to detect both stationary obstacles (e.g. trees, street lamps, walls, pillars and bollards) and stationary cars absolutely reliably as well as avoid sideswipes with stationary obstacles such as garage entrances, pillars and posts (Table 7.11).

The situation dictates that driving speeds for parking maneuvers are relatively low at under 10 km/h (Table 7.12). Here, too, however, there are a conspicuously high number of cases of damage when reversing (62.5%). By comparison, in cases of damage in third-party insurance claims that would have been avoidable with a parking assist system, the percentage of cases of damage that occurred when the car was reversing was 79.3% (see Table 7.5).

Table 7.11:
Collision type and other party involved in cases of damage that would have been avoidable with the parking assist system

Cases of damage that would have been avoidable with the parking assist system (n = 24)		
Collision type and other party involved	**Number**	**%**
Collision (when moving forward or reversing) with a stationary obstacle	15	62.5
Collision (when moving forward or reversing) with a stationary car	5	20.8
Sideswipe with a stationary obstacle	4	16.7
Total	**24**	**100.0**

Table 7.12:
Driving status of the liable party before the damage occurred

Cases of damage that would have been avoidable with the parking assist system (n = 24)		
Driving status	**Number**	**%**
Rolling forward at walking pace	3	12.5
Moving forward (<10 km/h)	2	8.3
Reversing	15	62.5
Not clear	4	16.7
Total	**24**	**100.0**

7.3.2 Effect of the parking and brake assist systems on cases of damage in fully comprehensive insurance

As shown in Table 7.10, almost 16% of the cases of damage to cars in fully comprehensive insurance claims (damage types 51, 56 and 74) could have been avoided with an intelligent parking assist system. When this percentage is applied to all of the accidents in the GDV statistics (see the extract in Table 7.13), the annual avoidance potential obtained is 429,932 cases of damage (as applied to the year 2008) – if all cars were equipped with an intelligent parking system.

As far as damage costs are concerned, 21% of the costs for the damage to cars in fully comprehensive insurance claims (damage types 51, 56 and 74) could have been avoided with the parking assist system. That corresponds to damage costs of €778,702,470 a year. It amounts to 16% of the total damage costs for cars (all damage types) in fully comprehensive insurance claims (€5.0 billion in the year 2008).

Table 7.13:
Extract from the GDV statistics for 2008 – fully comprehensive insurance (FC)

	No. of cases of damage	Damage costs
FC, all risk categories (WKZ), all damage types	3,827,778	5,843,735,000
FC, WKZ 112, all damage types	3,427,041	5,000,475,000
Of which damage type 51	506,442	1,507,099,000
Of which damage type 56	660,255	1,568,577,000
Of which damage type 74	1,520,376	632,431,000

A brake assist system for rear-end collisions would have had a positive effect on around 5% of the cases of damage to cars in fully comprehensive insurance claims (damage types 51, 56 and 74), as shown in Tabelle 7.10. By applying that percentage to all of the cases of damage in the GDV statistics, it is possible to say that the system would have a positive effect on 134,354 cases of damage in fully comprehensive insurance claims.

Rear-end collisions, as already mentioned, cause more damage than the average accident, which is why the brake assist system would be able to address around 8% of the total damage costs of €3.7 billion (damage types 51, 56 and 74). That amounts to damage costs of around €297 million or 6% of all damage costs for cars in fully comprehensive insurance claims. In order to calculate the total number of cases in fully comprehensive insurance claims that would be avoidable with a brake assist system, a more detailed study of a greater number of cases would be required.

8 Summary of the results

In the Advanced Driver Assistance Systems project, realistic safety potential values were obtained for (generic) advanced driver assistance systems (ADASs) based on insurers' damage claims. For this purpose, a representative body of case material was established and analyzed. The case material consisted of third-party motor insurance claims involving personal injury and at least €15,000 total claim value. It was possible to calculate an accident avoidance potential value for most ADASs. However, due to the specified functions of the ADASs and the different levels of detail in the claim files analyzed, for some ADASs it was not possible to do more than come up with a percentage of cases in which the system would have had a "positive effect" (Table 8.1).

The findings were essentially that modern advanced driver assistance systems can have a positive impact on the damage and accident statistics (accidents involving personal injury and at least €15,000 total claim value).

The various (generic) ADASs were found to have the following safety potential values for car accidents: 1% for the overtaking assistant, 2% each for the blind spot warning system and reverse assist system, 4% for the lane departure warning system and up to 43% for a highly intelligent emergency brake assist system.

The following benefits were calculated for trucks: 1% for the reverse assist system, 2% for the lane departure warning system, 4% for the turning assistant and 12% for the emergency brake assist system. In addition, ESC was found to have a positive effect on 6% of the cases investigated and a blind spot warning system was found to have a positive effect on 8%. Detailed analyses indicated that the benefits of the different ADASs varied depending on the truck category concerned (single-unit truck, truck with trailer, tractor unit with semitrailer). ESC was thus found to be most effective for tractor units with semitrailers and least effective for single-unit trucks. A turning assistant, on the other hand, was found to be most effective for single-unit trucks and least effective for trucks with trailers. These findings should be taken into account in cost-benefit considerations and when drafting legislation.

For buses, an avoidance potential value of almost 1% was calculated for the lane departure warning system and 2% for the turning assistant. In addition, ESC was found to have a positive effect on 3% of the accidents, the blind spot warning system 4% and an emergency brake assist system that detected both stationary and moving double-track vehicles 15%.

Due to the fact that little research has been carried out into ADASs for single-track vehicles, it was not possible to calculate their safety potential values for motorcycles. Instead, the main accident scenarios were described. It emerged that measures to reduce the accident rates of two-wheel motor vehicles should focus on the following scenarios: collision with an oncoming vehicle, collision with a vehicle that is stationary, parking or stopping for traffic, fall when traveling straight ahead and coming off the road to the right (i.e. the nearside).

In addition to accidents involving personal injury, car accidents involving damage to property only (third-party and fully comprehensive motor insurance) were also investigated in the ADAS project to examine the benefits of parking assist systems and brake assist systems (Table 8.2). The resulting analyses showed that 31% of third-party property damage claims could have been avoided with an intelligent parking assist system and that a further 22% (80 percent of 27.3%) could have been avoided with a brake assist system. In the case of fully comprehensive property damage claims, the safety potential of the two systems was lower but still considerable (16% and 5%, respectively).

Table 8.1:
Safety potential values of the advanced driver assistance systems investigated – summary

ADAS	Safety potential SP_{theor} [%]	Effectiveness
For cars	All car accidents = 100 %	
EBA 1	11.4	a*
EBA 2	17.8	a
EBA 2*	19.6	a
EBA 2*P	24.5	a
EBA 2*C	43.4	a
Lane departure warning system	4.4	a
Overtaking assistant	1.2	a
Blind spot warning system	1.7	a
Reverse assist system	2.3	a
For trucks	All truck accidents = 100 %	
Emergency brake assist system 1	6.0	a
Emergency brake assist system 2	11.9	a
Turning assistent	4.4	a
Blind spot warning system	7.9	pa**
Lane departure warning system	1.8	a
ESC	5.6	pa
Reverse assist system	1.2	a
For buses	All bus-accidents = 100 %	
Emergency brake assist system 1	8.9	pa
Emergency brake assist system 2	15.1	pa
Turning assistant (for P and C)	2.3	a
Lane departure warning system	0.5	a
Blind spot warning system	3.8	pa
ESC	3.4	pa

* a = = could have been avoided
** pa = could have been positively affected

Table 8.2:
Safety potential values of the parking and brake assist systems for cars for property damage alone – summary for cases of damage in third-party (3P) and fully comprehensive (FC) insurance claims

ADAS	Safety potential SP [%]	Effectiveness
	all car accidents in 3P = 100 %	
Parking assist system	31.0 %	a*
Brake assist system	27.3 % pa**, 22 % a	
	All car accidents in FC, damage types 51, 56 und 74 = 100 %	
Parking assist system	15.5 %	a
Brake assist system	5.2 %	pa
* a = could have been avoided ** pa = could have been positively affected		

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Appendix 1

Examples of trucks with a gross vehicle weight of 5 tonnes or more

Single-unit truck ≈ 5 tonnes

Single-unit truck ≈ 12 tonnes

Single-unit truck ≈ 18 tonnes

Truck with trailer ≈ 40 tonnes

Tractor unit with semitrailer ≈ 25 tonnes

Tractor unit with semitrailer ≈ 40 tonnes

Appendix 2

Property damage to cars; examples of different accident scenarios (as in Table 7.2)

Parking and leaving a parking space:
▪ Collision with a post or pillar when moving forward into a parking space
▪ Collision with car in front when moving forward into a parking space
▪ Collision with a car parked opposite when reversing out of a parking space
▪ Collision with an adjacent parked car when reversing out of a parking space

Rear-end collision:
▪ Vehicle 01 (the liable party) hits the back of vehicle 02 (the claimant), which is braking for traffic
▪ Vehicle 01 (the liable party) hits the back of vehicle 02 (the claimant), which is stopping for traffic
▪ Vehicle 01 (the liable party) hits the back of vehicle 02 (the claimant), which is stopping because of a traffic jam

Sideswipe:
▪ The side of vehicle 01 (the liable party) brushes against the side of vehicle 02 (the claimant), which is parked
▪ The side of vehicle 01 (the liable party) brushes against a waste bin next to the pumps at the filling station

Coming off the road/lane departure:
▪ Vehicle 01 (the liable party) skids on an icy road on a right-hand (nearside) bend and comes off the road
▪ Vehicle 01 (the liable party) skids on an icy road and hits a crash barrier on the nearside

Lane changing:
▪ Vehicle 01 (the liable party) changes into a faster lane and collides with vehicle 02 (the claimant), which is approaching from behind
▪ Vehicle 01 (the liable party) intends to change into a faster lane and touches vehicle 02 (the claimant), which is next to it

Failure to concede priority:
▪ Vehicle 01 (the liable party) fails to concede priority when turning left across oncoming traffic to vehicle 02 (the claimant), which is coming from the left (in Germany, where cars drive on the right)
▪ Collision when reversing out onto a main road with a car on that road

Appendix 3

Property damage to cars; descriptions of the generic ADASs

ADAS	Description of the functions
Parking assist system	Protects every side of the vehicle and prevents damage when parking by automatically braking; maneuvers the car into and out of parking spaces automatically (or by means of an “ideal” driver)
Brake assist system	Largely prevents rear-end collisions with stationary or moving vehicles by automatically braking
Blind spot warning system	Largely prevents lane-changing collisions (with vehicles in the blind spot or approaching from behind) by automatically braking and/or through steering intervention
Junction assistance system	Largely prevents violations of priority by automatically braking
Safe distance support system (side)	Largely prevents sideswipes by automatically braking and/or through steering intervention
Assistance system for pulling out (reversing with warning and intervention)	Prevents collisions when pulling out into moving traffic by automatically braking
ESC	Mitigates or prevents skidding accidents through braking intervention and engine management
Curve assistance system	Detects excessive driving speeds on the approach to bends and automatically brakes to the appropriate speed for the bend
Assistance system for pulling out (forwards with warning and intervention)	Prevents collisions when pulling out into moving traffic by automatically braking
Driver status detection system (alcolock)	Prevents the vehicle from being started when the driver is over the alcohol limit

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