# The ADAC Advanced Emergency Brake System test – a real life based approach for a better primary safety

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**Abstract:**

Rear-end collisions are the most frequent same and opposite-direction crashes. Common causes include momentary inattention, inadequate speed or inadequate distance. While most rear-end collisions in urban traffic only result in vehicle damage or slight injuries, rear-end collisions outside built-up areas or on motorways usually cause fatal or serious injuries.

Driver assistance systems that detect dangerous situations in the longitudinal vehicle direction are therefore an essential safety plus. In view of this, for ADAC, systems that alert drivers to dangerous situations and initiate autonomous braking complement ESC as one of the most important active safety features in modern vehicles.

The aim of ADAC is to provide consumers with technical advice and competent information about the systems available on the market. Reliable comparative tests that are based on standardised test criteria may provide motorists with important information and help them make a buying decision. In addition, they raise consumer awareness of the systems and speed up their market penetration.

The assessment must focus on as many aspects of effectiveness as possible and include not only autonomous braking but also collision warning and autonomous brake assist.

The work of the ADAC accident research is the development of the testing scenarios with direct link to accident situations and the identification of useful test criteria for testing.

## Introduction

With the development of passive safety features, vehicle safety has increased steadily over the past decades. The introduction of the safety belt and airbag were milestones in passive vehicle safety. In addition to the systems which mitigate the consequences of an accident, active systems for the prevention of accidents and the mitigation of their consequences have become increasingly important.

With the launch of ABS, the first driver assistance system was successfully introduced some 30 years ago. The mandatory introduction of ESC from 2012 will be another milestone in driver safety. While ESC is a highly effective technology to prevent cars from skidding or running off the road or to mitigate the consequences of an accident, it is more or less ineffective in accidents which occur in the same and opposite direction of traffic.

Rear-end collisions are the most frequent same and opposite-direction crashes. Common causes include momentary inattention, inadequate speed or inadequate distance. While most rear-end collisions in urban traffic only result in vehicle damage or slight injuries, rear-end collisions outside built-up areas or on motorways usually cause fatal or serious injuries.

Rear-end impacts are among the most common types of road accidents involving injury. Driver assistance systems that detect dangerous situations in the longitudinal vehicle direction are therefore an essential safety plus. In view of this, for ADAC, systems that alert drivers to dangerous situations and initiate autonomous braking complement ESC as one of the most important active safety features in modern vehicles.

The aim of ADAC is to provide consumers with technical advice and competent information about the systems available on the market. Reliable comparative tests that are based on standardised test criteria may provide motorists with important information and help them make a buying decision. In addition, they raise consumer awareness of the systems and speed up their market penetration.

Also, comparative product testing and the subsequent consumers' buying decisions cause the automotive manufacturers and suppliers to further develop their safety systems.

The test scenarios and criteria selected must be defined such that they represent real-life accidents and allow drawing differentiated conclusions on the state of the art. Test standards that are either too high or too low would cause the test results to be less diversified (e.g. all systems tested are rated either "very good" or "poor").

The assessment must focus on as many aspects of effectiveness as possible and include not only autonomous braking but also collision warning and autonomous brake assist. Additional maloperation tests must be introduced to minimise false alarms and increase the consumers' acceptance of the systems.

## Effectiveness analysis

The initial step in developing a new ADAC test is a catalogue of criteria established in cooperation with an expert group. This ensures a useful, efficient and reliable testing procedure that takes aspects of consumer protection, accident research and the state of the art into account. The developments presented in this report aim at establishing a test for active safety systems in passenger cars. The following aspects with regard to the significance of these systems for integrated safety were taken into account with a special view to AEBS development.

### Longitudinal driver assistance systems and where they can be effective

Since the incidents documented by the accident researchers are based on accidents where the ADAC rescue helicopters were deployed, high-severity injuries are typical. For instance, 95% of the incidents result in serious to fatal injuries. These characteristics differentiate the findings of this project from the totality of road accidents, as the following analyses will demonstrate. Since it is vital to prevent incidents resulting in serious injuries – or at least to mitigate their consequences – the trends revealed in the surveys point strongly to the need for further research into aspects of active and passive safety as well as traffic routing.

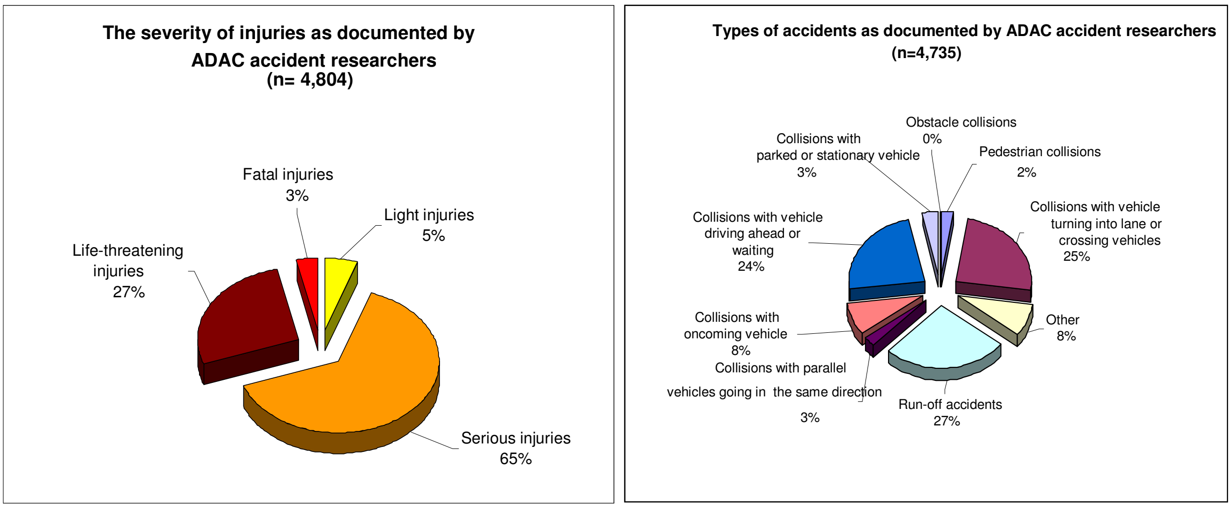



Figure 1: The severity and types of accidents as documented by ADAC accident researchers

The analysis of accidents by type shows percentages that correspond to the relevant data as in [1], [2] and [3]. With 24% of all accidents in the ADAC accident research database, rear-end collisions are the third most frequent accident type. The number one and number two accident types are run-off accidents (27%) and accidents caused by turn-on or intersection errors (25%).

The analysis also shows that the majority of accidents is caused by passenger cars (over 58%). Of the 1,117 rear-end accidents documented, 655 accidents were caused by passenger cars. This means that in 13.8% of all accidents documented by ADAC accident researchers a system that assists the driver in a rear-end impact could make a difference.

Since for the data recorded by ADAC accident researchers a special filter is used (deployment of rescue helicopter), standardised literature research is conducted for problem classification. The analyses of official statistics, accident research institutions and research centres show that results are comparable.

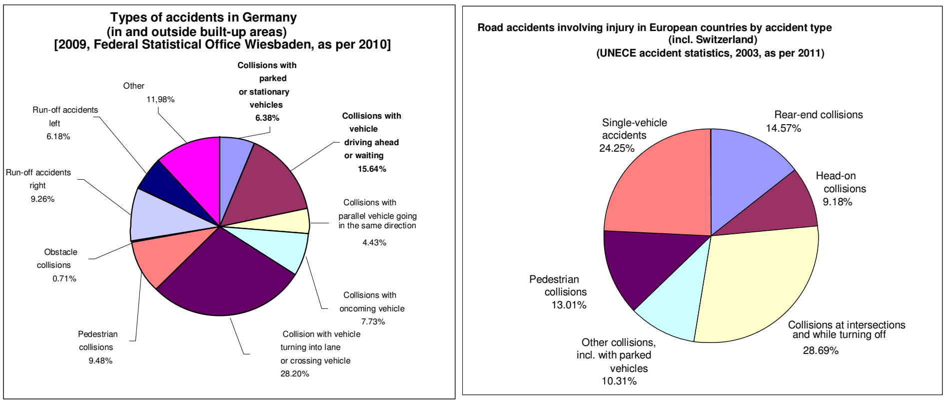



Figure 2: Types of accidents in the Federal Republic of Germany [2] and the EC [3]

According to the official statics for Germany and some European countries, rear-end impacts are the third most common accident type with an approx. 15% share in the total number of accidents involving injuries. The share varies greatly in some countries. For instance, the US 2006 share of rear-end collisions with stationary or moving vehicles was approx. 28% [10].

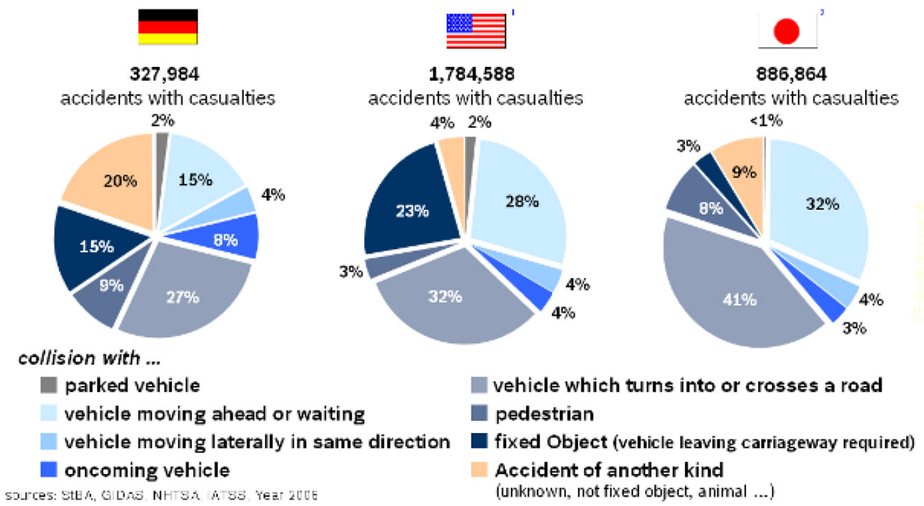



Figure 3: Accidents involving injuries by type of accident constellation [9], [10], [11]

An analysis of available effectiveness studies confirms the importance of focusing on rear-end collisions. In its GIDAS analysis of accidents that occurred before or in 2005, Bosch [1] identifies an AEBS effectiveness potential in 12% of accidents involving injury.

The German Insurance Association (GDV) conducted a study in 2009 to assess the potential of AEBS (incl. warning systems). The study showed that AEBS could prevent 17.8% of all car accidents involving injury. [12]

## Official rear-end collision statistics: road accidents/persons injured in Germany

The following section is based on data obtained from the 2010 official statistics of the Federal Statistical Office, Wiesbaden. Relative to the totality of the accidents, rear-end collisions are very significant, accounting for 16% of the 310,806 accidents involving injury.

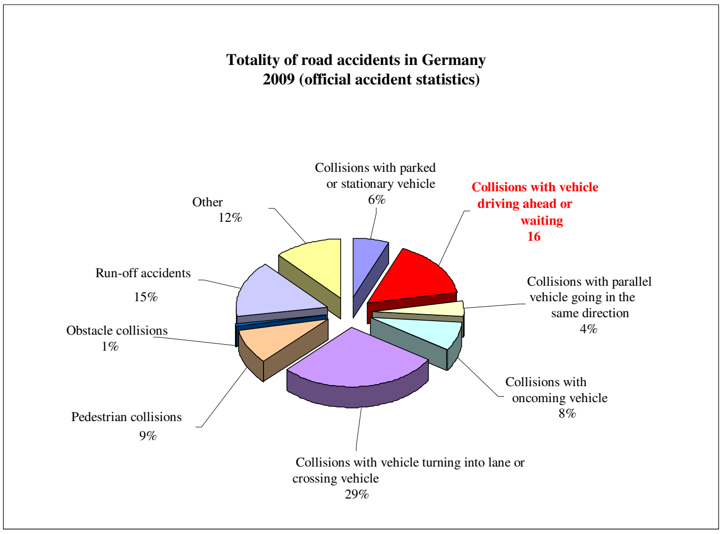



Figure 4: Accident types in Germany [2]

In these 48,625 rear-end collisions, a total of 71,106 persons sustained injuries [2], i.e. an average of 1.46 persons is injured in each rear-end collision. Assuming the validity of the same proportionalities as in the Bosch GIDAS analysis [1], AEBS would have prevented approx. 37,000 accidents involving injury and 54,000 casualties on German roads in 2009 (effectiveness = 12% of accidents).

## Road accidents/persons injured in Europe

To provide an overview of accidents across Europe, we analysed existing international accident statistics. The 2003 UNECE [3] accident data for 21 European countries (incl. Switzerland) enables a good comparison.

| Number | Country | **Total** | **Rear end collisions** | **Rear end Collisions in %** | Casualties in rear end collisions |
|---|---|---|---|---|---|
| | | | | | |
| 1. | Austria | **43.350** | 8.108 | **18,70%** | 11.299 |
| 2. | Czech Republic | **27.320** | 2.831 | **10,36%** | 3.677 |
| 3. | Denmark | **6.749** | 744 | **11,02%** | 1.055 |
| 4. | Estonia | **1.931** | 181 | **9,37%** | 215 |
| 5. | Finland | **6.907** | 594 | **8,60%** | 901 |
| 6. | France | **90.130** | 9.628 | **10,68%** | 12.477 |
| 7. | Germany | **354.534** | 55.991 | **15,79%** | 81.940 |
| 8. | Greece | **15.751** | 1.402 | **8,90%** | 1.977 |
| 9. | Hungary | **19.976** | 2.773 | **13,88%** | 3.787 |
| 10. | Ireland | **5.985** | 857 | **14,32%** | 857 |
| 11. | Lithuania | **5.965** | 403 | **6,76%** | 522 |
| 12. | Netherlands | **31.635** | 4.947 | **15,64%** | 6.727 |
| 13. | Norway | **8.248** | 1.375 | **16,67%** | 2.325 |
| 14. | Poland | **50.203** | 5.167 | **10,29%** | 7.027 |
| 15. | Portugal | **41.495** | 3.926 | **9,46%** | 5.371 |
| 16. | Romania | **6.654** | 103 | **1,55%** | 129 |
| 17. | Slovakia | **5.002** | 661 | **13,21%** | 922 |
| 18. | Slovenia | **11.676** | 2.266 | **19,41%** | 3.666 |
| 19. | Spain | **99.987** | 17.953 | **17,96%** | 31.276 |
| 20. | Sweden | **18.365** | 2.636 | **14,35%** | 4.522 |
| 21. | Switzerland | **23.840** | 5.033 | **21,11%** | 7.060 |
| | | | | | |
| | Gesamt | **875.703** | **127.579** | **14,57%** | 187.732 |

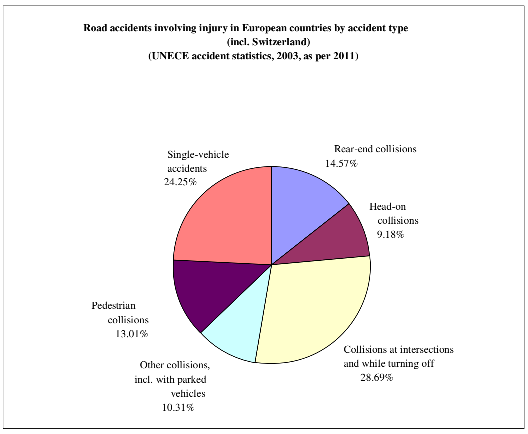



Figure 5: Total of rear-end collisions (left) and persons injured by accident type in Europe (right) [3]

An average of 15% of accidents on European roads involving injuries are rear-end collisions. However, this share varies greatly from country to country, ranging from 1.55% in Romania to 21.1% in Switzerland. In the 21 countries, 187,732 people got injured or killed in 127,579 rear-end collisions in 2003, i.e. 1.47 persons injured per rear-end collision.

Since thorough data on the effectiveness of driver assistance systems in Europe is limited, our test will be based on the assumption that effectiveness in Europe is comparable to that of Germany; the experts slightly reduced it to 10% of accidents involving injuries. This means that in the 21 European countries, AEBS can be effective in approx. 87,570 accidents with a total of 128,700 persons injured (2003).

Based on the official accident statistics [2] and a 10% effectiveness, in 2008, AEBS would have prevented the road injuries and deaths in the EU27 as set out below:

| EU27, 2008 official statistics [2] | | AEBS effectiveness |
|---|---|---|
| Accidents involving injury | 1,234,345 | 123,435 |
| Road casualties | 1,670,293 | 181,449 |

**Prevention and mitigation potential**

The assessment of rear-end collision prevention through AEBS aims at showing the potential of safety enhancements expressed in the number of casualties. To demonstrate the maximum benefit of AEBS, our considerations are based on a 100% AEBS penetration. We will use the accident data available and not make any forecasts on the European accident trends of the next few years.

ADAC cannot make any assumptions with regard to the system’s limits in rain, snow, built-up areas etc. since there is no relevant data available. Reduced functionality will lower the prevention and mitigation potential further. We will also consider our experiences with the future tests of different systems as well as different interpretations.

Since AEBS come with a warning system, the results will depend on how the driver responds to the warning signals and vehicle functions.

To make reliable assumptions on the prevention potential, we reviewed relevant studies. In addition to ADAC accident research analyses, we found basically two different sources of prevention potential data.

For the accidents documented by the ADAC accident researchers, AEBS has a potential to prevent 75% of the accidents where it can be effective. [4] identified a 7% road death prevention potential in the EU25. Georgi et. al. [1] show in their analysis that 72% of rear-end collisions could be prevented; this is a reduction in the totality of road accidents by 8.6%.

| | ADAC | eImpact [4] | Georgi et.al. [1] |
|---|---|---|---|
| **Effectiveness** | **13.8%** | | **12%** |
| **Prevention potential** | **75%** | | **72%** |
| **Prevention related to the totality of road accidents** | **10.4%** | **7%** | **8.6%** |
| **Dimension** | Serious accidents w. rescue helicopter deployment | Europe | Germany |

Figure 6: AEBS prevention potential: ADAC data, Europe [4] and GIDAS [1]

According to [4], the maximum benefit for Europe is a 7% reduction in road injuries and fatalities. In [1], the reduction rate is 8.6%. Based on the 2008 EU27 accident statistics and depending on the prevention model selected, this translates into a reduction by 12,000 to 15,000 persons injured or killed in the EU25. The methodology as described in [4] considers both a general reduction in road injuries and deaths in Europe and the AEBS penetration rate of the vehicle population. In 2020, the number of road injuries and deaths in the EU25 is expected to have decreased by 11,000.

In addition to preventing a collision altogether, AEBS reduce impact speed in rear-end collisions. According to [1], average reduction in collision speed is 50%. This reduction in speed causes a significant shift in injury risks and thus in the severity of the consequences of an accident.

## Accident scenarios and circumstances

The analysis of accident types is required to better understand conflict situations that cause rear-end collisions. Rear-end collisions resulting in serious injuries chiefly occur on motorways and extra-urban highways.

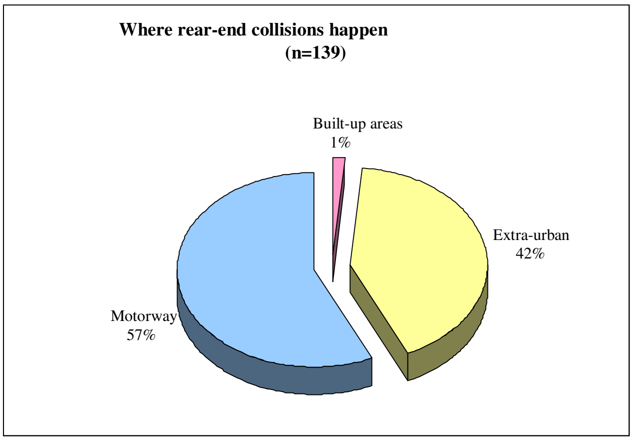



Figure 7: Where rear-end collisions happen as documented by ADAC accident researchers

Very many rear-end collisions in built-up areas result in light injuries and are consequently under-represented in the ADAC accident researchers' data. This is confirmed in [2] which shows that the 2009 number of people killed in Germany in rear-end collisions outside built-up areas was ten times as high as their number in built-up areas. This allows making indirect assumptions on the speed constellations. Average speed ranges between 70 and 100kph on extra-urban highways and between 100 and 130kph on motorways. To ensure that such accidents, where injury risk is high, are prevented, AEBS must work reliably also at speeds of around 100kph.

According to the German official accident statistics [2], almost two thirds of rear-end collisions involving injury (48,625) occur in built-up areas.

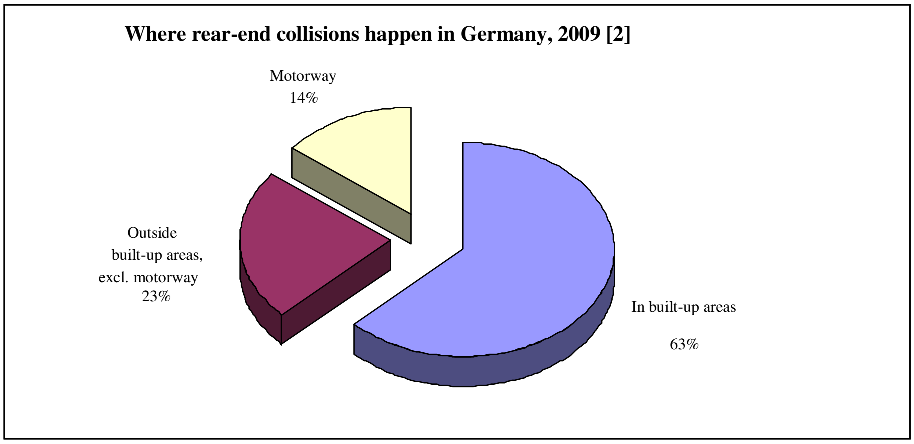
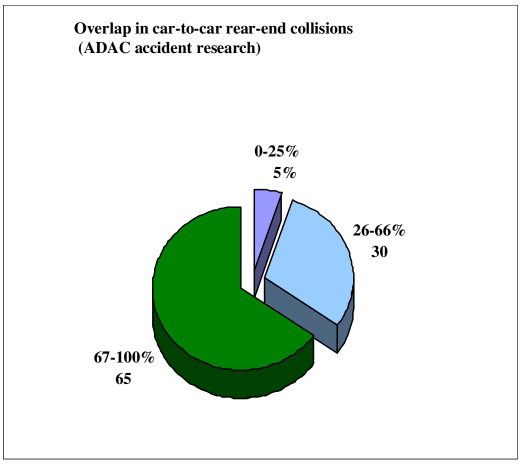



Figure 8: Where rear-end collisions happen in Germany, 2009 [2]

This is also what the analysis of European accident research data concludes. In several sources (e.g. [7]), it is concluded that average speed in rear-end collisions (initial speed) ranges between 40 and 60kph, meaning that in 55% of rear-end collisions, maximum speed is 50kph (speed limit in built-up areas).

In this speed range, rear-end collisions only rarely result in serious or fatal injuries. Nevertheless, rear-end collisions are statistically very significant. Up to 70kph, approx. 75% of rear-end collisions are AEBS-relevant. Where the vehicle behind travels at 110kph, this value increases to approx. 90%.

In addition to speed, overlap and the direction of impact are important factors for the development of test scenarios. ADAC accident researchers found out that in 65% of accidents overlap is over two thirds of the vehicle width. The PENDANT [7] project, where deformation width was quantified indirectly based on the Collision Deformation Classification (CDC), equally showed that in the majority of accidents (54%) overlap is at least two thirds of the vehicle width.



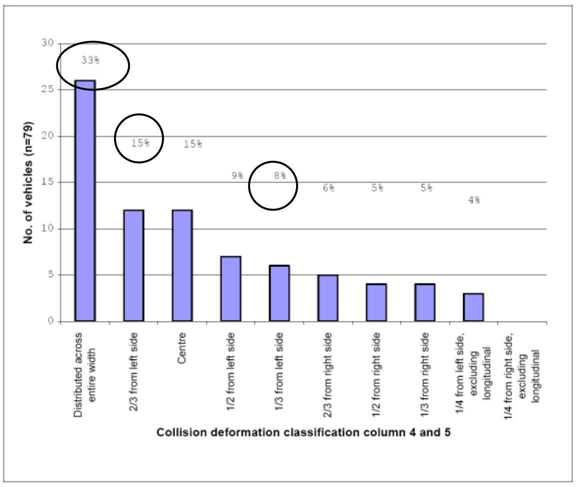
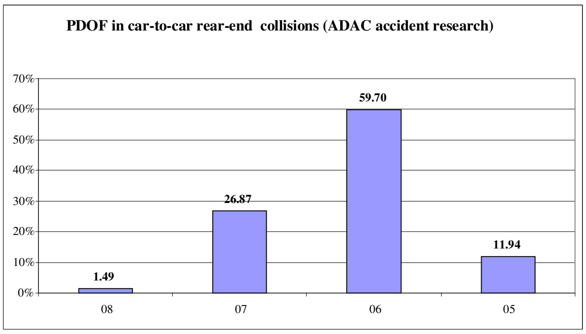



Figure 9: Overlap in rear-end collisions; left: ADAC accident research, right: PENDANT [7]

Another factor used to describe an impact is the direction of force upon impact. Based on CDC, it is defined as the Principal Direction of Force (PDOF). If the direction of force is longitudinal (value 06 corresponding to the 6 o'clock direction), this would indicate that the vehicle is impacted from the rear either directly at the centre or with a very large overlap.



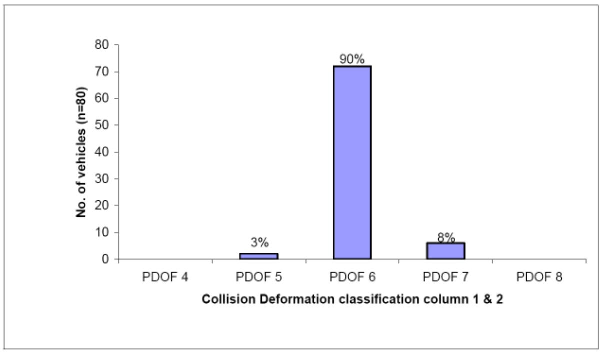




Figure 10: PDOF in rear-end collisions; left: ADAC accident research, right: PENDANT [7]

Both the ADAC accident researchers (60%) and the European PENDANT project (90%) show that vehicles are mainly impacted at 6 o'clock of the vehicle coordinate system. This means that in most rear-end collisions, the vehicle is hit directly at the centre or with a large overlap.

## Injury mechanisms

In severe rear-end collisions, the occupants' injury patterns are typical of the type of vehicle used. Where the rear-ending vehicle is a passenger car, their occupants very frequently sustain injuries to the chest, head and pelvis/legs.

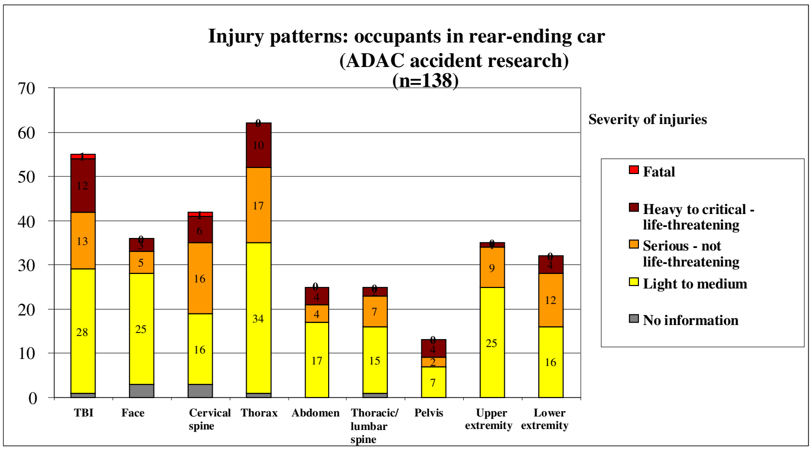



Figure 11: Injury patterns (occupants of rear-ending cars) in rear-end collisions (ADAC accident research)

Overlap is often large, subjecting the occupants to high deceleration forces which frequently result in chest and brain injuries.

The occupants of the rear-ended passenger car very frequently sustain injuries to the spine, chest and head.

Spinal injury is due to whiplash that occurs in rear-end collisions. Whiplash causes injuries to the spinal ligaments, the spinal cord and the vertebral bodies as a result of the occupant's motion and the interaction between the occupant and the seat and headrest.

In addition to the severe injuries mostly caused in accidents that occur in extra-urban traffic, accidents in built-up areas are statistically significant. Notably for the occupants of the rear-ended vehicles, cervical spine (whiplash) injuries are typical in low-speed rear-end collisions (impact speed of 10-30kph). The high-speed relative movement (nod) of the head causes a sprain or injury in the ligaments of the cervical spine a.k.a. whiplash. This type of injury is rarely life-threatening, but often causes considerable handicaps for the injured. The economic loss accountable to such injuries is considerable.

To sum things up, the injury mechanisms can be presented on risk charts in dependence of impact speed (cf. Figure 9).

A system that prevents accidents or absorbs a significant amount of vehicle energy (by reducing speed) tremendously lowers the occupants' risk of sustaining serious or fatal injuries.

## Driver behaviour

An analysis of the driver responses documented by the ADAC accident researchers shows that the drivers most frequently initiated a braking manoeuvre. Swerving occurred in only 5% of cases.

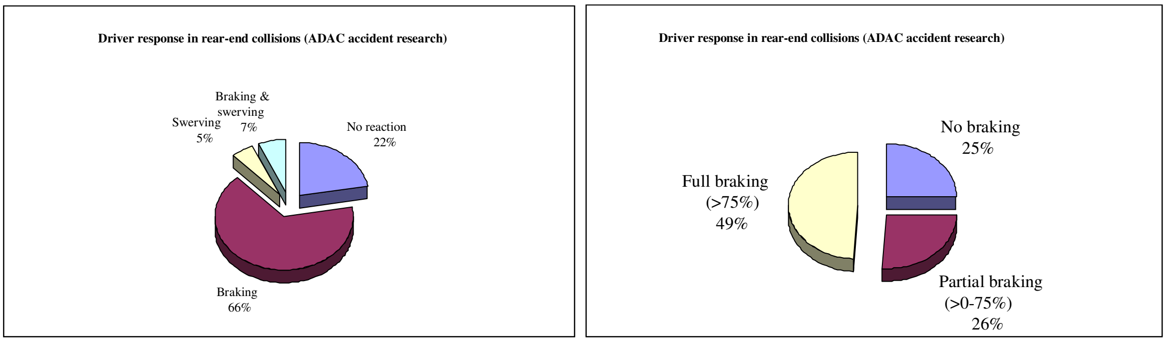



Figure 12: Driver response in rear-end collisions (ADAC accident research)

In almost 50% of braking manoeuvres, the drivers applied full braking pressure (>75%) even if they initiated the manoeuvres too late. In the remaining 50%, the drivers initiated partial braking or did not brake at all.

A GIDAS data analysis by Bosch [8] shows that driver response in rear-end collisions is very similar.

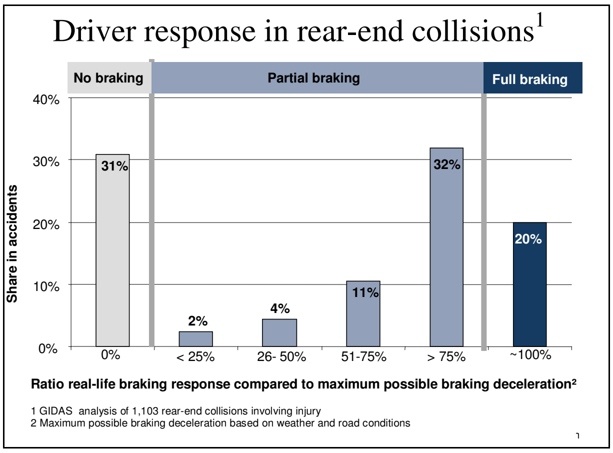



Figure 13: Driver response in rear-end collisions, GIDAS [8]

AEBS deliver a phased response. After an initial warning, there is a short jolt of the brakes to increase awareness. Finally, at the “point of no return”, when collision is unavoidable, full braking power is applied automatically (emergency braking).

**General accident scenarios**

The development of general accident scenarios includes:

- conflict situation
- speed range
- overlap

Based on the accident data, the most frequent conflict situations are set out below:

- Approaching a slow-moving vehicle
- Approaching a braking, strongly decelerated or stationary vehicle (traffic jam tail end, waiting traffic)

The relevant initial vehicle speed (before the rear-end collision) ranges between 50 and 70kph. Since injury risk is increased in accidents in extra-urban traffic, speeds around 100kph are also essential in relation to AEBS.

Overlap upon impact usually is >67% of the vehicle width.

## Test scenarios – Accident based scenarios

Since accidents primarily have 100% overlap, we chose full overlap for all accident-relevant scenarios.

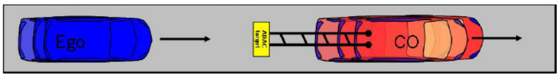
**Scenario B1:**

Represents typical accidents in urban traffic

and on motorways

Test speed: 50kph and 100kph

**4.1 Approaching a slow-moving object**




| Test no. | Speed Ego vehicle [kph] | Speed CO vehicle [kph] | Initial dis-tance [m] | Deceleration CO vehicle [m/s²] |
|---|---|---|---|---|
| B1_1 | 50 | 20 | 200 | 0 |
| B1_2 | 100 | 60 | 200 | 0 |

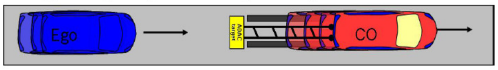
**Scenario B2:**

Represents any rear-end collision

Test speed: 60kph (between 50kph and 70kph

as described in Chapter 3)

**4.2 Approaching an object decelerating constantly**



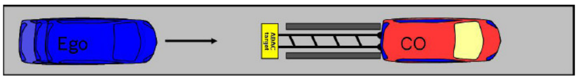

| Test no. | Speed Ego vehicle [kph] | Speed CO vehicle [kph] | Initial dis-tance [m] | Deceleration CO vehicle [m/s²] |
|---|---|---|---|---|
| B2_1 | 60 | 60 | 40 | 3 |

**Scenario B3:**

Mainly represents rear-end collisions in urban traffic

Test speed: 50kph

**4.3 Approaching an object which has come to a halt**



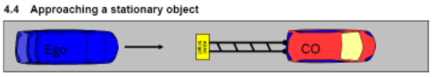

| Test no. | Speed Ego vehicle [kph] | Speed CO vehicle [kph] | Initial dis-tance [m] | Deceleration CO vehicle [m/s²] |
|---|---|---|---|---|
| B3_1 | 50 | 40 | 120 | 3 |

**Scenario B4:**

Represents rear-end collisions of any speed range

Test speed: 20kph to 70kph

**4.4 Approaching a stationary object**



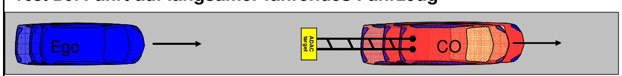

| Test no. | Speed Ego vehicle [kph] | Speed CO vehicle [kph] | Initial dis-tance [m] | Deceleration CO vehicle [m/s²] |
|---|---|---|---|---|
| B4_1 | 20 | 0 | 250 | 0 |
| B4_2 | 30 | 0 | 250 | 0 |
| B4_3 | 40 | 0 | 250 | 0 |
| B4_4 | 70 | 0 | 250 | 0 |

**Scenario B5:**

Represents typical motorway accidents

Test speed: 100kph

**Test B5: Fahrt auf langsamer fahrendes Fahrzeug**




| Test-Nr. | Geschw. Ego-Fzg. [km/h] | Geschw. CO-Fzg. [km/h] | Start-Abstand [m] | Verzögerung Ego-Fzg. [m/s²] | Verzögerung CO-Fzg. [m/s²] |
|---|---|---|---|---|---|
| B5_1 | 100 | 20 | 200 | -3* | 0 |

*1 Sekunde nach der ersten Warnung bremst Ego-Fahrzeug leicht (-3m/s²), sodass eine aktive Bremsunterstützung erforderlich ist, um den Aufprall zu vermeiden.

* Ego lightly brakes 1 sec. after first warning (-3m/s²), meaning that to prevent the collision, active brake assist is required

## Recommendations and limitations

The above scenarios are a first step in the assessment of active safety systems. We focused on the most important scenarios while neglecting any real-life disturbance. Any future assessment will require expanded testing procedures that take complex traffic situations and driver tasks into account.

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