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Real World Effects of Advanced Driver Assistance Systems

Accident patterns for cars with and without ADAS

GDV
Unfallforschung
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1. Introduction

The current study was presented on the 28th ESV conference and is based on the Master's theses of Isabella Aleshina-Baerwald and Marco Mario Lutze, supported by the German Insurers Accident Research and the Department of Vehicle Engineering at TU Berlin [1, 15]. The aim of this work is to identify real-life evidence of reductions in accident occurrence in support of the accident-reducing potential of automatic emergency braking systems for vehicle fronts, which has been assumed in many studies [2]. In its studies of 2020, 2021 and 2025, the IIHS-HLDI provided evidence of the impact of ADAS on various aspects of insurance statistics [3, 4, 5]. Thus, it was possible to observe a considerable reduction in loss frequency for vehicles equipped with AEB systems across all the manufacturers included in the study. There is no reason why it should not also be possible to compare accident groups with and without AEB in Germany. The systems have now been available on the market for long enough to achieve a suitably high level of penetration within the vehicle fleet. It was necessary to wait until this was the case in order for there to be enough accidents involving AEB-equipped vehicles for it to be possible to compare these with an equivalent group involving vehicles not equipped with this system. A survey conducted by the German Federal Highway Research Institute (BASt) for 2023 shows that up to 28% of the German vehicle fleet is now equipped with active braking systems [6]. With a prevalence of up to 54%, these systems are most frequently fitted in the upper midrange and luxury classes, as well as in SUVs.

In the past, assistance systems that support drivers in their lateral vehicle control tasks have also been presumed to have positive effects, albeit to a lesser extent [2]. Here again, the higher proportion of the vehicle fleet now equipped with these systems means that it is now possible to validate these figures on the basis of their real-world effects on accident occurrence. The German Federal Highway Research Institute estimates that the prevalence of these systems in Germany in 2023 could have been as much as 25% [6].

2. Underlying data and methodology

Using the method presented here, it will naturally not be possible to document accident prevention: By definition, an accident database does not contain accidents that were avoided. However, by designing the analyses appropriately, it will be possible to identify the shifts in accident patterns that are observed when comparing groups of vehicles either equipped or not equipped with AEB that are involved in accidents. This method will be applied not only to AEB but also to blind spot detection (LCA) and lane-keeping systems (LSS). These shifts occur because the system responds to (prevents) certain situations better than others. In turn, the situations that are not addressed then account for a larger share in the relative proportions of all situations.

Since the method used for all three systems is the same, it will be explained only in connection with AEB below. Nevertheless, the composition of the various analysis pools will be presented individually in the sections devoted to the various systems. The datasets for the various cases differ.

It should also be noted that, in contrast to the AEB evaluation, the analyses for LCA and LSS systems are somewhat more conservative. This is because both systems can be switched off and ignored by the driver. So, the accident data did not always clearly indicate whether the LCA/LSS system was actually active at the time of the accident (e.g., it was deactivated or not in use). For this reason, and due to the very small number of cases, a statistical significance analysis was not applied for these systems.

3. Accident database of German Insurers Accident Research (UDB)

German Insurers Accident Research has access to all the third-party motor insurance claims reported to the GDV. A representative selection of approximately 500 cases per year are recorded in the UDB database. However, only accidents involving personal injury and damage costs of at least 15,000 € are entered in the UDB. Cases involving property damage but not personal injury and accidents involving personal injury and damage costs of less than 15,000 € are not included in the UDB. The database currently includes 10,500 accidents involving cars. The study was based on a relevant subset of accidents from the UDB in which at least one car equipped with an emergency brake assist system was involved. The sample comprised accidents for the years 2011 to 2022. Car accidents without emergency braking systems from the same period were selected as the comparison group. The overall sample therefore comprised 3,027 accidents involving a total of 5,023 cars (see Figure 1).

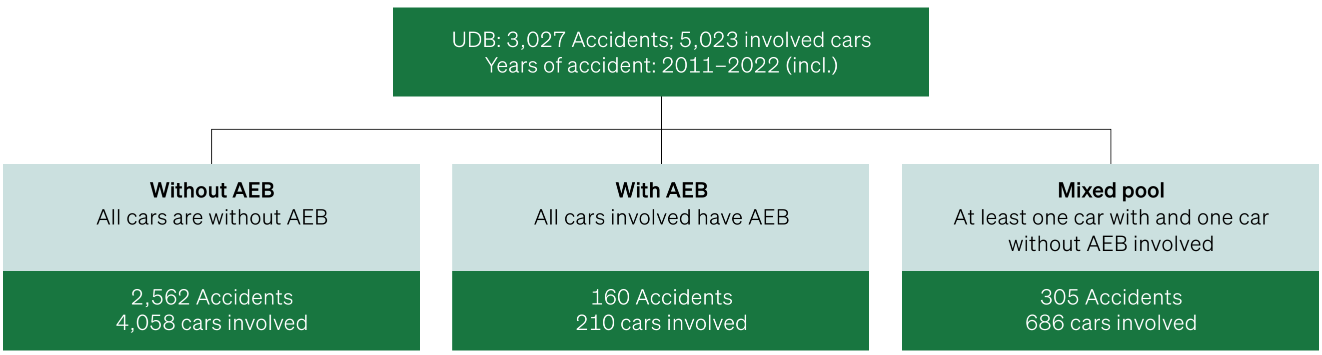
Identification and analysis of AEB-relevant accident scenarios

The analysis consisted primarily of the following steps:

a. Formation of the data pools for comparison (with and without AEB)
b. Identification of relevant accident scenarios which fall within the scope of modern AEB systems
c. Comparison of the two pools (with and without AEB) with regard to the course of the accidents, their severity and their consequences
d. Identification of shifts in the accident patterns
e. Identification of the reason why AEB did not trigger or did not trigger sufficiently.

Accidents with cars with and without AEB were analyzed in different pools

Figure 1 · Overview of the individual relevance pools for the comparative analysis of accidents “with AEB” and “without AEB”



a. The relevant pools were formed in a number of different stages on the basis of a case-by-case analysis. In each case, the exact course of the accident and the presence of a system at the individual vehicles were taken into account. One and the same accident could involve cars both with and without AEB (Figures 1). Following an initial preliminary selection of three pools ("only with AEB", "only without AEB", "with and without AEB"), the vehicles were assigned to the appropriate category and the accidents were finally collated within two pools: "with AEB" and "without AEB". The question of whether or not the car in question had caused the accident was not the deciding factor. This is because by extending the analyses to all the vehicles involved (and not just the vehicle causing the accident), it was possible not only to gain a picture of all the accidents that fall within the scope of action of AEB, but also to increase the number of cases for the individual pools. Example: If, in an accident involving three parties, the car with AEB system was the third party to be involved, namely in the form of a rear-end collision with the second party driving in front of it because this second party had to swerve suddenly due to an earlier mistake of another vehicle, then the accident was considered to be relevant.

b. An initial, general identification of accident black spots was performed on the basis of the "Accident type" and "Kind of accident" characteristics [7, 8]. A case-by-case analysis was performed due to the large number of collision scenarios that theoretically fall within the scope of action of AEB systems but can nevertheless not be fully defined based on the above-mentioned characteristics.

c. The comparative analysis of the two pools – "with AEB" and "without AEB" – was performed based on selected characteristics taken from the UDB database [1].

d. All shifts in the accident patterns were also determined on the basis of a case-by-case analysis. The results are presented in simplified form based on Accident type and Kind of accident, as well as in detail based on selected characteristics from the UDB. In connection with this, the presentation of the results based on Accident type and/or accident category is also intended to show how multifaceted the scenarios covered by AEB can be.

e. In the light of the vehicle manufacturers' specifications regarding the scope of operation of automatic emergency braking systems, the study analyzed not only shifts in accident patterns but also possible reasons why the accidents occurred despite being theoretically covered by the operation of the AEB system. This made it possible to identify the reasons for the accident in more detail, e.g.:

   - Limit of the system's operating capabilities reached, e.g. high speed ranges / sudden cutting-in by the vehicle in front
   - Hazard detection impacted/disrupted by external factors (e.g. overrides resulting from steering maneuvers or acceleration due to mistaken pedal use)
   - System failed to react because components not robust or susceptible to technical errors.

4. Stages of technical development (AEB) in the light of consumer protection and legislation

In 2013, the EuroNCAP consumer protection organization published the first assessments of various manufacturers' automatic emergency braking systems [9]. As part of the corresponding tests, EuroNCAP developed its Generic Vehicle Target (GVT). Since January 2014, the automatic emergency braking system has been taken into account in the star rating awarded to every new vehicle [10].

The first tests differentiated between AEB inside and outside of built-up areas. In both cases, the aim was to detect rear-end collisions with double-track vehicles. In the case of AEB systems for use in built-up areas (AEB City), automatic emergency braking should be performed in response to stationary obstacles. The test vehicle is traveling at between 10 and 50 km/h. At higher speeds (up to 80 km/h), AEB for use outside of built-up areas (Interurban AEB) should be able to react to stationary and slow-moving vehicles as well as to vehicles performing sudden braking maneuvers. In these tests, a warning of an impending collision (FCW – Front Collision Warning) is expected and the systems should be able to brake automatically. The speed ranges in which the system was able to prevent a rear-end collision as well as those in which it was able to reduce accident severity are documented. The tests are performed with and without the driver reacting to the warning.

As of 2016, AEB systems have been tested for their response to pedestrians. This opened up a new test category and the AEB Pedestrian Protocol was introduced alongside AEB Car-to-Car. The first pedestrian tests consisted of three classic scenarios: a pedestrian crossing from both sides and a child running out onto the road between parked cars [11]. EuroNCAP developed pedestrian targets with adult and child builds for these tests (EPT – EuroNCAP Pedestrian Target).

In 2018, EuroNCAP added a scenario with a pedestrian walking in front of the car and in the same direction as it. The first tests in the dark were performed. In addition, a further AEB functionality of the test vehicles was put to the test – reaction to cyclists. The first two scenarios were designed to test daylight collision situations with crossing cyclists and cyclists traveling in the same direction as the car.

In the years up to 2020, the test speeds and rating points for the rear-end collision scenarios were adapted and test scenarios with an overlap to the slow-moving target vehicle were added. Since 2020, the distinction between City and Interurban AEB has been eliminated due to the advances made in vehicle sensor technology. In AEB Car-to-Car, the systems are rated on the basis of their responses in various speed ranges. Reactivity to stationary vehicles located at an offset to the target and a collision situation with a left-turning vehicle in the oncoming traffic stream were also added. In 2020, the scenarios involving unprotected road users were also revised. The systems were now required to react to cyclists even with the view on the right-hand side blocked, and reversing and turning vehicles had to be able to react to pedestrians. In 2023, only two accident scenarios were added for unprotected road users: Detection of cyclists approaching from the opposite direction prior to the turning maneuver and responsivity to a child running out between cars in the dark. A major review was conducted in the field of Car-to-Car AEB. The result was that the AEB system was required to react to oncoming traffic and turning double-track vehicles. The requirement to be able to detect two-wheel motor vehicles was also added. Since then, interactions with motorcyclists have been tested with the following three scenarios: slow-moving motorcycle traveling in the same direction ahead of the car, stationary motorcycle, and oncoming two-wheel motor vehicle while car performing a left-turn maneuver. With the exception of the last scenario, the systems are tested both for automatic braking and for braking with driver reaction [12].

The requirements of the tests and crash tests are constantly adapted by EuroNCAP. The requirements are always more stringent than the legal minimum standards, where these exist. The continuous further development of the test procedures is always based on knowledge gained from accident research and currently accepted engineering practices. The General Safety Regulation (EU Regulation 2019/2144) governs the mandatory introduction of new safety technologies for new type approvals and newly registered vehicles in the European Union [13].

This Regulation defines time points by which all new vehicles must be equipped with AEB systems and the functionalities which these systems must provide. The dates for the mandatory introduction of automatic emergency braking systems can be found in Table 1.

The are different dates for the mandatory introduction of AEB systems depending on their functionalities

Table 1 · Requirements for the equipping of class M1 and N1 vehicles with AEB systems [13]

Requirement	Scope of application	Date of introduction
Review of the literature and Equipping of vehicles of classes M1 and N1 with an AEB system	New type approvals	From 6th July 2022
	New vehicle registrations	From 7th July 2024
Active intervention by systems on detection of pedestrians and cyclists	New type approvals	From 7th July 2024
	New vehicle registrations	From 7th July 2026

5. Results regarding AEB

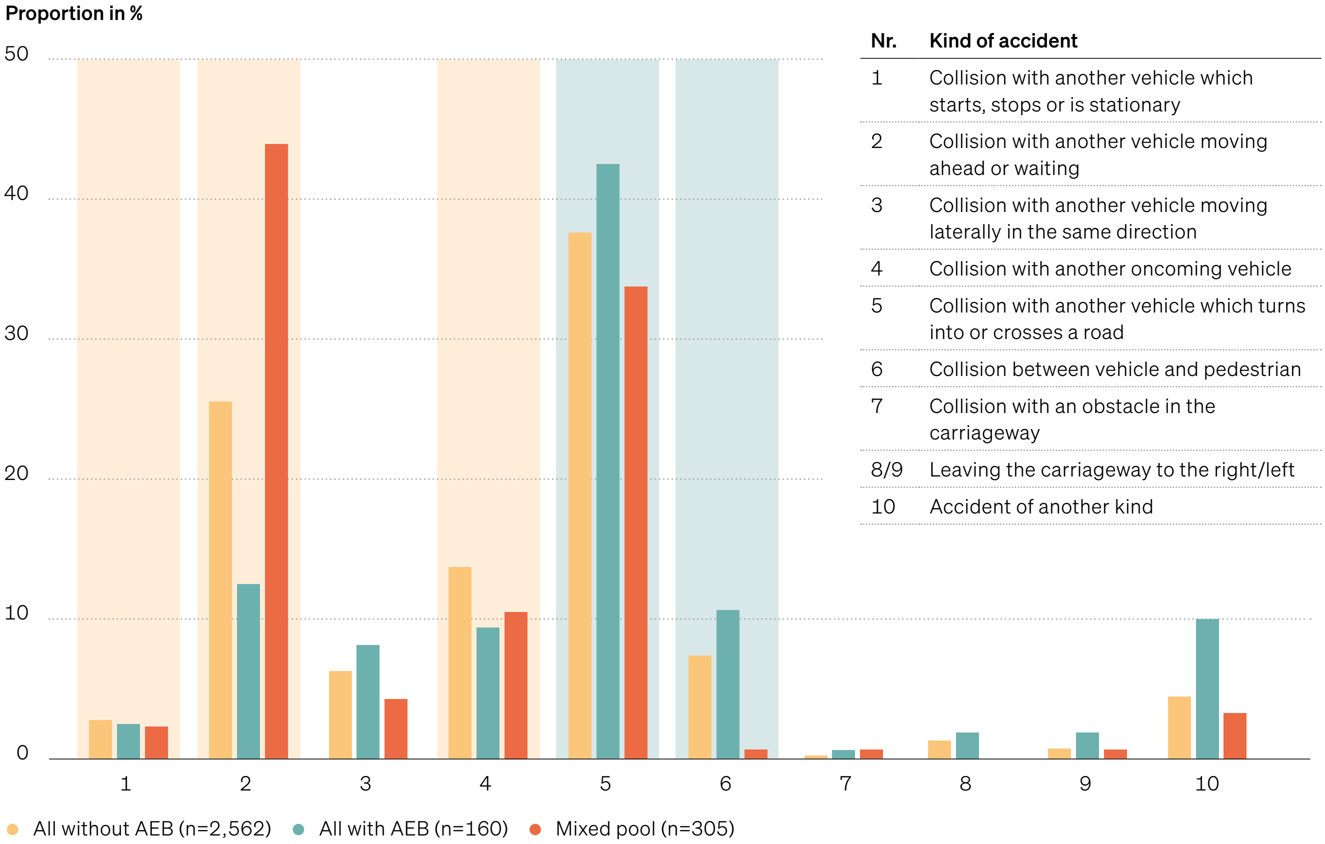
The relevant accident scenarios were identified based on the individual relevance pools (see Methodology section, Figure 1) and taking account of the various stages in the development of AEB. These scenarios were subdivided into the following categories:

a. Rear-end collisions with double-track vehicles
b. Collisions with unprotected road users (pedestrians and cyclists)
c. Collisions with two-wheel motor vehicles
d. Collisions with oncoming traffic
e. Collisions with double-track vehicles turning into/crossing the carriageway.

This subdivision of the ten Kinds of accidents makes it possible to identify the first general shifts in the accident patterns (Figure 2). A comparison of the results for the first two pools immediately shows that Kind of accident 1, 2 and 4 occur less frequently in the pool "All with AEB" than in the pool "All without AEB". This type of positive shift can be seen for Kind of accident 2 "Collision with moving or stationary vehicles in front": Whereas a quarter of all accidents in the pool "All without AEB" can be assigned to this Kind of accident, the proportion in the pool "All with AEB" is only 12.5%.

AEB systems show their highest benefit in terms of reducing the share of rear end accidents

Figure 2 · Overview of the individual relevance pools and presentation of the shifts based on the "Accident category" characteristic



Nr.	Kind of accident
1	Collision with another vehicle which starts, stops or is stationary
2	Collision with another vehicle moving ahead or waiting
3	Collision with another vehicle moving laterally in the same direction
4	Collision with another oncoming vehicle
5	Collision with another vehicle which turns into or crosses a road
6	Collision between vehicle and pedestrian
7	Collision with an obstacle in the carriageway
8/9	Leaving the carriageway to the right/left
10	Accident of another kind

One apparently negative shift, reflected by a higher proportion of accidents in the pool “with AEB”, can be seen in connection with Kind of accident 5 and 6. On the one hand, this may be due to the 100% formed from the remaining accidents excluding Kind of accident 1 and 2. Another reason, however, is that the technical requirements placed on the sensors and data processing technology for the detection of unprotected road users and crossing vehicles (accident category 5) are different from those involved in the detection of leading double-track vehicles. At first glance therefore, this makes the higher proportion of these accident categories in the pool “with AEB” plausible. To make the situation clearer, these accidents were examined again separately. A further differentiation between accidents with cyclists and pedestrians and accidents with two-wheel motor vehicles was considered necessary because, among other things, these groups have different typical speed ranges.

The detection of oncoming vehicles (Kind of accident 4) is not currently considered to be one of the primary areas of action for AEB systems, and emergency braking to avoid accidents resulting from high relative speeds will occur only infrequently. Consequently, the results for accident category 4 cannot be interpreted without more detailed examination. The further-reaching analysis of accidents with oncoming traffic in the following sections should make it clear whether the reduction is due to the effect of the AEB system or to other systems.

6. Rear-end collisions

Accident patterns, casualties

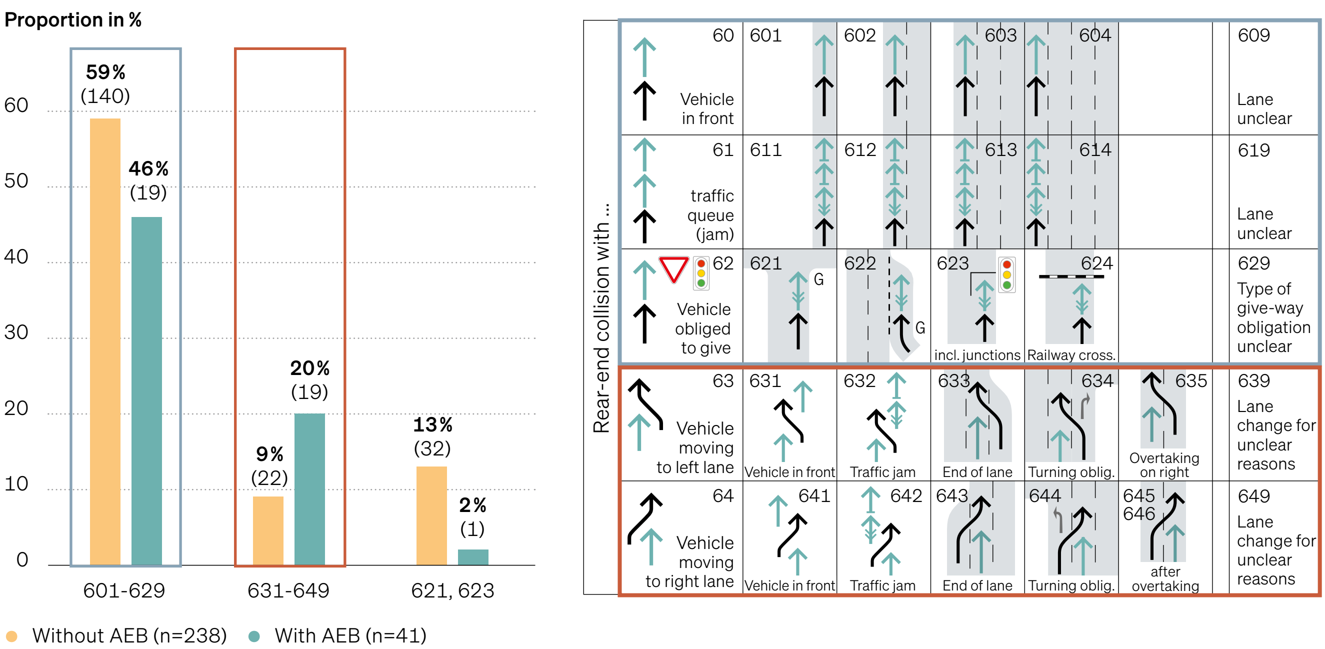
By definition, rear-end collisions are primarily represented by "Kind of accident" characteristics 1 and 2 [8].

A reduction in their proportion in the pool "All with AEB" in Figure 1 might in itself be an indication that the use of automatic emergency braking systems effectively prevents such accidents. The question of whether the systems are indeed effective in such cases is examined below. To this end, both rear-end collisions involving two parties and accidents involving more than two parties were taken into account, subject to the proviso that the case-by-case analysis had indicated that these accidents fall within the scope of action of AEB. Since the analyses for the two groups paint a similar picture, only the results for the larger group, i.e. accidents involving two parties, are presented by way of an example here. The shifts already revealed based on the Kinds of accidents 1 and 2 are extended and demonstrated more concretely here on the basis of the relevant three-digit Accident types [7] of accidents in longitudinal traffic (Figure 3).

In general, the Accident types 601-629 (Group 1) listed in Figure 3 describe classic rear-end collisions with a vehicle moving ahead or waiting, whereas Accident types 631-649 could initially be seen as belonging to the so-called "cut-in" scenarios (when a vehicle moving ahead suddenly cuts into the traffic stream). The fact that the proportion of accidents in Group 1 (Figure 3, red border) is 13% lower indicates that automatic emergency braking systems may be effective in such situations. The accidents described in this group represent the primary area of action for AEB

AEB benefit visible in terms of lower share of standard rear-end scenarios but not for "cut-in" scenarios

Figure 3 · Rear-end collisions involving two parties – Presentation of the shifts based on the three-digit Accident type



systems and were already addressed in the initial EuroNCAP protocols. However, at this point, the observed purely descriptive tendency for the number of rear-end collisions to be reduced by emergency braking systems cannot yet be proven using statistical methods.

This is contrasted by the observed distribution of cut-in situations in the defined data pools (Figure 3, blue border). Accident types 631- 649 are 11% more frequent in the pool “with AEB”. Given that it is known to be difficult to prevent this category of collisions due to sensor-related (limits of the lateral detection area) and physical reasons (generally small distances and short braking windows), the correlation can be interpreted as being statistically significant in a one-tailed test with a small effect size.

Accident types 621 and 623, by contrast, generally describe typical rear-end collisions at junctions in built-up areas. These are 11% less frequent in the pool “with AEB” than in the comparison pool “without AEB”. There is a statistically significant correlation with a small effect size. The results therefore point to a possible need to optimize the systems with regard to cut-in scenarios leading to rear-end collisions.

Further insights can be gained from considering accident severity, which is expressed here in terms of “collision speed” and “braking before accident” (Table 2). Here again, a reduction can be observed in the pool “with AEB”. Thus, Table 2 shows that vehicles with AEB braked 26% more often before the accident and that, on average, they decelerated by 30km/h more than vehicles without AEB.

This picture is also confirmed by an analysis of the severity of the consequences of the accidents. This shows that the proportions of fatalities and cases of serious injury are both 3% lower in the pool “with AEB”. A comparison of the MAIS injuries clarifies things further: The proportion of MAIS3+ injuries is 7% lower in the pool “with AEB” than in the pool “without AEB”.

Benefit of AEB visible in terms of less severe accidents due to a higher share of braking maneuvers

Table 2 · Rear-end collisions involving two parties – Presentation of the shifts based on accident severity

Criterion	**Without AEB** (n=82)	**With AEB** (n=32)	**Statistical significance**
Average year of initial vehicle registration	2014	2017	–
Average personal injury and damage costs	61,400 €	33,700 €	no, U=1,048.5; Z=–1.58; **p=0.12**
Braking before accident	42%	68%	yes, χ^2 (1)=4.09; **p=0.04**; ϕ=0.26
Average deceleration [km/h]	10	40	no, U=7.5; Z=–1.613; **p= 0.154**
Total fatalities	4 (3%)	0 (0%)	no, U=1,264; Z=–1.09; **p=0.28**
Total serious injuries	22 (18%)	8 (15%)	no, U=1,303; Z=–0.08; **p=0.94**
Total minor injuries	97	47	no, U=1,166.5; Z=–1.04; **p=0.3**
Total life-threatening injuries (MAIS 3+)	10 (9%)	1 (2%)	no, U=1,208.5; Z=–1.33; **p=0.18**

Recommendations for developing more robust systems

The following recommendations for the further development of the systems can be made based on the identified accident patterns, key issues and detailed analyses:

- Improved functionality in the high speed range
- Better detection of cut-in situations as well as of hazards after turning-off maneuvers and in bends (see Figure 3).
- More reliable hazard recognition in conditions of poor visibility and complex situations (ADAS as an extension of driver's abilities)
- Extension of detection range through purposeful merging with other systems (e.g. V2X)
- Recognition of incorrect driver interventions and unintentional overriding of system (e.g. steering).

With regard to the EuroNCAP test protocols, the recreation of more realistic test environments is also strongly recommended as a way of improving the robustness of the systems. Based on the results, the following extensions are proposed:

- Poor visibility, e.g. rain, dark, fog, glare from sunlight, contrasted lighting (shadow)
- Recreation of motorway environment for tests in high speed range, e.g. with crash barriers, vehicles passing by at speed, no lighting at night
- Replication of dense traffic situations, e.g. with more vehicles in the immediate environment and traveling at a similar speed.

With regard to legislation, the following recommendations are made for adapting system requirements and approval tests:

- Extension of the speed range in which the automatic emergency braking system must be active: Inclusion of higher speeds (> 60 km/h) in the approval tests and replication of situations in which the vehicle pulls away after stopping (0-20 km/h)
- Requirement for correct collision detection when vehicles partially overlap: Variation of the collision positions of the test vehicles in the case of overlaps
- Requirement for hazard detection in the dark: Variation of the lighting conditions in the test scenarios
- Detection of hazards during turning-off maneuvers.

7. Accidents involving unprotected road users

The following sections present the results of the comparative and case-by-case analyses of accidents involving pedestrians and cyclists. To exclude possible effects of the improved passive safety of more recent vehicles in protecting other road users, older vehicles (with year of initial registration before 2011) were extracted from the data pool "without AEB". This permitted a better comparison of the two pools.

Accident patterns, casualties

Figure 4 shows the breakdown of the seven Accident types for the two pools. One striking feature is the low proportion of crossing-over accidents, which explicitly point to collisions with pedestrians, in the pool "with AEB". This initially suggests that AEB successfully prevents such accidents.

Although the observed shifts cannot be validated as being statistically significant, they nevertheless support the assumption that AEB systems are gradually showing their effectiveness in a way that corresponds to the timing of the introduction of the system functionality. Thus, crossing-over accidents were one of the first test cases examined by EuroNCAP, being assessed as of 2016, whereas turning-off scenarios involving unprotected road users have only been taken into account as of 2020.

AEB systems show their benefit in terms of reducing accidents with crossing pedestrians

Figure 4 · Accidents involving unprotected road users – Breakdown of Accident types

This picture is also confirmed when the accidents are considered in the light of the direction of movement of the car alone (Table 3) or the relative directions of movement of the parties involved in the collision (Table 4). Accidents in which the car is traveling straight ahead and collides with a crossing unprotected road user occur less frequently in the pool "with AEB" than in the pool "without AEB", suggesting that such situations are successfully prevented by AEB. The difference in the relative frequencies of these cases is approximately 24% and is statistically significant in a one-tailed test (Table 4).

AEB systems show their benefit in terms of reducing the share of accidents with cars travelling ahead but not for turning-off scenarios

Table 3 · Accidents with unprotected road users – Direction of travel of car prior to accident

Criterion for comparison	**Without AEB** (n=346)	**With AEB** (n=12)	**Statistical significance**
Proportion of accidents with car travelling **straight ahead**	31%	18%	yes, $\chi^2(1)=5.2$; **p=0.023**; $\phi=-0.12$
Proportion of accidents with car **turning off**	48%	82%	yes, $\chi^2(1)=5.48$; **p=0.19**; $\phi=0.13$

AEB systems show their benefit in car to VRU accidents with perpendicular moving direction of the involved parties

Table 4 · Accidents with unprotected road users – Directions of movement of car and pedestrian/cyclist prior to collision

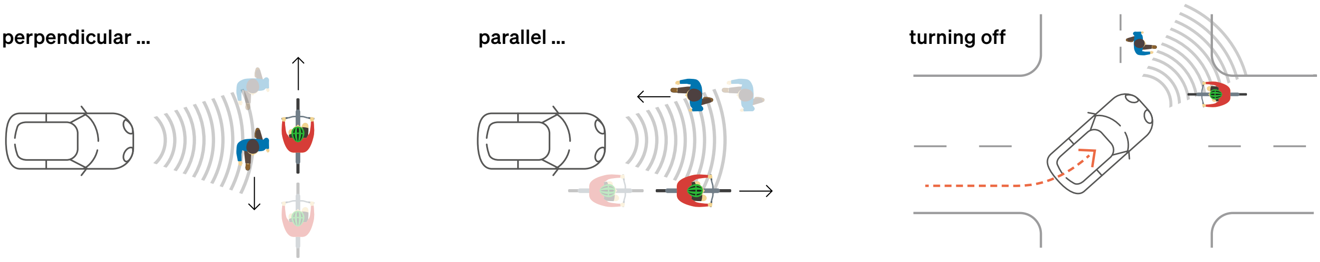
Criterion for comparison	**Without AEB** (n=346)	**With AEB** (n=12)	**Statistical significance**
Proportion of accidents with **perpendicular** directions of movement)	33% (114)	9% (1)	yes, one – tailed tests $\chi^2(1)=4.04$; **p=0.066**; $\phi=-0.11$
Proportion of accidents with **parellel** directions of movement	9% (31)	9% (1)	no, $\chi^2(1)=0.05$; **p=1**
Proportion of accidents during **turning off**	28% (97)	58% (7)	no, $\chi^2(1)=5.43$; **p=0.04**; $\phi=-0.13$

These results were compared with the EuroNCAP scenarios on the basis of the time of introduction (Figure 5). It can be seen that the scenario "car travelling straight ahead vs. crossing VRU" was the first tested scenario in the timeline history of EuroNCAP [14].

AEB systems show their benefit in VRU scenarios that were tested first in EuroNCAP history

Figure 5 · Car accidents involving cyclists and pedestrians – Analysis of the directions of movement based on the EuroNCAP test scenarios [14]

Criterion for comparison	Without AEB (n=346)	With AEB (n=12)
Proportion of accidents with **perpendicular** directions of movement (Euro NCAP scenarios since 2016 or 2018)	33% (114)	9% (1)
Proportion of accidents with **parallel** directions of movement (Euro NCAP scenarios since 2018)	9% (31)	9% (1)
Proportion of accidents during **turning off** (Euro NCAP scenarios since 2020 or 2023)	28% (97)	58% (7)



In addition to the above-mentioned positive effects, the breakdowns of the Accident types in Figure 4 and of the directions of movement in Tables 3 and 4 also point to two aspects that reveal potential weaknesses in the AEB systems. Thus, the pool with AEB shows tendentially negative shifts in the following two configurations:

- Turning-off maneuvers by the car
- Accidents involving parties moving parallel to one another.

The higher proportion of turning-off accidents in the pool "with AEB" confirms the impression that further optimization is needed in this area, while also showing that this functionality has not yet been able to produce any visible effect on real-world accident occurrence due to the later introduction of the test scenarios (since 2020). The statistical significance of these shifts confirms this observation.

The higher proportion of turning-off accidents also explains the lower average vehicle speed (turning-off maneuvers are typically performed at lower speeds than driving straight ahead) and the higher frequency of accidents at junctions.

However, it is also necessary to mention that turning-off scenarios have only been evaluated by EuroNCAP as of 2020/2023. The effectiveness of this extended functionality is not yet observable in the analyzed dataset, in which the average year of initial registration of vehicles equipped with AEB is 2020. This can be seen in the higher relative frequency of these cases in the pool "with AEB".

On the one hand, this lack of impact may be due to the fact that the vehicles do not yet possess a given functionality because this was not part of the specifications for their model year. On the other, the extended functions may only have a limited effect despite the presence of test requirements. A certain development and market penetration period is necessary to improve the robustness of the systems and achieve their more widespread use in vehicles before it becomes possible to observe their positive effects in real-world accident occurrence.

Recommendations for developing more robust systems

The following adaptations to the EuroNCAP test protocols are suggested in order to achieve the aims embodied in the recommendations:

- Replication of situations in which the AEB vehicle pulls off after stopping as part of the pedestrian and cyclist tests.
- The scenarios with crossing pedestrians and cyclists are due to be included in the "Start-from-Stop" protocols as of 2026.
- It is also recommended that the tests should be carried out with the wheels at full lock in order to simulate the intention to turn off.
- It is considered advisable to adapt the weighting of the turning-off scenarios in the overall assessment so that reliable detection and reaction in these scenarios contributes more heavily to the star rating.

With regard to legislation, the following adaptations to the system requirements and approval tests are recommended:

- Extension of the test scenarios to include lower lighting levels in order to improve detection in the dark
- Testing of system functionality not only on straight roads but also during turning-off maneuvers
- Extension of the lower speed limit during the approval tests (in particular with low speeds in the scenarios with unprotected road users).

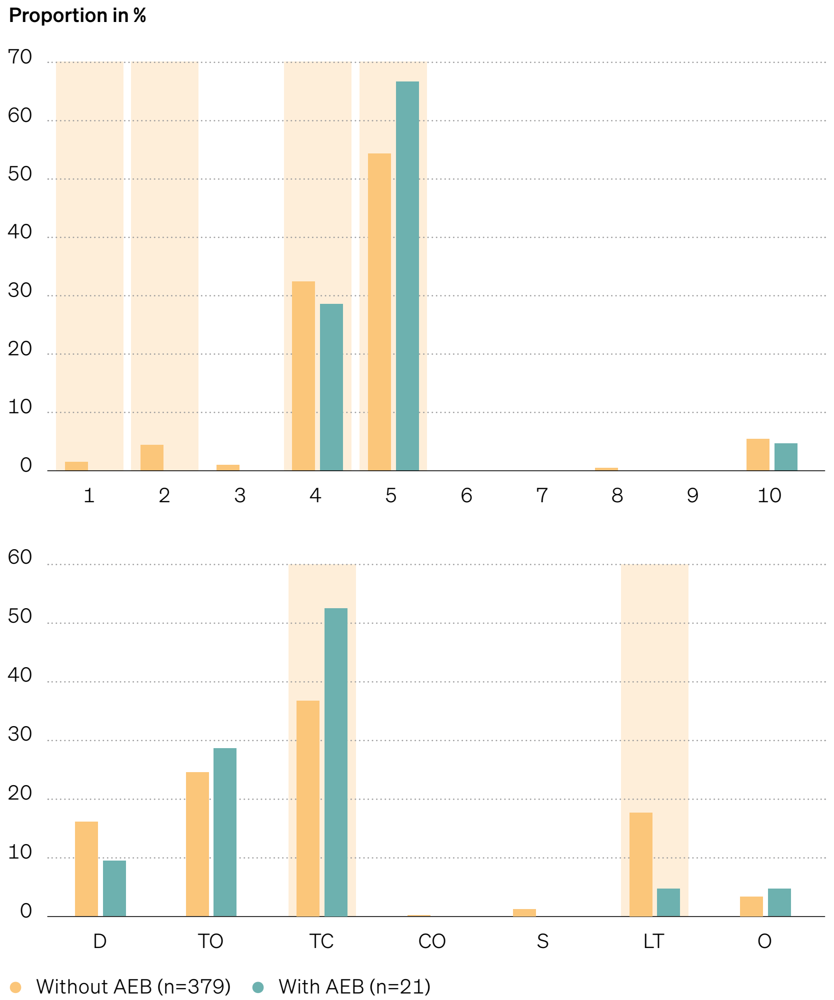
8. Other scenarios

Accidents involving motorized two-wheelers

Overall, no positive shifts were observed in connection with accidents involving motorized two-wheelers. The lower proportion of rear-end collisions (Kinds of accidents 1 and 2) and collisions with oncoming traffic (Kind of accident 4) in the pool “with AEB” (Figure 6, top) may indicate the effect of automatic emergency braking systems, on the one hand, and also the influence of other advanced driver assistance systems (such as the Lane Support System (LSS) or Electronic Stability Control (ESC)), on the other. At the same time, by contrast, the higher frequency of collisions with vehicles that are turning into or crossing the carriageway (Accident type) points to a possible need for optimization (Figure 6, bottom). However, these differences are not statistically significant. Recommendations for ways of making the systems more robust and the EuroNCAP test protocol regarding accidents involving two-wheel motor vehicles are described in [1].

No positive shift can be observed for cars with AEB in terms of less accidents involving motorized-two-wheelers

Figure 6 · Comparison of the pools “with AEB” and “without AEB” based on Kind of accident and Accident type of accidents involving motorized two-wheelers



Nr.	Kind of accident
1	Collision with another vehicle which starts, stops or is stationary
2	Collision with another vehicle moving ahead or waiting
3	Collision with another vehicle moving laterally in the same direction
4	Collision with another oncoming vehicle
5	Collision with another vehicle which turns into or crosses a road
6	Collision between vehicle and pedestrian
7	Collision with an obstacle in the carriageway
8/9	Leaving the carriageway to the right/left
10	Accident of another kind

Abbrev.	Kind of accident
D	Driving accident
TO	Accident caused by turning-off
TC	Accident caused by turning into a road or by crossing it
CO	Accident caused by crossing the road
S	Accident involving stationary vehicles
LT	Longitudinal accident
O	Other accident

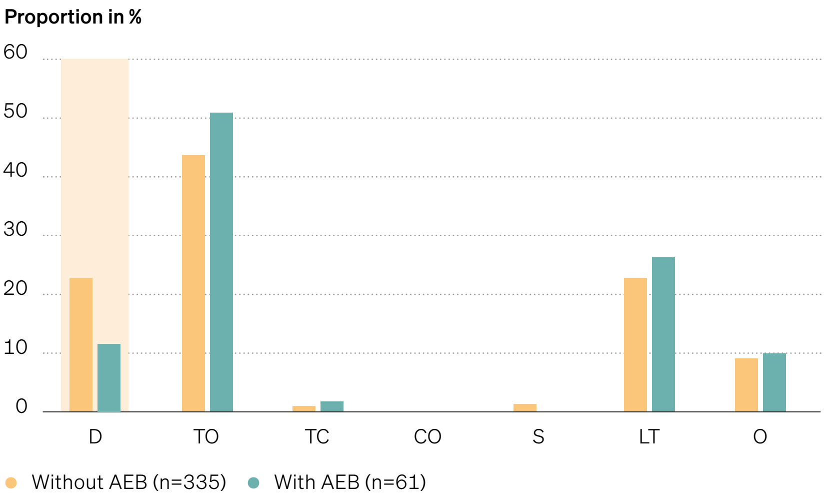
Accidents with oncoming traffic

Figure 7 shows the breakdown of the Accident types in accidents with oncoming traffic for the two comparison pools. The presentation of these accidents on the basis of the “Accident type” accident characteristic is necessary and shows that different situations can lead to an accident with oncoming traffic. Example: Collision when turning off to the left between the vehicle that is turning off and the oncoming vehicle (Accident type: turning-off accident, Figure 7).

First of all, one can see a striking and statistically significant shift in the driving accidents: The proportion in the pool “with AEB” is more than 10% lower. However, given that driving accidents typically result from loss of control and are not part of the immediate area of activity of AEB systems, it is unlikely that the emergency braking system has a direct effect here. Systems such as ESP or LSS are more relevant in such situations because they help maintain the vehicle’s stability and lane-keeping.

No AEB benefit is observable for oncoming accidents – the supossedly positive shift for driving accidents can not be attributed exclusively to the effect of AEB

Figure 7 · Breakdown of Accident types in accidents with oncoming traffic



Abbrev.	Kind of accident
D	Driving accident
TO	Accident caused by turning-off
TC	Accident caused by turning into a road or by crossing it
CO	Accident caused by crossing the road
S	Accident involving stationary vehicles
LT	Longitudinal accident
O	Other accident

Furthermore, a separate analysis of the pools to determine whether or not the vehicles were equipped with ESP and LSS supports the assumption that the reduction in accidents with oncoming traffic in the pool “with AEB” that can be seen in Figure 7 is not primarily due to the emergency braking system, but instead to the effects of other advanced driver assistance systems, such as the two above-mentioned systems for example: This analysis showed that 93% of the AEB vehicles were equipped with ESP and 66% of them with LSS. The proportions in the comparison pool without AEB were considerably lower (66% with ESP, 2% with LSS). Recommendations for ways of making the systems more robust and the EuroNCAP test protocol regarding accidents with oncoming traffic are described in [1].

Accidents when turning into a road or crossing it

Generally speaking, the analysis of accidents involving vehicles turning into and crossing the road did not reveal any significant shifts that might point to a positive effect of the emergency braking system. The Accident types are therefore not presented here. Instead, some results for selected UDB characteristics that point to areas of optimization for AEB systems are shown.

Table 5 shows that the speed level in the two pools was the same. However, the very small proportion of braking maneuvers in the pool “with AEB” clearly indicates that the AEB system was not triggered. A comparison of the accidents in terms of accident location also failed to reveal any significant differences (Table 6).

On the basis of the analyzed accident data, it is therefore not possible to prove that the automatic emergency braking systems had any effect on the occurrence of accidents of this category.

No benefit can be observed for cars with AEB in crossing accidents – despite more frequent braking of AEB cars

Table 5 · Comparative analysis of selected accident characteristics

Criterion for comparison	**Without AEB** (n=697)	**With AEB** (n=111)	**Statistical significance**
Average year of vehicle registration	2007	2017	–
Average driving speed [km/h]	45	45	–
Average collision speed [km/h]	40	40	–
Braking before accident	20%	9%	yes, $\chi^2(1)=3.98$; **p=0.49**; $\phi=-0.09$

No benefit can be observed for cars with AEB based on various accident characteristics of crossing accidents

Table 6 · Comparative analysis of accidents caused by cars without and with AEB based on selected accident characteristics from the UDB

Criterion for comparison	**Without AEB** (n=457)	**With AEB** (n=93)	**Statistical significance**
Percentage of accidents in built-up areas	65%	65%	–
Percentage of accidents on rural roads	35%	35%	–
Percentage of accidents at junctions	51%	53%	no, $\chi^2(1)=0.17$; **p=0.68**; $\phi=0.02$
Percentage of accidents at T-intersections	38%	34%	no, $\chi^2(1)=0.4$; **p=0.53**; $\phi=-0.03$
Percentage of accidents in bends	0.2%	0%	–
Percentage of accidents in driveways	8%	11%	no, $\chi^2(1)=0.83$; **p=0.36**; $\phi=0.04$

However, the analysis of driving speeds during the identification of so-called “start-from-stop maneuvers” (when the car pulls off after being stationary) revealed certain shifts that suggest potential optimizations for AEB systems in crossing situations (Table 7). To this end, the pools in Table 7 were first subdivided into two levels of involved party – the party mainly responsible for the accident (Party 01) and the other party involved (Party 02). The driving speeds of the respective parties were then examined for differences between the pools “with AEB” and “without AEB”. It is immediately evident that the parties mainly responsible in the pool “with AEB” did so at a lower average driving speed and that these parties caused the accident from a start-from-stop situation in 33% more of cases. The characteristics of Party 02 do not differ between the two pools.

This observation underscores the need to also test AEB systems in start-from-stop situations. Happily, EuroNCAP will address a substantial proportion of these scenarios in its Start-from-Stop protocols as of 2026.

No benefit can be observed for cars with AEB for start-from-stop accidents

Table 7 · Comparative analysis of driving speeds in accidents involving vehicles turning into and crossing the carriageway

Criterion for comparison	Without AEB (party causing accident.; n=317, other party; n=379)	With AEB (party causing accident.; n=46, other party; n=65)	Statistical significance
Average driving speed – party mainly responsible [km/h]	25	5	yes, $U=77$; $Z=-2.97$; **$p=0.002$**; $r=-0.1$
Average driving speed – other party [km/h]	55	55	–
Braking – party mainly responsible	7%	0%	no, $\chi^2(1)=2.55$; **$p=0.11$**; $\phi=-0.09$
Braking – other party	27%	18%	no, $\chi^2(1)=1.54$; **$p=0.22$**; $\phi=-0.074$
Start-from-stop maneuver – party mainly responsible	10%	43%	yes, one – tailed tests $\chi^2(1)=2.79$; **$p=0.095$**; $\phi=0.09$
Start-from-stop maneuver – other party	4%	0%	no, $\chi^2(1)=0.9$; **$p=0.34$**; $\phi=-0.05$

With reference to accidents involving vehicles turning into or crossing the carriageway, one general recommendation to improve the robustness of the systems is to combine them in meaningful ways with other assistance systems – e.g. V2X communication or distraction warnings – in order to extend the capabilities of conventional hazard protection by means of AEB systems in the specific cases involved in such accidents. Further recommendations are documented in [1].

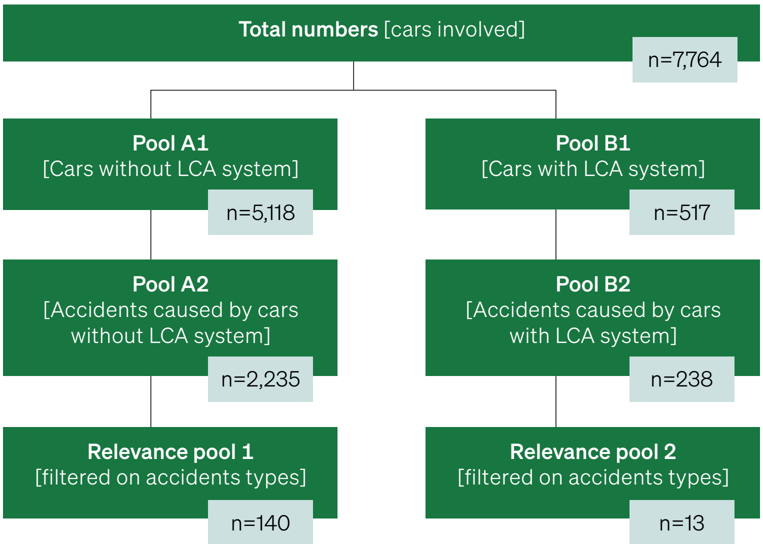
A different data pool from the one used for the AEB analyses was used for the analysis of the blind-spot warning system (LCA). Figure 8 shows how the two analysis pools were obtained for vehicles with and without LCA. The two pools A1 “without LCA” (n=5,118) and B1 “with LCA” (n=517) were initially formed from the total number of n=7,764 accidents caused by cars in the UDB database.

9. Identification and analysis of LCA-relevant accident scenarios

It appeared sensible to analyze the accidents from the perspective of the party causing the accident. In accidents resulting from a change of lane, the party changing lane generally bears the main responsibility for the accident. This makes it easier to identify the relevant cases. However, in a few very rare cases, the change of lane may lead to a rear-end collision in which the vehicle closing from behind bears the responsibility. These cases are rare and are not taken into account here. Filtering out the cases with parties responsible for the accident therefore results in pools A2 and B2 (Figure 8).

Cars with and without LCA were analyzed in different pools

Figure 8 · Overview of the data pools and the individual relevance pools for the analysis of accidents with and without LCA systems



A case-by-case analysis was then carried out within pools A2 and B2 to identify all the accident scenarios falling within the scope of action of LCA systems. These are accidents in which the party causing the accident collided with a one-track or a two-track vehicle traveling on the neighboring lane when changing lanes. These include, for example, side collisions resulting from sudden changes of lane when two vehicles are traveling next to one another or accidents during turning-off or overtaking maneuvers, as well as rear-end collisions involving closing vehicles, that is to say the so-called cut-in scenarios (see also section on AEB). Equally, a following vehicle can evade the vehicle that is changing lane and collide with another vehicle.

Relevance pool 1 for vehicles without LCA and relevance pool 2 for vehicles with LCA were formed from pools A2 and B2. In the following sections, these pools are referred to as the pool "without LCA" and the pool "with LCA".

A detailed description of the methodology can be found in [15].

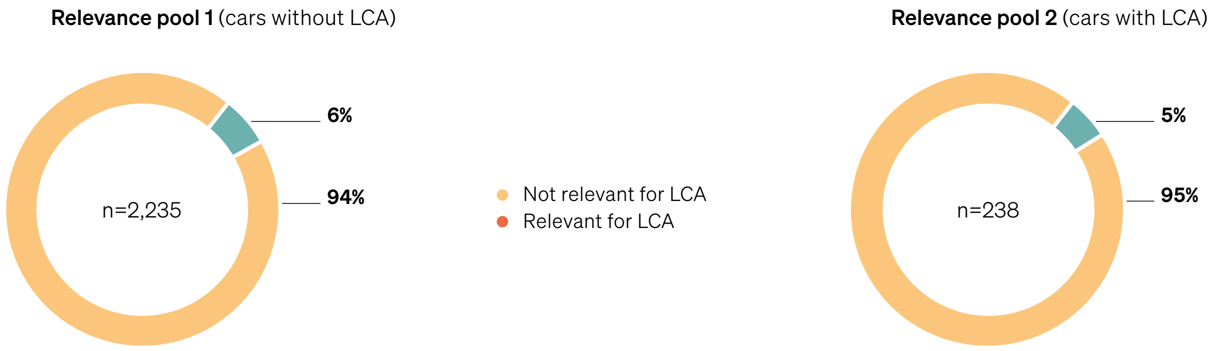
RESULTS FOR LCA – ACCIDENTS DUE TO LANE CHANGES

Accident patterns, casualties

The comparison of relevance pools 1 and 2 in Figure 8 already shows that the proportion of accidents covered by LCA is only slightly lower in the pool "with LCA" (approximately 5%) than in the pool "without LCA" (6%). At a higher level, this does not initially suggest any noteworthy shift in favor of LCA systems (Figure 9).

No clear shift for cars with LCA can be recognized in general

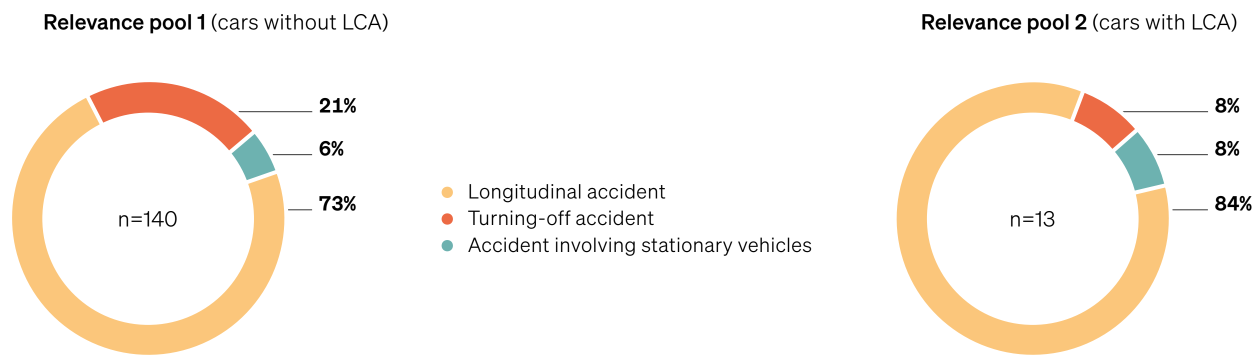
Figure 9 · Comparison of the proportions for the relevance pools for vehicles with and without LCA



The next step consisted in evaluating the single-digit Accident type for both relevance pools. This clearly showed that, at approximately 7%, the proportion of accidents of type "turning-off accident" was smaller by a factor of 3 than in the pool "without LCA" (Figure 10). In the case of these accident configurations, there is a clear positive shift in favor of vehicles equipped with an LCA system.

First effects of LCA systems are visible in terms of reducing the share of turning-off accidents

Figure 10 · Comparison of the relevant Accident types for the relevance pools for vehicles "with" and "without" LCA



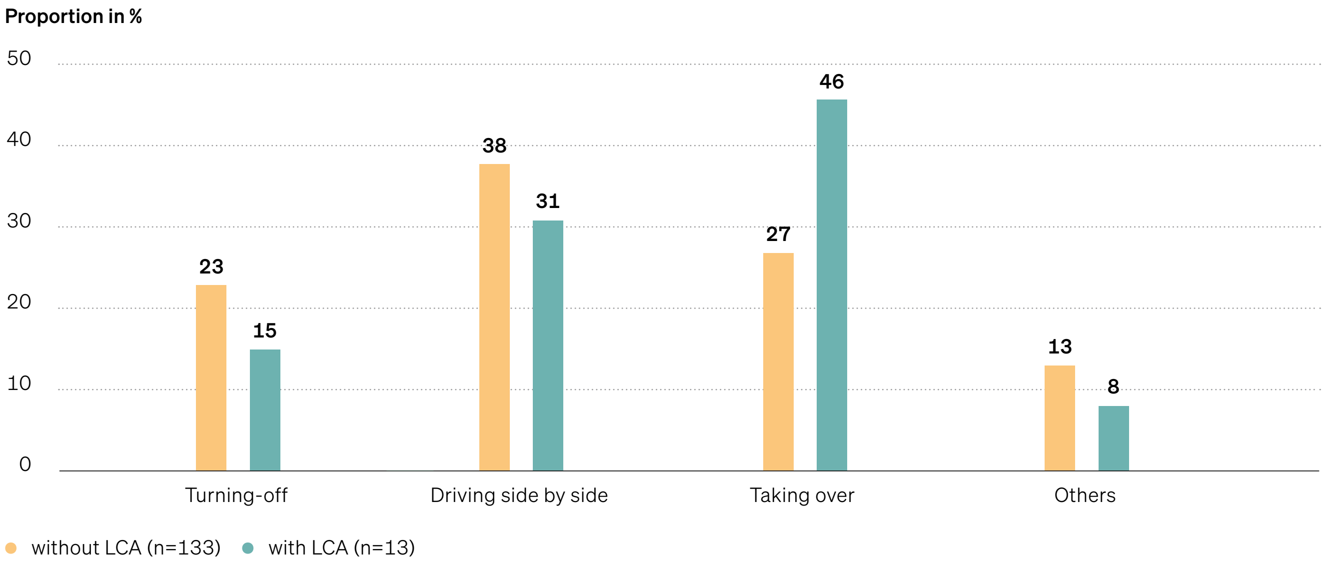
Further indications regarding these shifts could be identified by examining the accident causes in terms of mistakes when performing lane change (Figure 11). These shifts relate to:

- Accidents due to lane change when “turning off” (–8%)
- Accidents due to lane change when “driving side by side” (–7%).

There is no shift in the case of accidents that occur due to lane changes when “overtaking”. One possible explanation for this could be that LCA systems are more often ignored when initiating an overtaking maneuver than they are during turning-off maneuvers or when driving side by side. This applies in particular to risky and illegal overtaking on the right adjacent lane on motorways. Some examples will be presented in the follow-up analysis regarding accident location. The overtaking accidents in the examined dataset consisted mostly of accidents involving minor injuries.

No positive benefit can be observed for LCA systems regarding overtaking maneuvers

Figure 11 · Comparison of the identified accident causes related to lane change in the relevance pools for vehicles “with” and “without” LCA



There are also positive shifts at the level of the accident consequences. These are compared in Table 8 on the basis of the total accident costs, that is to say the overall costs for personal injuries and damage, and the official severity of the injuries to the parties involved. It is clear that, with total personal and damage costs of 62,000 €, accidents caused by vehicles without an LCA system are considerably more expensive (factor of 2.5) than accidents caused by vehicles with this system. The consequences of the accidents for the parties involved are also greater in the case of accidents without LCA system. In such cases, the proportion of fatalities and serious injuries as defined in German national statistics [8] is higher by a factor of 3 than in accidents caused by vehicles with LCA system. This shows that LCA systems also have a positive impact in the case of severe accidents.

Cars with LCA cause less frequently fatal or severe accidents than cars without system

Table 8 · Comparison of the 'personal and damage cost' and 'injury severity' characteristics of accidents caused by vehicles "without" and "with" LCA system

Criterion for comparison	**Without LCA** (n=140)	**With LCA** (n=13)
Average personal and damage cost	62,005 €	25,976 €
Total fatalities	3 (1%)	0 (0%)
Total serious injuries	58 (23%)	2 (11%)
Total minor injuries	188 (76%)	17 (90%)
Fatalities and injured persomns per accident	44%	15%

To add greater clarity to the observation that LCA systems reduce the severity of the consequences of accidents, the "Accident location" and official "Injury severity" [8] characteristics were evaluated and crossed with one another.

Thus, at 8%, the proportion of accidents on roads outside of built-up areas in the pool "with LCA" is almost a quarter of the corresponding value in the pool "without LCA". By contrast, no positive shift can be observed in the case of accidents on roads in built-up areas and on motorways (Figure 12). For accidents on motorways, following plausible explanations could be found:

→ In the analysed cases, high driving speeds of the accident causer (car with LCA) and also high approach speeds/driving speeds of the other parties involved in the accident were found; these can be related to short reaction time, i.e. short time window in which the warning system can still be effective, especially when the lane change has already been initiated.

→ In at least half of the cases, inappropriate or risky driving behavior played a central role, e.g., overtaking on the right lane (this is forbidden on German motorways) or very abrupt, multiple lane changes (sometimes across several lanes). These are maneuvers that tend to fall outside the typical system intention. In such situations, it is plausible that the protective effect of a warning system is limited because warnings are either deliberately ignored or the situation is so dynamic or irregular that the system can no longer "grip" in time.

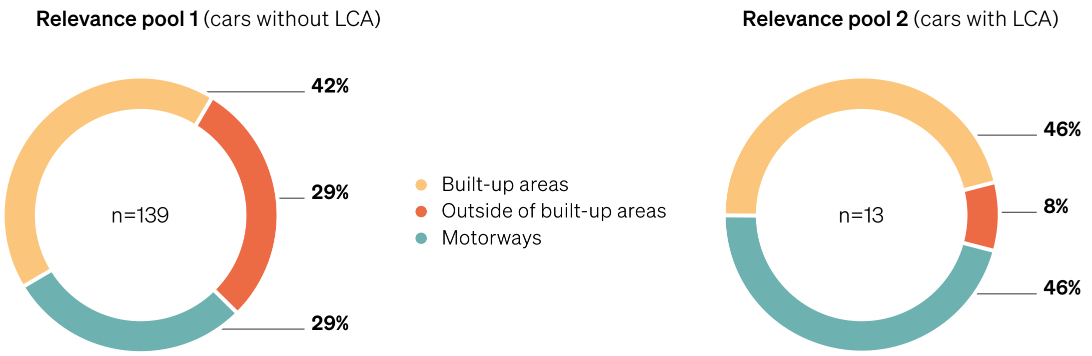
→ The low number of cases and the formation of 100% in this group might also have played a role.

If one considers the breakdown of injury severities by location (Figure 13), it can be seen that there are no accidents involving fatalities and almost 20% fewer accidents involving serious injuries in the pool "with LCA" than there are in the pool "without LCA".

To sum up, it can be seen that the overall positive effect of LCA systems is small in percentage terms and is visible only in the detailed accident patterns, for example for Accident types, and also only for certain accident locations. At the same time, however, this effect applies to a large proportion of the serious and fatal accidents, which primarily take place outside of built-up areas (Figure 13).

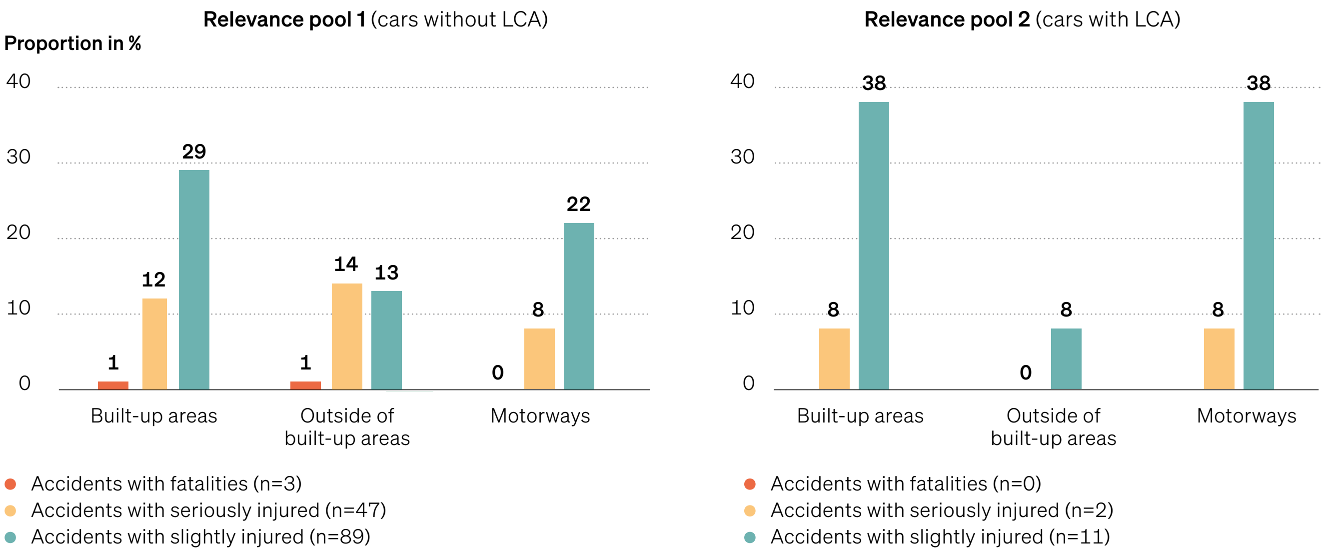
LCA systems show their effect for accidents that occur outside built-up areas

Figure 12 · Comparison of the relevance pools by accident location for accidents caused by vehicles “without” and “with” LCA system



The benefits of LCA systems are mostly visible in terms of less fatal and serious accidents outside of built-up areas

Figure 13 · Comparison of the relevance pools by location and accident consequences for accidents caused by vehicles “without” and “with” LCA system



In some cases, the accident descriptions of the motorway accidents indicated that an intentional lane change was initially discontinued and then performed in a subsequent attempt. This often occurs when multiple vehicles change lane at the same time. Such behavior indicates the presence of complex traffic situations. The complex nature of such accidents has already been identified in another study [16]. Here, it is assumed that the warning issued by the system was ignored.

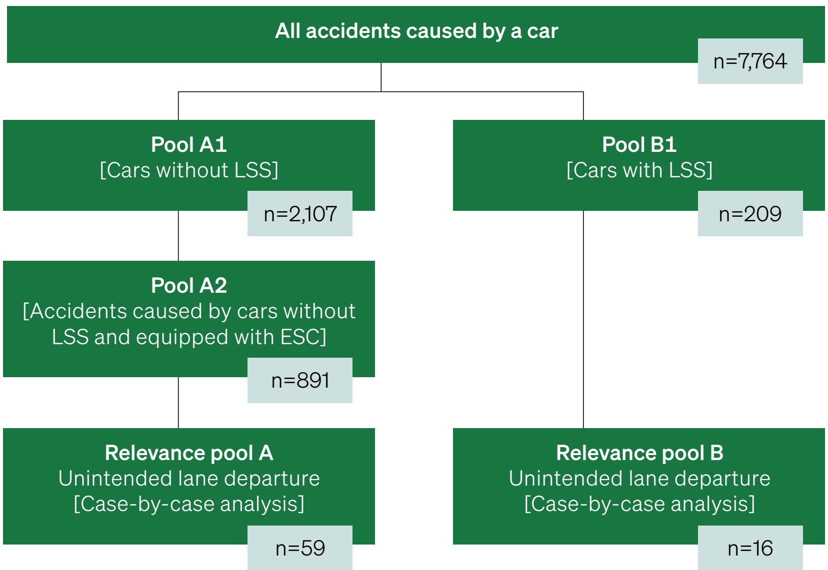
10. Identification and Analysis of LSS-Relevant Accident Scenarios

The procedure for Lane Support Systems was identical to that used for LCA systems and resulted in the two relevance pools A "without LSS" containing n=59 cases and B "with LSS" containing n=16 cases (Figure 14).

To form the relevance pools, all cases in which the driver had previously departed from their lane unintentionally for whatsoever reason were considered. Since neither the Accident type nor the accident category precisely delineate these accidents, the relevant cases were selected on the basis of a case-by-case examination. Lane changes as a result of evasive action or as part of an overtaking maneuver, for example, were therefore excluded, as were accidents in which the driver left their lane due to inappropriate speed (typical driving accident). These are not relevant for LSS.

Cars with and without LSS were analyzed in different pools

Figure 14 · Overview of the data pools and the relevance pools derived from them for the analysis of accidents with and without lane-keeping systems



RESULTS FOR LSS – ACCIDENTS DUE TO LANE DEPARTURE

Accident patterns, casualties

In the data examined here, unintentional lane departure led to various accident configurations that are indicated below on the basis of the Kind of accident [8]. Of these, however, only two Kinds of accidents are crucial when it comes to assessing the benefits of LSS systems (Figure 15). On the one hand, these Kinds of accidents account for approximately 80% of the accidents and, on the other, they are also associated with the most severe accident consequences:

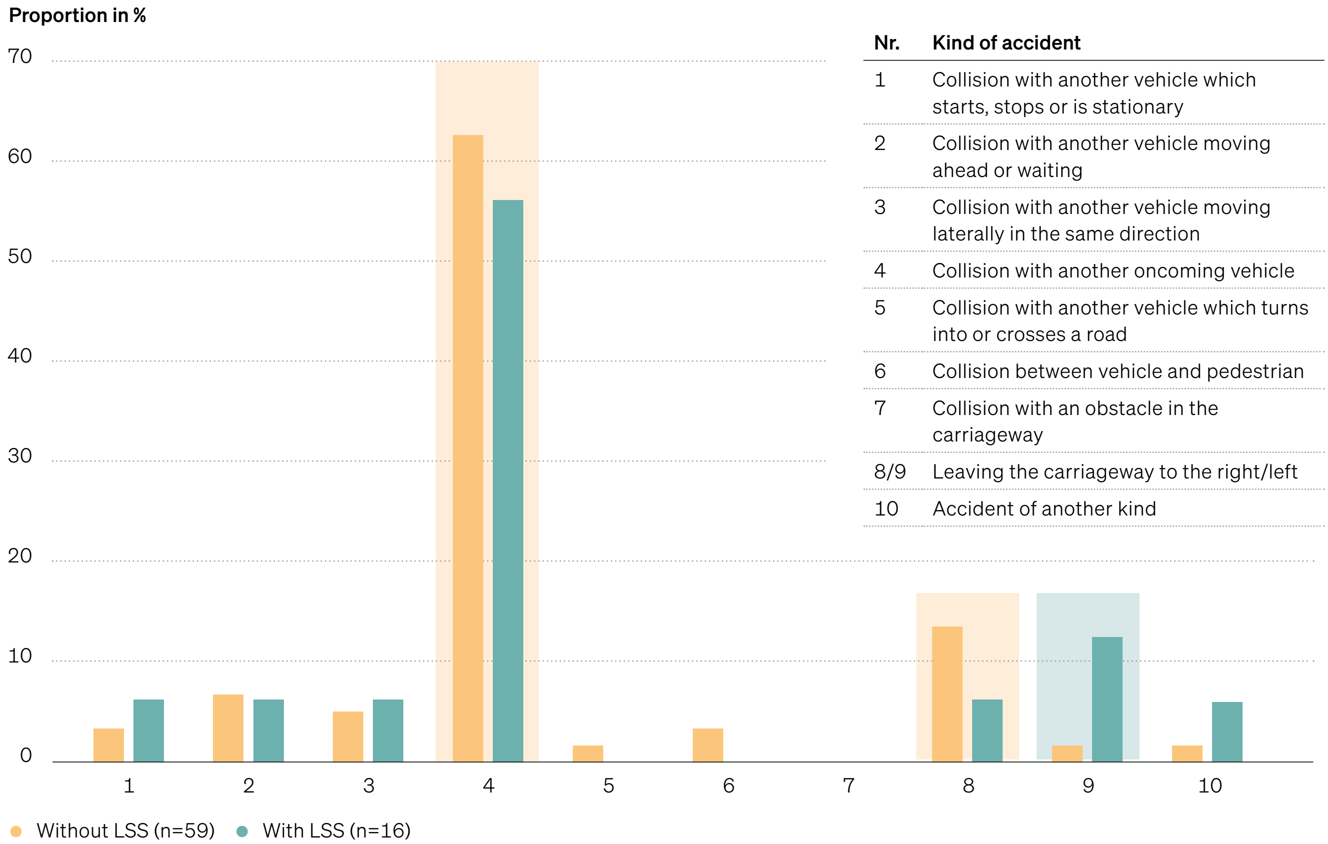
- Collision with an oncoming vehicle (Kind of accident 4)
- Leaving the carriageway to the right/left (Kind of accident 8/9).

By definition, Kind of accident 8/9 describes single-vehicle accidents. These generally end in a collision with an obstacle next to the carriageway. At this point, it is once again necessary to point out the methodological limitation which causes single-vehicle accidents to be underrepresented in the UDB database. As a result, collisions with oncoming vehicles gain a greater weight in percentage terms in the data examined here.

The comparison of the relevance pools “without LSS” and “with LSS” in Figure 15 shows that the two named Kinds of accidents occur less frequently in the pool “with LSS” than in the pool “without LSS”. The percentage difference in the pools is approximately 3%. This order of magnitude corresponds to the current state of knowledge in this field [2]. On the basis of this, a theoretical (ideal) accident avoidance potential of up to 4% has been calculated and/or forecast for lane-keeping systems.

The benefit of LSS is visible for lane departure collisions with oncoming traffic

Figure 15 · Comparison of the accident categories in the relevance pools for vehicles with and without LSS



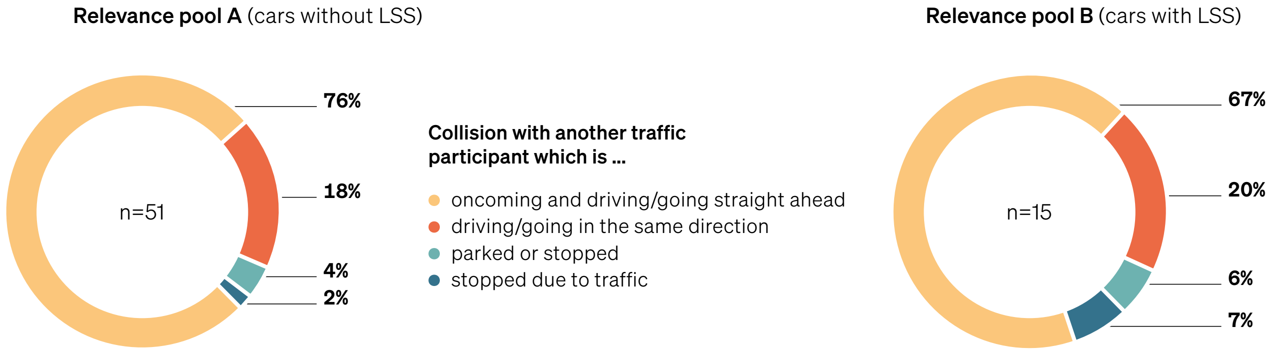
Nr.	Kind of accident
1	Collision with another vehicle which starts, stops or is stationary
2	Collision with another vehicle moving ahead or waiting
3	Collision with another vehicle moving laterally in the same direction
4	Collision with another oncoming vehicle
5	Collision with another vehicle which turns into or crosses a road
6	Collision between vehicle and pedestrian
7	Collision with an obstacle in the carriageway
8/9	Leaving the carriageway to the right/left
10	Accident of another kind

The analysis of the characteristic “Direction of movement of the vehicles relative to one another” confirms the original impression in terms of less collisions with oncoming traffic. For the configuration “Other vehicle oncoming and driving straight ahead”, the difference compared to the pool “without LSS” is -9% (Figure 16). Because the accidents are being considered in detail here, the percentage reduction is actually somewhat greater.

If the accidents are then further considered on the basis of location, considerable shifts can be seen for “outside of built-up area” and “motorway” (Figure 17). The proportion is approximately 10% lower in the relevance pool “with LSS” for the two locations taken together.

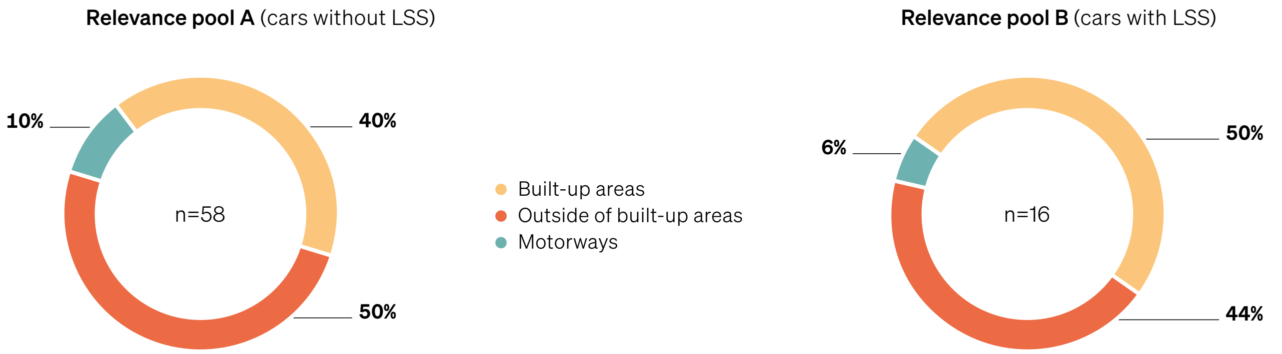
A look at lane departure collisions with vehicles that are oncoming and moving ahead confirms the picture of a positive benefit of LSS

Figure 16 · Comparison of the directions of movement of the opponent party in the relevance pools for vehicles with and without LSS



Cars equipped with LSS cause less frequently accidents outside built-up areas and on motorways than cars without LSS

Figure 17 · Comparison of the accident location in the relevance pools for vehicles with and without LSS

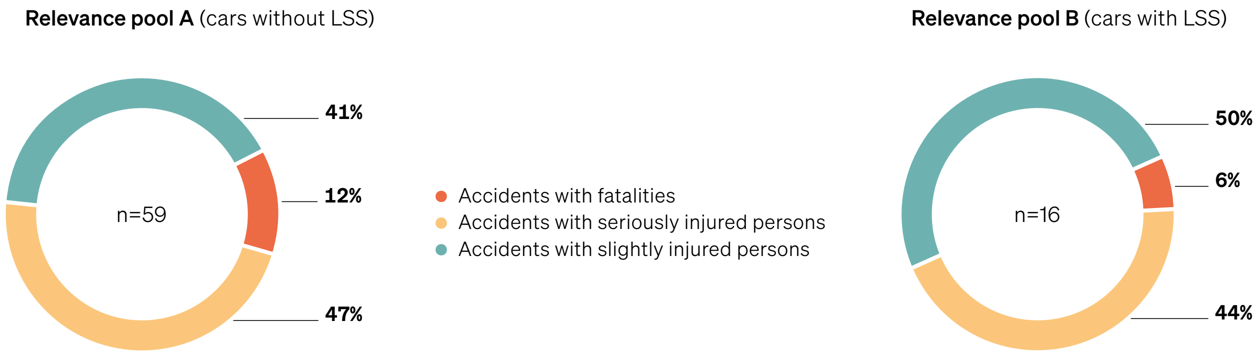


The “Accident category” characteristic as used in German national statistics [8] was used for the analysis of the accident consequences (Figure 18). Here again, differences can be seen between the two relevance pools. Thus, the proportions of accidents involving serious injuries (-3%) and especially fatalities (-6%) are both lower in vehicles equipped with a system than in those without such a system. This result is particularly noteworthy because while, in total, accidents due to unintentional lane departure (relevance pool) account for only approximately 7% of all the accidents caused by cars in the UDB, they are nevertheless responsible for some 43% of the fatalities.

The knowledge gained thus far therefore provides evidence for a clear positive shift towards a reduction in accidents on roads outside of build-up areas and on motorways. At the same time, it is primarily serious and fatal accidents that are involved here.

Cars equipped with LSS cause less fatal accidents than cars without LSS

Figure 18 · Comparison of the accident categories in the relevance pools for vehicles with and without LSS



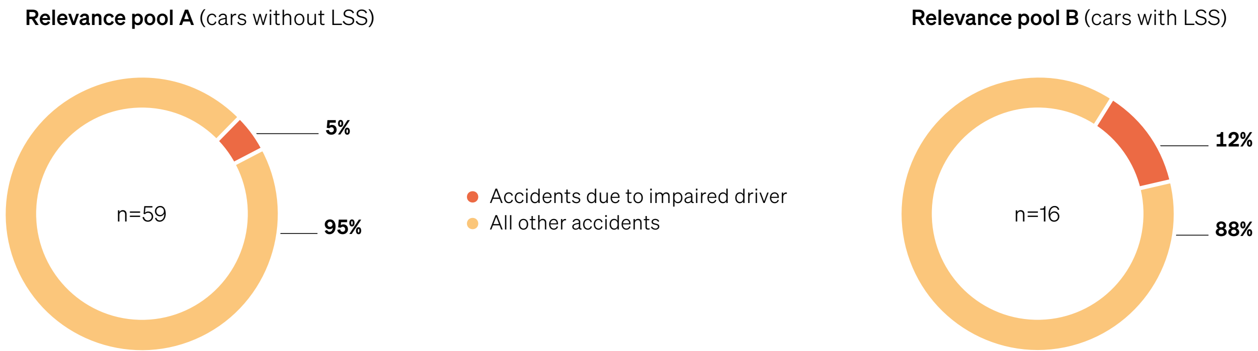
A further analysis was performed to investigate the driver's status. We already know from former research, that impaired driving is a problem in accident scene especially when it comes to an unintentional lane departure [19, 20]. This analysis showed that the proportion of impaired drivers was more than twice as high when the vehicle was equipped with LSS (Figure 19). However, driver impairment in general did not play a dominant role in any of the analyzed pools. For the vehicles equipped with LSS a more differentiated analysis was performed on the n=16 drivers. Following types of impairment were found:

- fatigue
- distraction
- unresponsive driver due to sudden health issues (e.g., heart attack, loss of consciousness).

These accidents could be addressed by a combination between LSS and driver monitoring [21].

A higher share of impaired drivers can be observed in cars with LSS in comparison to cars without LSS

Figure 19 · Comparison of the share of impaired drivers in the relevance pools for vehicles with and without LSS



Due to the small number of cases, no precise conclusions for the different types of impairment can be drawn from this analysis. However, the results indicate that, in general, the driver status should be considered in the robustness discussion for improving LSS systems.

The analyses also reveal certain problem areas for LSS systems. This can be seen, on the one hand, in the fact that there is no positive shift towards a reduction in accident numbers in built-up areas. One plausible explanation may be found in the preconditions for system operation, according to which the activation threshold for lane-keeping systems is 60 or 72 km/h [17, 18]. One recommendation here is to reduce this threshold to at least 30 km/h. In connection with this, a current UDV study has shown that accidents due to lane departures can also often end in fatalities inside of built-up areas, in particular when they lead to collisions with trees or other obstacles next to the carriageway [19].

At the same time, it is also necessary to consider the problem of the system potentially being deactivated. It is known that excessively frequent warnings and/or interventions that do not correspond to the driver's intentions and the traffic situation generally greatly reduce the acceptance of the systems and tend to lead to them being switched off.

11. Conclusion and Outlook

This study shows that it is possible, on the basis of the currently available data, to reveal differences in accident occurrence among vehicles with or without advanced driver assistance systems and to derive recommendations for the further development of these systems in order to make them more robust and extend their real-world scope of action.

With regard to rear-end collisions, the accident data made it possible to identify a number of positive effects of AEB systems: It was thus possible to observe a statistically significant reduction in typical linear rear-end collisions, and in particular collisions with vehicles waiting or braking at junctions as well as collisions with the rearmost vehicle in a traffic jam.

Accident frequency was also reduced in the low speed range, indicating that the system functions effectively in such scenarios. What is more, even when collisions were not prevented, a reduction in accident severity was identified and is due to the more frequent and more effective braking maneuvers of vehicles equipped with AEB.

However, alongside these positive results, clear potentials for optimization were also identified. Thus, the effectiveness of the system was shown to be limited at high driving speeds and on motorways. The detection of and response to hazards in curved stretches of road also showed itself to be problematic. Weaknesses were also observed in so-called cut-in situations, in which other vehicles suddenly change to the lane in which the AEB vehicle is traveling. A susceptibility to malfunctions in conditions of poor visibility as well as in unclear accident environments was also observed.

No statistically significant reduction in accident severity was observed in connection with collisions with pedestrians and cyclists. This is presumably due to the fact that the accidents documented in the UDB database typically lead to serious injury, irrespective of the presence of automatic emergency braking systems. Despite this, it was possible to observe the first indications of accident prevention in connection with the earliest EuroNCAP standard scenarios, which have therefore been tested the longest.

With regard to collisions with two-wheel motor vehicles, collisions with oncoming traffic and accidents involving vehicles turning into or crossing the carriageway, it was not possible to identify any effects that can be directly attributed to the action of automatic emergency braking systems.

It is, however, heartening to note that many of the identified possible weaknesses of AEB systems have already been identified by EuroNCAP and are due to be incorporated in the planned adaptations to the protocols as of 2026. On the one hand, this underscores the validity of the analyzed patterns and, on the other, shows that EuroNCAP is purposefully pursuing the further development of the systems.

It was also possible to show that both LCA and LSS systems have a positive impact on accident occurrence. Although the effects are admittedly not as pronounced as in the case of AEB, it is necessary to remember that these two systems are only relevant for a small proportion of accidents. Furthermore, the fact that they also have a positive effect in many severe and fatal accident scenarios emphasizes their importance.

The positive shifts observed for LCA systems relate to:

- Turning-off accidents
- Accidents on roads outside of built-up areas
- Serious and fatal accidents outside of built-up areas.

In the case of LSS systems, they relate to:

- Accidents with oncoming traffic
- Accidents caused by lane departures (single-vehicle accidents)
- Accidents on roads outside of built-up areas and on motorways
- Serious and fatal accidents in general.

In general, the following recommendations can be made for both systems:

→ The systems should remain permanently active while the vehicle is being driven

→ Improved warning strategy, ideally involving a combination of a clear warning and active countermeasures (LCA)

→ Combine driver monitoring systems with LSS systems and implement minimum risk maneuver (system brings the car to a controlled stop) in order to adress impaired drivers [21].

→ Reduction of activation threshold to speeds below 60 km/h (LSS).

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