ADVANCED DRIVER ASSISTANCE SYSTEMS FOR TRUCKS – BENEFIT ESTIMATION FROM REAL-LIFE ACCIDENTS

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ABSTRACT

Advanced Driver Assistance Systems (ADASs) are today becoming increasingly common in the market. This also applies to trucks, in particular. In order to quantify the effects of ADASs on truck accidents in Germany, a comprehensive study was performed, using third-party vehicle claims involving personal injury and a total claim value of at least €15,000. This study is based on a total of 443 truck accidents. Statistical methods were used to extrapolate these accidents up to 18,467 claims.

To determine the possible effects of ADASs, relevant accident scenarios were identified, and system characteristics for generic ADASs were derived. Different stages of development for some of the systems were defined and evaluated, and the theoretical safety potentials of the generic ADASs were determined by systematic case-by-case analysis.

All types of road users (cars, trucks, buses, motorcycles, bicycles, and pedestrians) were included as the other parties to the collisions involving the trucks (gross vehicle weight more than 5,000 kg); single-vehicle truck accidents were also included. The calculated theoretical safety potential of the different ADASs is based on the assumptions that 100% of the truck fleet is equipped with these systems and that the driver reacts perfectly when warned.

The conclusions of the analyses are as follows: an autonomous emergency braking system (AEBS), which is able to detect moving and stationary two-track vehicles, warn the driver and perform a braking maneuver autonomously, was able to prevent up to 12% of all truck accidents in the data sample compared to just 6% for a system that is not able to detect stationary vehicles. The safety potential of a "turning-assistant system" and an intelligent rear view camera accounts for 6% of prevented accidents in relation to all truck accidents. Detailed analysis reveals that this covers 55% of all truck accidents against vulnerable road users (VRUs). Compared to current rear-view mirror technology, these assistance systems are much more effective. The theoretical safety potential of a lane departure warning (LDW) system was found to be up to 2%. Nevertheless, this small percentage equates to about 39% of all truck accidents caused by departing the lane.

The results of the study indicate that ADASs do not achieve the same safety potential for each of the three truck categories "solo truck", "truck and drawbar trailer" and "semi-trailer truck". This should be taken into consideration for future legislation. Although some of the ADASs examined show considerable safety potential for VRUs, the current European legislation does not take this into account.

DATABASE

The UDV (German Insurers Accident Research) is a department of the German Insurance Association (Gesamtverband der Deutschen Versicherungswirtschaft e.V. – GDV) and has access to all the third-party vehicle insurance claims reported to the GDV. There were 3.4 million of these claims in 2009. For the purposes of accident research, the UDV set up a database (referred to as the UDB), taking a representative cross-section of this large data pool. The data collected is conditioned for interdisciplinary purposes for the fields of vehicle safety, transport infrastructure and road use behavior. The contents of the claim files from the insurers form the basis of the UDB. The depth of information provided by the UDB is significantly greater than that of the German federal statistics [2]. Around 700 to 800 new cases are added to the UDB each year.

Data set and representativeness

Only third-party vehicle claims involving personal injury and damage costs of at least €15,000 were taken into account in the GDV accident database. Cases involving only damage to property and less se-

rious accidents involving personal injury (damage costs < €15,000) are not included in the UDB. Each year, a random sampling method [3] is used to collect stratified random samples that take into account the type of traffic involvement, the damage sum class and the time of year as stratification variables. Case-dependent extrapolation factors allow the sample in the UDB to be extrapolated to the target population of all claims in Germany. This ensures that the statements with respect to the safety potential of driver assistance systems refer to a representative sample of all claims dealt with by German insurers.
This study is based on a total of 443 truck accidents, which were extrapolated to a total of 18,467 cases. All types of traffic involvement were taken into account as the other collision party for the truck (cars, trucks, buses, motorcycles, bicycles and pedestrians) as well as single-vehicle truck accidents. Single-vehicle truck accidents are, however, underrepresented, since cases in which there is no injury or damage to a third party are not brought to the attention of the GDV.

METHOD

Analysis of the safety approach was carried out using a multi-step procedure (Figure 1). In the first step, the accidents involving trucks were selected ("B – Data pool") from the accident data stored in the UDB ("A – UDB database"). In the second step, key aspects of the course of the accidents were identified, and groups of ADASs were defined ("C – relevance pool 1") that could be expected to have a positive effect on the key aspects of the accidents (e.g. autonomous emergency braking system). In the third step, the system characteristics were derived for generic ADASs. Different stages of development of the systems were defined and evaluated ("D – Relevance pool 2"). It is of no significance for the analysis whether it is currently already possible to implement the technical system characteristics and whether the systems under consideration are already available on the market. It was also not the intention to carry out a comparison of the products. Fourthly, the theoretical safety potentials of the defined generic ADASs were determined by systematic case-by-case analysis ("E – Calculation of the theoretical safety potential SP_{theor}").
The cases were analyzed using the "What would happen if..." method. The prerequisite for this is that none of the vehicles involved in the accidents that were analyzed were fitted with an ADAS. This approach considers the course of the accident as it happened in reality and contrasts it with the course of the accident as it would have been with an ADAS (see also [4]). This makes it possible to determine the effect an ADAS would have had on the course of the accident if all the trucks had been fitted with the ADAS considered. Although a comparison between "trucks with ADAS" and "trucks without ADAS" would have been theoretically possible, this was not done. This is because there are still too few trucks fitted with modern ADASs in the overall total (and involved in the accidents). In addition, it was not intended to compare specific products.

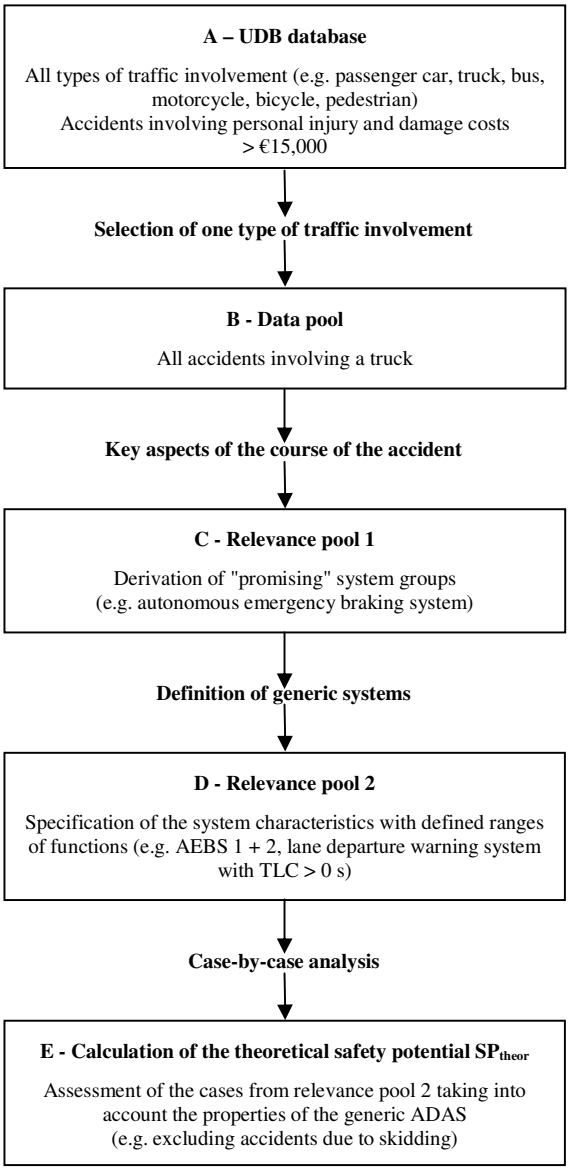


Figure 1. Multi-step approach in which A ≥ B ≥ C ≥ D ≥ E with respect to the size of the data pool.

The method of investigation selected initially assumes that a driver reacts perfectly 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. It is clear that this statement does not apply to completely autonomous ADASs.

RESULTS

The underlying case material here comprises 443 truck accidents from the years 2002 to 2006 involving 570 trucks. These were extrapolated to 18,467 accidents involving 22,863 trucks using the method described in [3]. Only accidents involving at least one truck with a gross vehicle weight of 5 tonnes or more were included. Pictures showing examples of such trucks are included in appendix 1.
The breakdown of the accident material with regard to the other collision parties in the accidents involving the trucks is shown in Figure 2. Only the main other collision party of the truck is shown. This is the road user with which the truck had the most serious collision involving the worst personal injuries. Cases in which trucks were indirectly involved (e.g. minor subsequent collisions between a vehicle already involved in a serious accident and the truck) are not shown in Figure 2. Truck/car collisions are the most common, accounting for 63% of the total, followed by truck/truck collisions (16%) and then collisions with cyclists (7%), motorcyclists (6%) and pedestrians (6%). Single-vehicle truck accidents account for less than 1% of the UDV's accident material and are thus clearly underrepresented in relation to the official statistics [2].

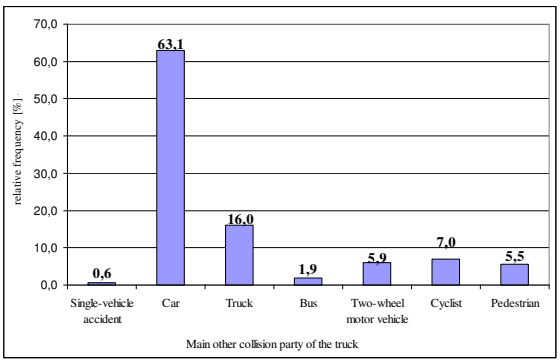


Figure 2. Single-vehicle truck accidents and main collision parties of the trucks in the accident material.

Accidents involving trucks were subdivided by " kind of accident" (see [2] for a definition) to determine the most frequent accident scenarios and rank them (Figure 3).
It is important to bear in mind here that the kind of accident only takes into account the first collision in an accident and therefore only delivers information about the constellation of the first collision, not about any further, secondary collisions. The kind of accident therefore does not necessarily indicate the collision that caused the most personal injury.
The most common accident scenario for trucks is a rear-end collision. These collisions, which account for almost 32% of the total, could be addressed by means of autonomous emergency braking systems. Scenarios (3) and (5) together account for the second largest share (23.6%). Lane departure warning systems and ESC systems could have a positive effect on this group of accidents.

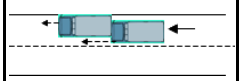
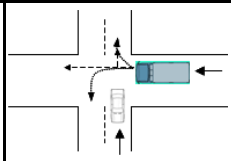
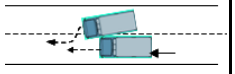
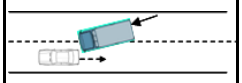
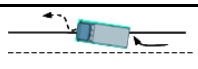
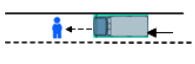
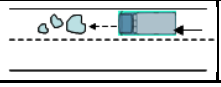
The most frequent accident scenarios $N_{data\ pool}$ **= 18,467 [100%]**		**% share**
(1) Collision with another vehicle that is: - Driving in front or waiting - Starting up, stopping or standing in stationary traffic		31.6%
(2) Collision with another vehicle that is turning into a road or crossing traffic		22.3%
(3) Collision with another vehicle that is moving laterally while traveling in the same direction		18.5%
(4) Collision with another vehicle that is traveling in the opposite direction		14.3%
(5) Vehicle leaving the road to the left or right		5.1%
(6) Collision between the vehicle and a pedestrian		4.4%
(7) Collision with an obstacle on the road		0.4%

Figure 3. Frequency of different accident scenarios in the truck data pool.

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

- Autonomous emergency braking system 1 and 2
- Turning assistant (for pedestrians and cyclists)
- Lane departure warning system
- Blind spot monitor
- ESC
- Reverse assist camera (for pedestrians)

The calculated safety potentials of all of these ADASs can be summed up (see "CONCLUSIONS").

Truck autonomous emergency braking system (AEBS) – description and safety potential

In this part of the investigation, only autonomous emergency braking systems were considered that address rear-end collisions exclusively and are thus very much on the model of the autonomous emergency braking systems that are currently available on the market. Two levels of system were defined: autonomous emergency braking system 1 (Table 1) only responds to moving, double-track vehicles ahead, whereas autonomous emergency braking system 2 can also detect stationary double-track vehicles.

Table 1.
System properties and derived database attributes for the current generation of autonomous emergency braking systems (AEBS 1)

AEBS 1:	
System description	**Application to the UDB**
- Forward detection of the environment (using the radar sensors of the adaptive cruise control system)	- Rear-end collisions with double-track vehicles ahead
- Detection of moving, double-track vehicles ahead (not stationary)	
Max. achievable deceleration: 7 m/s² (dry road); 6 m/s² (wet road)	- Breakdown of accidents by road conditions (dry/wet)
- Speed range: from 15 km/h; minimum speed of the vehicle ahead: 10 km/h	All accidents in which the speed of the truck that hits the vehicle in front is known
- Inability to detect vehicles that suddenly change lane	
- Warning by the system at TTC 3.3 s	
- Partial braking at TTC 2.3 s with 30% of the maximum braking power	
- Full braking with maximum braking power at TTC 1.3 s	

Truck autonomous emergency braking system 1 (AEBS 1) Taking the truck data pool as a basis (18,467 accidents), all rear-end collisions were selected in which the vehicle that hit the one in front was a truck and had not been in a collision with another road user beforehand (relevance pool 1). This pool was then further restricted to obtain rear-end collisions with moving, double-track vehicles (relevance pool 2). These were then subjected to a case-by-case analysis to examine the effect of AEBS 1. This system is an autonomous emergency braking system of the current generation. It is a fully automatic system that issues a warning when it detects acute danger, initiates partial braking and finally, if the driver does not react, maximum braking until the vehicle comes to a stop. It only responds to moving vehicles. The system properties of AEBS 1 are shown in Table 1.
The case-by-case analysis was carried out based on a simplified, conservative calculation that assumes the driver would not have reacted to the system's warning in any of the cases. Each case was then recalculated and only categorized as preventable if, taking into account a warning period of a second, a partial braking period of a second and possibly full braking, the speed of the truck would have been reduced to the speed of the vehicle in front of it without a collision. This calculation was thus purely theoretical and carried out, moreover, on the premise that the adaptive cruise control (ACC) system was switched off, because the ACC system generally uses the same sensors as the autonomous emergency braking system and would normally intervene first and initiate partial braking. For this reason and because it is assumed that the driver does not react, the figures given below represent the lower limit of the maximum prevention potential that can be expected for AEBS 1.
With an adjusted data pool of 12,273 cases (only accidents in which the truck's speed is known), the safety potential calculated for AEBS 1 is 6% of preventable accidents (Table 2) and 4% of both preventable fatalities and serious injuries (Table 3). When applied to all truck rear-end collisions (relevance pool 1: 2,815 cases), as many as 26.5% of these accidents could be prevented.
In Tables 2 and 3 as well as the subsequent tables, the

95% confidence interval [7] is specified in addition to the calculated safety potential. Due to these confidence intervals, SP_{theor} can – in some cases – decrease to "zero", especially if the number of (prevented) accidents and/or fatalities and injuries is small.

Table 2.
Accidents that could be prevented by AEBS 1

Truck accidents that could be prevented by	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
AEBS 1	12,273	2,815	1,239	746 **6% ± 2.7%**

Table 3.
Fatalities and injuries that could be prevented by AEBS 1

Fatalities and injuries that could be prevented by **AEBS 1**	Number of fatalities and injuries in the data pool (all truck accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	2,509	88	**3.5 ± 4.8**
Serious injuries	8,635	345	**4.0 ± 2.5**
Minor injuries	14,927	1,112	**7.4 ± 2.6**

Truck autonomous emergency braking system 2 (AEBS 2) A glance at relevance pools 1 and 2 in Table 2 reveals that collisions with stationary vehicles (the difference between the figures for the two pools, amounting to 56%) are of particular relevance as far as truck collisions with the vehicle in front are concerned. A new relevance pool 2 (of 1,576 cases) was therefore formed from the existing relevance pool 1. This consists of all the cases in which a truck has driven into a stationary, double-track vehicle. It was then examined to determine the effect of an enhanced autonomous emergency braking system (AEBS 2).
In addition to having the functionality of AEBS 1, AEBS 2 can also detect stationary vehicles. The method used to calculate the potential benefits of AEBS 1 was therefore adjusted in such a way that the theoretical prevention of an accident required braking that would bring the truck to a standstill without having a collision with the vehicle in front.
The accident prevention potential of AEBS 2 is considerably higher than that of AEBS 1 because it can detect stationary vehicles. It has a safety potential of 12%, which is almost twice that of AEBS 1 (Table 4). The potential for preventing fatalities is 4.9% (Table 5), while the potential for preventing serious injuries is 8.4%. AEBS 2 has the greatest effect on minor injuries, which are reduced by 17.5%. Over half of all collisions in which trucks collide with the rear end of another vehicle (52.3%) could be prevented by AEBS 2.

Table 4.
Accidents that could be prevented by AEBS 2, taking AEBS 1 as a basis

Truck accidents that could be prevented by	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
AEBS 1	12,273	2,815	1,239	746 6%
AEBS 2	12,273	2,815	1,576	725 (5.9%) **11.9% ± 3.8%**

Table 5.
Fatalities and injuries that could be prevented by AEBS 2, taking AEBS 1 as a basis

Fatalities and injuries that could be prevented by **AEBS 2**	Number of fatalities and injuries in the data pool (all truck accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	2,509	123	**4.9 ± 5.6**
Serious injuries	8,635	723	**8.4 ± 3.6**
Minor injuries	14,927	2,614	**17.5 ± 3.8**

Turning assistance system – description and safety potential

A further analysis of the accident material (18,467 cases) revealed that approximately 13% of truck accidents happen when trucks turn into another road. 80% of these cases involve the truck colliding with a cyclist or pedestrian. Collisions with cyclists and pedestrians make up a total of around 10% of all serious

truck accidents in the UDB. With a view to carrying out an analysis of a suitable advanced driver assistance system for turning maneuvers, all truck turning accidents were combined (relevance pool 1). The collisions with cyclists (641 cases) and pedestrians (170 cases) were selected from this pool to form relevance pool 2.
The generic system properties correspond to the properties of the turning assistance systems already developed for modern trucks [5]. However, additional functionalities were assumed (Table 6). The system has sensors that allow it to monitor the areas in front of and to the side of the truck and warn the truck driver when starting off or turning that a cyclist or pedestrian is approaching the truck. The turning assistance system can prevent the turning maneuver if there is a pedestrian in front of the vehicle at the time (at traffic lights, for example).
For the case-by-case analysis, an ideal driver was again assumed who reacts to the warning in good time and applies the brakes appropriately. The course of events in each case was examined anew, and it was assessed whether the accident was preventable given the assumptions made (e.g. the driver performs an emergency braking maneuver, or the system prevents the vehicle from starting off). The analysis of preventability was carried out with a view to establishing whether the driver had made a mistake. If the accident happened, for example, because the cyclist swerved while being overtaken and fell after contact with the truck/trailer (i.e. the truck driver could not have influenced the situation), the accident was considered to be not preventable.
A theoretical prevention potential of 4.4% of all truck accidents was calculated for the turning assistance system (Table 7). The prevention potential calculated for all accidents between trucks and cyclists/pedestrians was 42.8% (Table 8). As far as fatalities and injuries are concerned, 31.4% of fatalities, 43.5% of serious injuries and 42.1% of minor injuries would be preventable in these accidents (Table 9). This clearly indicates the great benefits of the system, particularly given that over 90% cyclists and pedestrians involved in these accidents were killed or seriously injured. 4% of the fatalities and 5% of the serious injuries occurring in all truck accidents would be prevented.

Table 6.
System properties and derived database attributes for the truck turning assistance system for cyclists and pedestrians

<table>
<tr><td colspan="3">Turning assistance system (cyclists and pedestrians):</td></tr>
<tr><td colspan="2">System description</td><td>Application to the UDB</td></tr>
<tr><td colspan="2">- Forward detection of the environment (sensor-independent)</td><td>- Turning accidents with cyclists and pedestrians</td></tr>
<tr><td rowspan="6">Detection of:</td><td>- Cyclists moving slowly close to the truck’s near side that are overtaken by the truck</td><td rowspan="7">All truck turning accidents with pedestrians and cyclists, accidents with pedestrians who cross in front of the truck when it is stationary or turning and accidents where the truck overtakes a cyclist</td></tr>
<tr><td>- Cyclists approaching the truck from behind as it turns to the near side</td></tr>
<tr><td>- Cyclists who stop on the near side of the stationary truck</td></tr>
<tr><td>- Pedestrians who approach the truck from the side when it is stationary or turning</td></tr>
<tr><td>- Pedestrians who are in front of the truck when it starts up</td></tr>
<tr><td></td><td>- No potential when turning to the off side</td></tr>
</table>

Table7.
Truck accidents that could be prevented by the turning assistance system for trucks, as a proportion of all truck accidents

Truck accidents that could be prevented by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Turning assistance system	18,467	2,414	811	811 **4.4% ± 1.9%**

Table 8.
Truck accidents that could be prevented by the turning assistance system for trucks, as a proportion of all accidents between trucks and pedestrians/cyclists

Accidents between trucks and pedestrians/cyclists that could be prevented by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Turning assistance system	1,892	854	811	811 **42.8% ± 13.2%**

Table 9.
Fatalities and injuries that could be prevented by the truck turning assistance system in accidents between trucks and pedestrians/cyclists

Fatalities and injuries that could be prevented by the **turning assistance system**	Number of fatalities and injuries in the data pool (all accidents between trucks and pedestrians/cyclists)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	369	116	**31.4 ± 25.2%**
Serious injuries	1,512	658	**43.5 ± 15.2%**
Minor injuries	171	72	**42.1 ± 43.3%**

Lane change and lane departure

In order to carry out an analysis for a Lane Keeping Assist system or lane departure warning system, accidents caused by drivers leaving their lane were identified. Although these are reflected in scenarios (3) and (5) in Figure 3, relevance pool 1 was formed because it describes these accident scenarios in a more concrete form for the purpose of carrying out further analyses. It only contains cases in which a collision occurred because the truck driver changed lane deliberately or left it inadvertently. Relevance pool 1 (2,297 cases) accounts for 12% of the underlying data pool (18,467 cases). In this section, the potential is calculated for the first group of cases, which occurred because of an intentional lane change. These cases (1,452) form relevance pool 2 and could be addressed by means of a suitable blind spot monitor.

Blind spot monitor – description and safety potential The blind spot monitor used here is a purely generic system that does not yet exist in this form for trucks. It monitors the adjacent lanes and detects road users of all kinds. If the driver indicates his intention to change lane by using an indicator and the system recognizes that a collision with a vehicle in the adjacent lane is imminent, it gives the driver a warning. The functionality of this generic blind spot monitor thus corresponds to that of the blind spot monitor that is already available for cars [8].
The analysis of relevance pool 2 shows that accidents that occur because of a deliberate lane change are generally not serious. This is frequently the case when the sides of the vehicles come into contact but neither of the vehicles goes into a skid or is forced off the road. Even the few rear-end collisions that result from a lane change are rarely serious. However, the case-by-case analysis clearly revealed that truck accidents that occur as a result of a lane change can only be inadequately analyzed, since the course of the accident and accident location rarely provide enough evidence to allow a reliable statement to be made about preventability. In some collisions with cars, for example, the truck driver did not immediately notice that the accident happened and simply continued driving. Contradictory accounts from witnesses and a lack of information about the accident location meant that it was no longer possible to work out retrospectively when and under what circumstances the lane change or collision occurred. As a result of this uncertainty, it was not possible to calculate the accident prevention potential of the blind spot monitor for trucks. The positive effect of the system was merely estimated.
The number of cases in which the system could have a positive effect corresponds to relevance pool 2 and is calculated as being 7.9% of all truck accidents (Table 10). Table 11 confirms that fatalities are very rare in these accidents and the number of serious personal injuries is also low. Only 1.4% of serious injuries could be prevented by a blind spot monitor, and the number of fatalities would not change at all.

Table 10.
Accidents that could be addressed by the truck blind spot monitor

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

Table 11.
Fatalities and injuries that could be addressed by the truck blind spot monitor

Fatalities and injuries that could be addressed by the **blind spot monitor**	Number of fatalities and injuries in the data pool (all truck accidents)	Fatalities and injuries that could be addressed	
		Number	SP_{theor} [%]
Fatalities	2,766	0	**0**
Serious injuries	11,959	172	**1.4 ± 1.4%**
Minor injuries	22,194	2,100	**9.5 ± 2.6%**

Lane departure warning system – description and safety potential The second group of accidents caused by drivers leaving their lane (relevance pool 1, containing 2,297 cases) consists of accidents caused by drivers inadvertently leaving their lane (relevance pool 2, containing 845 cases). The analyses showed that these cases were generally attributable to the truck driver being fatigued, distracted or inattentive. These accidents could be addressed by a lane departure warning system.

The functionality of the advanced driver assistance system considered here is based on the lane departure warning systems that are already available on the market [6]. The way in which it works is only slightly different from how the systems used in cars work. A video camera behind the windshield evaluates detected lane markings and warns drivers when they are about to leave the lane inadvertently. It thus helps drivers to keep in lane on freeways and other major roads outside built-up areas when they are being inattentive.

In the case-by-case analysis, the course of each accident was analyzed, assuming an ideal driver and a system working to optimum effect. The material on file is generally well documented and allowed an assessment to be made of preventability. If there was sufficient evidence to indicate that the truck would not have left its lane if the system had been in use, the accident was considered to be preventable.

The safety potential of the lane departure warning system as a percentage of all truck accidents is 1.8% (Table 12). The picture is similar for fatalities and injuries: 1% of serious injuries and 2% of minor injuries would be preventable (Table 13).

The accidents that could be prevented by a lane departure warning system (329) have a safety potential (SP_{theor}) of 38.9% of all accidents in which the driver leaves the road or lane inadvertently (845 cases).

Table 12.
Accidents that could be prevented by the lane departure warning system for trucks

Truck accidents that could be prevented by the	**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 13.
Fatalities and injuries that could be prevented by the lane departure warning system for trucks

Fatalities and injuries that could be prevented by the lane departure warning system	Number of fatalities and injuries in the data pool (all truck accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	2,766	0	**0**
Serious injuries	11,959	210	**1.0 ±1.2%**
Minor injuries	22,194	404	**1.8 ±1.2%**

ESC – safety potential

Although truck accidents caused by skidding and/or a rollover are rare (5% of all truck accidents), they often have serious consequences. The analysis of the UDB revealed that there is at least one person seriously injured or one fatality in around 60% of these cases.

To begin with, reference pool 1 (consisting of 1,035 cases) was formed from the data pool (of 18,467 cases). This reference pool contains all accidents in which a truck became involved in an accident as a result of unstable driving dynamics. There were a number of possible causes for this instability, such as:

- An evasive maneuver (the truck started to skid as a result of an evasive maneuver, for example, while overtaking when there was traffic coming in the opposite direction)
- Skidding after a minor collision
- Skidding/tipping on a bend in the road (as a result of leaving the road due to excessive speed)
- Skidding on a straight stretch of road (as a result of leaving the lane due to fatigue/inattentiveness and a subsequent corrective steering maneuver).

Relevance pool 2, which was used to examine the potential positive effects of an advanced driver assistance system, was the same as relevance pool 1. The effect of ESC (electronic stability control) was examined. Electronic stability control systems are already optionally available in some new trucks and will be mandatory for all newly registered trucks in the EU from 2013 [1]. The system has sensors that allow it to monitor the vehicle's driving dynamics. If there is a risk of the truck or trailer skidding or tipping, the sys-

tem intervenes by selectively applying brakes to individual wheels and stabilizing the vehicle combination.
Due to the complex processes involved in ESC intervention and insufficient knowledge about the actual course of the skid, it was not possible to carry out a calculation or analyze preventability in the same way as was done for the autonomous emergency braking system. Instead, an assessment was made as to whether ESC would have had a positive effect.
The result was that ESC had the theoretical potential to have a positive effect on 5.6% of all truck accidents (Table 14). There would also have been a positive effect on around 5% of all fatalities and serious injuries (Table 15). In other words, either the seriousness of the injury could have been reduced or accidents would have avoided so that no injuries occurred.

Table 14.
Accidents that could be addressed by ESC for trucks

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

Table 15.
Fatalities and injuries that could be addressed by ESC for trucks

Fatalities and injuries that could be addressed by ESC	Number of fatalities and injuries in the data pool (all truck accidents)	Fatalities and injuries that could be addressed	
		Number	SP_{theor} [%]
Fatalities	2,766	57	**2.1 ± 3.5**
Serious injuries	11,959	605	**5.1 ± 2.5%**
Minor injuries	22,194	1,169	**5.3 ± 1.9%**

Reverse assist camera – description and safety potential

Taking the truck data pool of 18,467 cases as a basis, the group of truck/pedestrian collisions (see scenario 6 in Figure 3) was also examined with a view to estimating the potential for preventing them. In these truck/pedestrian accidents (833 cases), it was conspicuous that there was a very high number of pedestrians injured when the truck was reversing. In the next step the extent to which an ADAS could have a positive effect on these accidents was examined.
It was assumed that the generic system monitors the area behind the truck and shows this area on a screen. If the engine is running and there is a pedestrian in the critical area behind the vehicle, an audible warning is given. The system prevents the vehicle from moving off or applies the brakes automatically if the driver does not react.
In the case-by-case analysis, the course of each accident was examined again and it was assessed whether the collision would still have happened under the assumed conditions. As expected, the potential benefits are relatively low: 1.2% of all truck accidents would be preventable by this system (Table 16). On the other hand, 27.1% of truck/pedestrian accidents could be prevented (Table 17). A glance at the number of preventable fatalities and injuries (Table 18) makes the benefits of a truck reverse assist camera even clearer: 18.1% of fatalities and 25.9% of serious injuries caused by all truck/pedestrian accidents could be prevented by a reverse assist camera.

Table 16.
Truck/pedestrian accidents that could be prevented by a truck reverse assist camera, as a proportion of all truck accidents

Truck/pedestrian accidents that could be prevented by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Reverse assist camera	18,467	833	226	226 **1.2% ± 1.0%**

Table 17.
Truck/pedestrian accidents that could be prevented by a truck reverse assist camera, as a proportion of all truck/pedestrian accidents

Truck/pedestrian accidents that could be prevented by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Reverse assist camera	833	226	226	226 **27.1% ± 11.8%**

Table 18.
Fatalities and injuries that could be prevented in truck/pedestrian accidents by a truck reverse assist camera, as a proportion of all truck/pedestrian accidents

Fatalities and injuries that could be prevented by the **reverse assist camera**	Number of fatalities and injuries in the data pool (all truck/pedestrian accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	226	41	**18.1 ± 26.7**
Serious injuries	632	164	**25.9 ± 22.9**
Minor injuries	57	21	**36.6 ± 66.8**

Relevance of ADASs for different truck categories

In this section it was investigated whether the advanced driver assistance systems (ADASs) investigated as described above had the same significance for different truck categories (i.e. whether they have the same potential benefits). Distinctions were drawn between the following truck categories:

- Solo truck
- Truck and drawbar trailer
- Semi-trailer truck

Table 19 examines the number of accidents that could be prevented by a specific ADAS in relation to the number of trucks involved in each of the three categories. To take an example, 2,890 trucks on their own were involved in the truck accidents under examination, and 64 accidents could have been prevented if the truck had AEBS 1, resulting in safety potential of 2.2%. Since the number of accidents is examined in relation to the number of vehicles involved here, the potential calculated is not directly comparable with the values calculated in the previous sections. However, they can be compared against each other in Table 19.
The two most important ADASs with the greatest potential for all three truck categories are the second autonomous emergency braking system (AEBS 2) and the blind spot monitor. ESC comes in third place for the categories “truck and drawbar trailer” and “semi-trailer truck”, whereas a turning assistance system can be expected to bring considerably greater benefits than an ESC system in the “solo truck” category. Table 19 also shows that a reverse assist camera has far greater safety potential for solo trucks than for trucks with drawbar trailers or semi-trailer trucks.

Table19.
Safety potential of ADASs depending on vehicle category

Advanced driver assistance system (ADAS)	Safety potential, SP [%]		
	Solo truck	Truck and drawbar trailer	Semi-trailer truck
AEBS 1 (p *)	2.2	6.1	5.1
AEBS 2 (p)	7.9	10.7	9.5
Turning assistance system, cyclists (p)	4.2	0.6	2.9
Turning assistance system, pedestrians (p)	0.5	0.9	0.8
ESC (pep **)	1.5	4.6	6.1
Blind spot monitor (pep)	6.8	5.2	6.4
Lane departure warning system (p)	1.6	1.8	1.3
Reverse assist camera (p)	3.0	0.5	-

* p = preventable

** pep = positive effect possible

CONCLUSIONS

EU legislation [1] requires that new truck models (with a gross vehicle weight of 3.5 tonnes or more) must be equipped with an autonomous emergency braking system and a lane departure warning system from November 1, 2013. Moreover, ESC is mandatory for some truck categories from November 1, 2011. This is intended to bring about the universal introduction of ADASs for trucks as quickly as possible.
The investigation showed that modern ADASs for trucks can have a positive effect on real-life accidents (involving personal injury and damage costs of €15,000 or more). The generic truck ADASs investigated were found to have safety potential (in terms of the preventability of accidents) of 1.2% of all truck accidents for a reverse assist camera, 1.8% for a lane departure warning system, 4.4% for a turning assistance system, which detects pedestrians and, in particular, cyclists, and 11.9% for an autonomous emer-

gency braking system, which detects double-track vehicles whether they are moving or stationary and automatically applies the brakes. In addition, a blind spot monitor could have a positive effect on 7.9% of all truck accidents, and ESC a positive effect on 5.6%. If all trucks with a gross vehicle weight of 5 tonnes or more were equipped with an autonomous emergency braking system, a turning assistance system, a lane departure warning system and a reverse assist camera, around 20% of the truck accidents examined in this investigation could be prevented. Moreover, a blind spot monitor and ESC could have a positive effect on around 15% of them.
However, the analyses carried out also showed that not every ADAS is equally valuable for every truck category. For example, the second autonomous emergency braking system (AEBS 2), a blind spot monitor and a turning assistance system are particularly important for solo trucks, whereas AEBS 2, a blind spot monitor and ESC are particularly important for trucks with drawbar trailers and semi-trailer trucks.

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APPENDIX 1

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

Solo truck ≈ 5 tonnes GVW

Solo truck ≈ 12 tonnes GVW

Solo truck ≈ 18 tonnes GVW

Truck + drawbar trailer ≈ 40 tonnes GVW

Semi-trailer truck ≈ 25 tonnes GVW

Semi-trailer truck ≈ 40 tonnes GVW