Development of a test target for AEB systems

Development process of a device to test AEB systems for consumer tests

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ABSTRACT

Rear-end collisions are one of the most frequent crashes in Europe. Common causes include momentary inattention, inadequate speed or inadequate distance. Rear-end impacts are among the most common types of road accidents involving injury e.g. Germany with an approx. 15% share in the total number of accidents involving injuries. Accident data shows that the rear end collisions with 65% and more overlap is most common. To test the effectiveness of advanced emergency braking systems and show up their performance to the consumer, a new test setup and assessment has to be developed.

Based on the data of different accident research programs the most common rear end accidents are in a right angular with an overlap of more than 2/3 of the vehicle width. Impact scenarios could fixed to three situations, collision with stand still objects, with stopping objects and with objects of a lower driving speed. Impact speed up to 50kph and more could be seen in the accident data analyses.

Taking into account the findings of the accident research, a test equipment needed to be developed to allow to test all kind of AEB systems in a longitudinal situation, simulating driving, slowing down and stationary condition. On the other hand a system has to be designed to show the consumer the effectiveness of different systems and therefore a target which must be able to strike has to be developed. A balloon car was the best solution for these requirements. In a fist stage the balloon target needed to be developed in a way that nearly all AEB systems could detect it to assess different systems and show the consumer the performance of this new technology. In a second phase the target needed to be improved in a more realistic way according a vehicle rear end, which would make it less easier to detect, but still taking into account the different information of the variable sensors such as radar, lidar, camera or PMD. In addition to the test target also a propulsion system is needed, which should not be recognized by the test vehicle, but allowing testing all the scenarios mentioned before. A ladder frame based system was designed which could be town by a vehicle in front of the target, while the target was place on a movable platform on this ladder frame. Stationary impacts as well as decelerating scenarios up to $6m/s^2$ must be realized with this device.

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 is 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.

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% [1].

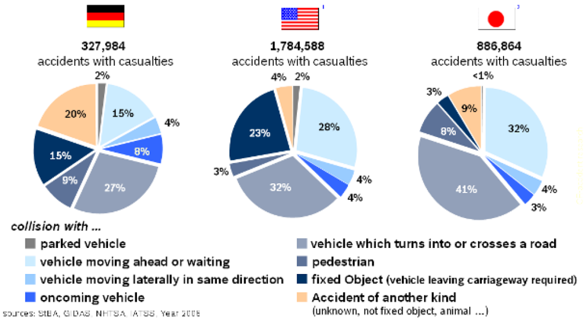


Figure 1: Accidents involving injuries by type of accident constellation [1], [2], [3]

In view of this, 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.

ADAC, Project Report, advanced emergency braking 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.

According to ADAC accident researchers, longitudinal driver assistance systems can be effective in 13.8% of all accidents.

The literature emphasises the importance of rear-end collisions. They are a common type of accidents in Germany and Europe as well as in the USA and Japan.

The Bosch GIDAS data analysis [4] shows that AEBS can be effective in 12% of German road accidents involving injury (accidents recorded before or in 2005).

Impact velocity

This is also what the analysis of European accident research data concludes. In several sources ([5], [9]), 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).

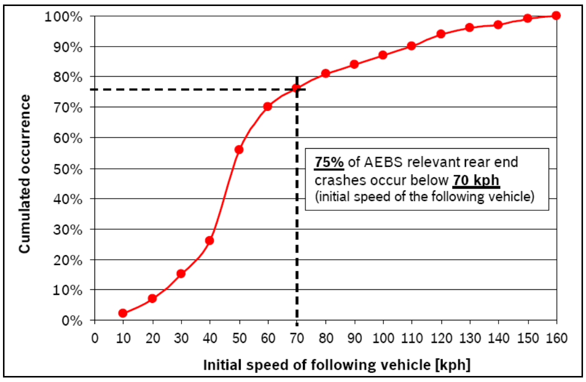
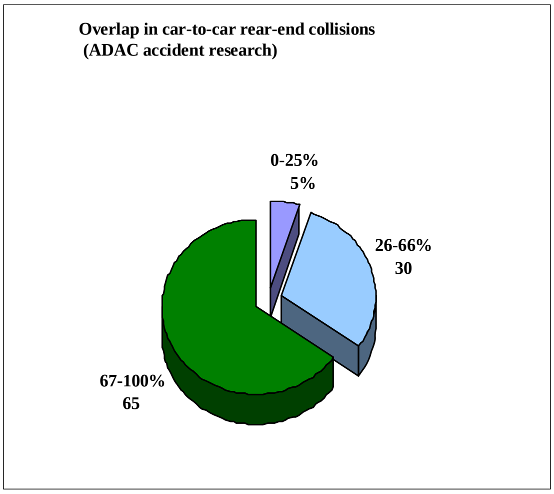


Figure2: Initial speed in rear-end collisions, GIDAS [5]

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 could increase to approx. 90%.

Test scenarios resulting from Accident research

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 [6] 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.



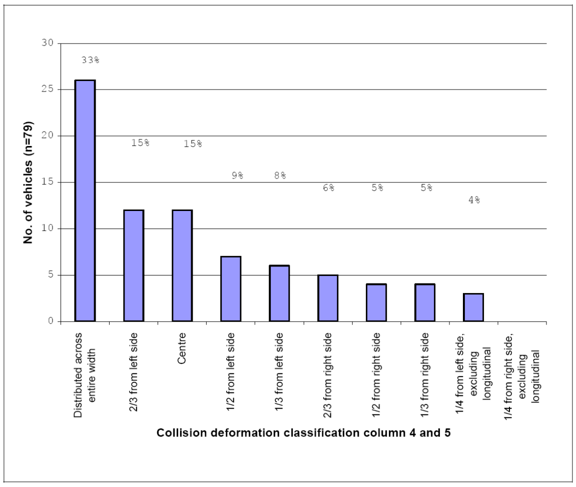


Figure 3 Overlap in rear-end collisions; top: ADAC accident research[7], right: PENDANT [6]

Accident scenarios and circumstances

The analysis of accident types is required to better understand conflict situations that cause rear-end collisions. A GIDAS analysis [5] presents the major accident conflict situations in Germany.

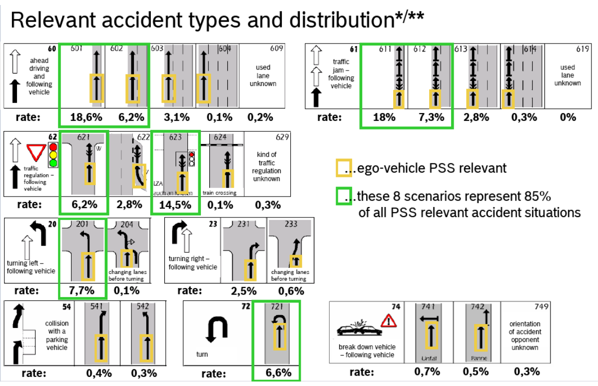


Figure4: Major conflict situations in rear-end collisions, GIDAS, 2001-2006, Dresden and 2001-2005, Hannover [5], accident constellation images based on GDV

DEVELOPMENT OF A TEST TARGET FOR CONSUMER TESTS

Preconditions

The analyses of the accident data, based on several European statistics gave the framework conditions for the setup of a test device for autonomous emergency braking systems.

1. Longitudinal impact

    Approaching a slow-moving vehicle

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

2. Relevant vehicle speed

The maximum 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 maybe in the focus of testing

3. Overlap upon impact usually is >67% of the vehicle width, 100% in a first approach focused

These test scenarios need to be full filled with a test equipment which should be able to be detected by all of the systems actual available on the market, easy to handle and capturing all tests without any need of huge changes to the system and causing no damages to the tested vehicle.

From the ADAC vehicle database information of the average vehicle size is given by 1600mm to 1850mm in width and 1400mm 1600mm in height, which should be addressed by a simulated target vehicle.

AEB systems are based on radar, lidar camera and other foresight systems to check whether the obstacle in front is a vehicle or a different object, so the target has to full fill all the requirement of the different systems. These requirements capture, radar reflexion, from the metal work of a real car, the dimensions and optical view of a rear end of a vehicle, such as a licence plate, rear lights 3D view and a shadow below the vehicle. Only the target vehicle itself should show these specifications, the towing system should not be detected by the AEB systems to avoid different triggering.

Target

Several suppliers and OEM were using a system with the shape of a vehicle to test AEB systems. With the cooperation partners Continental and Bosch the first step was to use a balloon car, developed for stationary tests, developed by Continental. This balloon car has a front and a rear camber, which are connected by 4 tubes. The front of the balloon should distribute the load; the horizontal 4 tubes, 2 placed on the bottom and 2 on the top of the target should deform and reduce the load during the impact.

Figure 5: inside view of the ballon target

The maximum impact speed is 50km/h on the balloon car without any damages to the balloon, so the impact velocity, formulated in the preconditions could be full filled.
Not all of the requirements are full filled with the use of this stationary target. Whether the vehicle siluette nor the possibility of a dynamic movement is given by the balloon car. The handling, stability and energy absorption seem to be a good reason for the use mentioned above.

Towing device
The chosen target was only designed for stationary impacts, a solution to tow the balloon car to the recommended speed needed to be developed. Scenarios for rear impact in longitudinal traffic show that a vehicle, parallel to the target vehicle and running with the similar speed is unlikely in real world. Another solution is to place the towing system or vehicle in front of the target, which shows the actual situation on the road. This setting would also allow using a towing vehicle and a device, which is covered by the balloon car and can not be detected by the tested vehicle.
With this configuration also a normal passenger car could be used for towing the balloon car and could be steered and decelerated by a person or optional by a steering and braking robot.
Concept 1: frame device as foldable ladder with an overall length of 10m, which is divided into 2 parts, on the rear part the target is mounted and on the other end the frame is attached to the towing vehicle. In case of an impact the system would work like a hinge and be folded together. This system is cheap and easy to realize, but not able to be used at a higher impact speed due to the hinge angle. The system could not be overridden by a vehicle. Small offsets would also load the system in a way that exact longitudinal movement could not be realized.
Concept 2: Telescopic arms on the rear of the towing vehicle, which could guide the target also to a higher speed, but the length could not be realized and also the production and price of telescopic arms of that length as well as the durability would lead to enormous costs.
Concept3: Based also on a ladder frame as concept 1 a solution was developed using the frame as a towing and guiding mechanism for the balloon car. Mounted on a small sled, the balloon car is strike able from the rear and it could be pushed forward the completely length of the ladder frame. With a long frame also higher impact speeds could be realized, even if the AEB system would not work or having only small mitigation. The stability of the system at higher speeds is good and the handling of the test system is easy to use and the production will cause not too many difficulties, without any electric devices used.

Figure 6: balloon car mounted on a ladder frame

The direct comparison between these 3 concepts lead to the decision for the ladder frame, sled based towing device which seemed to have the highest potential to full fill the requirements of the chosen test scenarios and causing the less influence of the target detection. Due to the length of the device, higher impact speed and also malfunctions of AEB systems will not lead to a directly damage of the system.
From the concept phase to the first prototype for testing different other test circumstances have to be sorted out and implemented in the towing device. The ground clearance of the modern sporty cars is lower than 100mm, so the maximum height for the system must be less than this dimension. The width of the rail system must be less than the distance between the tyres, so in case of an impact the tested vehicle will not get in touch with the rail system, even with a small offset during the impact. To avoid contact of the target and the towing vehicle, in case of an impact, the towing device has to stop the hidden target before that point. This is realized with a damping mechanism fixed to the towing hook of the leading vehicle. Wheels, mounted to the ladder frame, avoid contact with the ground and allow a longitudinal movement with nearly now movement to the side. This is important to full fill very tight tolerances for the striking of the target.
The movable sled, guided on the rail system is attached to the frame by wheels to avoid friction and to allow the sled together with the target an easy movement on the ladder frame to reduce the loads on the front of the tested vehicle.
In the test procedures, scenarios were foreseen were the vehicle in front is slowing down or even braking up to a deceleration of $6m/s^2$. This is in contradiction with the recommendation of a target which is easy movable, to avoid damages during an impact, and to keep it in position during this braking deceleration. Experiments with different magnetic elements have been carried out to realise high deceleration and easy movement. An

ideal compromise has not been found yet. The adjustment for the release force could be adjusted with different spacers, which are reducing the magnetic force. To realize the best possible alignment of the towing device with the magnets a bearing was implemented, for the best contact between the surfaces. To use the balloon car as a stationary target a separate sled was designed, to reproduce the same height of the target as on the towing device, but to reduce load in case of an impact the sled was reduced in weight and the sliders on the bottom allow an easy movement on the ground.

Target development

The balloon car, which was chosen as the best compromise of a 3D view and a strike able structure needs several improvements to be realized as the rear end of a vehicle by all of the different types of AEB systems.

For the first test series the concept behind the design of the balloon car was to be detected by the different systems such as camera, radar, lidar or PMD sensor to collect test data for a comparison of different systems under best conditions for detection.

Figure 7 balloon car with cover ADAC V1

The **1st version of the ADAC** target used a cover for the balloon car which shows rear and side windows, rear lights and a licence plate. In figure7 the geometric dimensions of the target and a real car is shown. For radar based systems the balloon car itself was equipped with 2 lower corner reflectors on the lower part and on the left and right outboard side. Relexion material was placed behind the rear window and behind the licence plate.

Figure 8: corner reflectors and reflexion foil on the balloon car

Figure 9: impact of the target in scenario leading vehicle slower

After the first consumer test series the target was updated to a more vehicle based response and an improved optical shape.

In several round robins inside the vFSS group and the HP2 platform of Euro NCAP the response was improved according the recommendation of different OEM with different types of sensors. The focus was to have a target, which is not easy to detect and as close as possible to the response of a real vehicle, for all type of sensors.

During these comparison tests the critics included the 3D view of the target including a more realistic picture of the rear view of a car. The corner reflectors left and right were contra productive, without these, the response was even better. The stability of the test device even at higher speed and wind was rated good.

With the **2nd version of the target** ADAC tried to cover all the critics from round robin tests and the result of consumer test carried out with this system.

The original balloon car showed no critics during the performed tests, it is stable in all weather conditions, even with wind from the side or the pressure on the front at higher speed showed no difficulties. While

impacting the balloon no damages were recognised on the test vehicles up to impact speeds of 50kph. The durability in all test scenarios, standing and moving was good, no damages to the outer shell or loss of pressure could be recognized. So no changes were made to this structure. The biggest changes were done on the cover of the balloon and the radar reflexion. For a better recognition with camera based systems a real picture of a car was taken and printed on the cover. Reflecting materials on the outside and a real licence plate, with the combination of a shadow simulation with anti reflex material should give the cameras a real life picture of the backside of a car.
The criticized corner reflectors on the left and right outside were removed and replaced by a single one in the centre in the region of the licence plate.

Figure 10:Target Version 1 left and Version 2 right

The rear bumper was fixed to the car with a radius of 2,65m and attached to it reflexion foil for radar systems. The attachment of the cover on the sled and the balloon structure was improved to have a tight fit not affected by the wind in the driving conditions.
Equipped with the new improvements for all kind of sensors of AEB systems another round robin and comparison test was carried out on a test track over several days to evaluate the new structure, reflexion materials and position as well as the new siluette and the optics. Also the new attachment was tested.
The outcome of this new round robin test was a better visibility for the camera based systems with the new print on the cover, but still will need some improvement in the lower and the side part of the cover. To have a 3D view and the shadow and tyre area at the bottom of the target needs some improvement for a better recognition. With the balloon car mounted on the sled system, made of alloy the radar response is too high in comparison to a real car. So the backplate and the sled system need to be covered by anti radar reflexive material to reduce the response, while a main response from the rear surface would deliver a better and more realistic signal. For both systems radar and camera the position of the licence plate should be moved between the rear lights to position it in a comparable height with actual vehicles.
The last recommendation came up with the use of the PMD sensor were reflective parts are a need on the rear of a car. So a reflex foil instead of the printed rear/brake lights will be a need, to identify and make a clarification of the object. During this test series several test targets were compared to each other. It was concluded that the ADAC inflatable target was the preferred target for the moment, based on its sensitivity to current generation Radar, LIDAR, camera and PMD sensors and with the recommendations implemented it will show a very good overall performance.

Euro NCAP Vehicle Target (EVT)
All the recommendations of this round robin test end of 2011 were implemented in the next evolution of the target, leading to **version 3.** In May 2012 the final round robin tests use the final version of the target and make to official freeze for the use as Euro NCAP testing device took place. Also that time all different types of vehicles equipped with different kind of sensors, representing the actual state of the art and prototypes were represented in the test.
The final cover should be neutral and not easy to detect in daylight, so silver colour was chosen to make it most complicated for camera based systems, especially in bright daylight to recognize the vehicle target. To realize a 3D view also the left and right side of the cover were printed, looking like rear windows and tyres. The shadow of the vehicle between the tyres was improved by a dull leather part to cover the sled/towing system and the tyres geometries were formed by the cover. The licence plate was set to a higher place, between the rear lights, to meet the requirements of ground clearance Reflexion foil was attached in the area of the rear/brake lights for a better recognition and in a geometric line of the original car.

Figure 11: Original vehicle and target vehicle

The radar reflexion is improved with the coverage of the sled and backplate by anti radar reflexion foam as well as between the cover and the balloon car on the rear end. The bumper element radius is less rounded to 4,5m and covered with reflexion foil. A second stripe of reflexion foil is fixed right behind the rear lights, while a triple mirror, covered by foam to avoid damage, is placed right in the centre of the target just above the bumper element.

Figure 12:ADAC Target Version 3 stripped down

An evaluation of Thacham, Volvo and ADAC showed the improvement of this latest version of the vehicle target. The direct comparison between a real car, in this case a Volkswagen Touran and the comparable ADAC target version 3, is shown in Figure13 .Both objects were approached by a Volvo V60, equipped with camera and radar system. The approaching speed was app. 20kph.

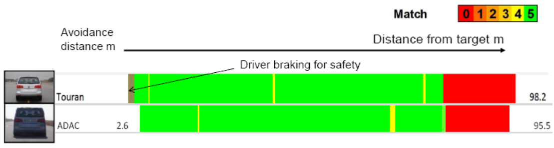


Figure 13 System outputs confidence level of an object based on radar and visual attributes

After this evaluation, the ADAC Vs3 target was specified with all the dimensions, material specification and setup procedure in the Annex A of the Euro NCAP Testing protocol for AEB systems. The name changed to Euro NCAP EVT (EuroNCAP Vehicle Target) and it will be used for stationary and moving impact for assessing AEB systems in interurban and city scenarios which will be the content of the paper 13-0269.[8]

Figure 14:Final Version of the EVT to be used by EuroNCAP from 2014 onwards

ADAC wants to thank the OEMs and suppliers for their support and feedback on the test target and all the members of the P-NCAP WG.

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