Evaluation Methods for the Effectiveness of Active Safety Systems with respect to Real World Accident Analysis

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ABSTRACT

Starting around 1980 with the introduction of ABS, followed in 1995 with the presentation of ESP/ESC, and recently with the development of radar and camera based driver assistance systems, the automotive industry has introduced a great number of electronic systems with the specific goal of enhancing the active safety of vehicles.

The paper discusses evaluation methods for the effectiveness of modern Active Safety systems with respect to:

- Analyses of accident statistics
- In-depth studies on real world accidents
- Case by case evaluations of real world accidents and/or field studies
- Performance tests and measurements on test tracks

The paper gives an overview of the latest methods with their benefits and limitations as seen by an OEM.

INTRODUCTION AND MOTIVATION

One of the first electronic systems that was introduced to enhance Active Safety was ABS. The degree of innovation of the system at that time made it necessary to demonstrate the specific characteristics and highlight the benefits that ABS delivers in critical driving and braking situations. There was a need to convince authorities to homologate and consumers to purchase this innovative technology. Figure 1 shows one of the typical demonstrations that displayed the benefits of ABS controlled braking vs. conventional braking.

Figure 1: ABS Demonstration 1978

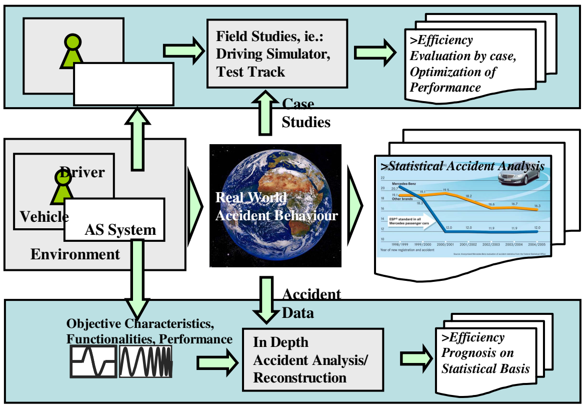
However, not only practical demonstrations were done at this time. Already, attempts were made to quantify the accident reduction potential of ABS on the basis of statistical accident data [1]. In this study, an effect of 4 to 7% accident reduction due to the introduction of ABS was assumed. Unfortunately, the attempts to confirm this prognosis in retrospective accident analyses were not successful. Only many years later it was possible to create a successful retrospective accident analysis – for a different system, the Electronic Stability Program (ESP) / Electronic Stability Control (ESC) [2, 3, 4, 5, 6].

The motivation to show potential benefits of Active Safety systems has grown over the years due to the increased complexity and functionality of the systems. Consumers need to be informed and motivated and authorities are not only in the position to homologate but also play an important role of raising consumer awareness and even implementing legislation. Additionally, rating organizations and insurance companies have entered the scene to play their part in enhancing the market penetration of certain Active Safety systems. All these interested parties have a strong interest to assess the efficiency of Active Safety systems.

EVALUATION METHODS FOR THE EFFICIENCY OF ACTIVE SAFETY SYSTEMS

Figure 2 gives an overview of potential methods that can be used to evaluate the efficiency of Active Safety systems.

Figure 2: Examples for Efficiency Evaluation of Active Safety



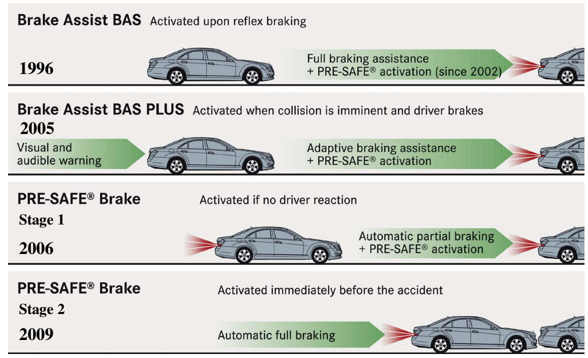
Defining and predicting efficiency is a very challenging task: An Active Safety system cannot be analyzed "stand alone" since it functions together with both the driver, his perception and specific driving skills and the vehicle with its specific dynamic characteristics. So even when the objective characteristics, the functionalities and the performance of an Active Safety system can be defined and measured, they are by far not sufficient to quantify system efficiency. In this paper the following approaches will be discussed:

- Analysis of accident statistics
- In-depth studies of real world accidents
- Case by case evaluation of real world accidents and/or field studies
- Performance tests and measurements on test tracks

Which method is applicable depends on the system type and functionality.

Examples are given for several Mercedes-Benz braking assistance systems in Figure 3.

Figure 3: Mercedes-Benz Braking Assistance Systems from BAS to PRE-SAFE® Brake



The Brake Assist BAS interacts with the driver: If the drive applies the brake pedal in a way which is characteristic for emergency reactions, brake pressure is automatically increased to provide full deceleration. This system is complemented by the radar based Brake Assist Plus. It warns the driver in case of an imminent collision danger and - upon pedal application - increases the brake pressure to the level that is necessary to avoid the accident. PRE-SAFE® brake reacts if the driver ignores the visual and audible warning and initiates a partial braking (stage 1) and a full deceleration (stage 2). PRE-SAFE® brake stage 2 is activated approximately 0.6s before the impact, i.e. when an accident can not be avoided. PRE-SAFE® brake stage 2 is designed to mitigate the crash outcome and can therefore be regarded as an "electronic crumple zone".

ANALYSIS OF STATISTICAL ACCIDENT DATA

The most impressive method to prove and quantify the efficiency of an Active Safety system in real world accident scenarios is clearly the retrospective accident analysis. The excellent results that could be obtained for the Electronic Stability Program (ESP) in numerous studies [i.e.: 2, 3, 4, 5, 6] are a very good example. They were so impressive that they caused the brake-through of this assistance system.

Unfortunately, it was not possible to verify the real world performance for any other Active Safety system in a comparable magnitude. The main challenge is identifying statistically relevant changes in accident behavior between cars with and without a system that project beyond the noise of accident data. ESP was rapidly introduced over numerous model lines and hence the effect on accident statistics was so significant.

A further example of a successful retrospective accident analysis is the efficiency of the Mercedes-Benz Brake Assist BAS. BAS was introduced in 1996 and became standard equipment on all Mercedes-Benz passenger vehicles by 1997. Again, a very steep gradient of introduction allowed to clearly distinguish between cars with and without Brake Assist, allowing a tangible evaluation of the effect of BAS on rear end crashes in accident statistics.

Figure 4: Analysis of Accident Statistics, Brake Assist (BAS): Fewer Rear-End Accidents.

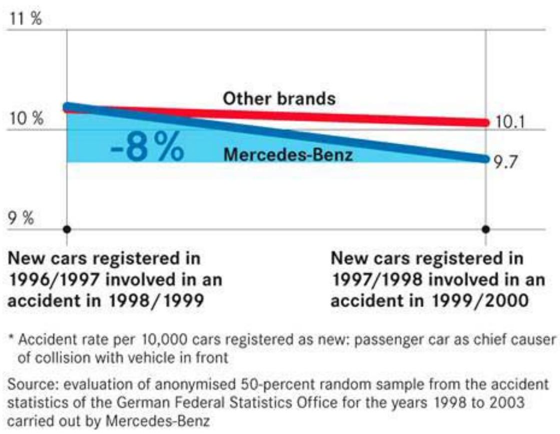


Figure 4 shows an 8% decrease in rear end crashes after the introduction of BAS.

Of course, a retrospective analysis of accident data is only possible if a system has been on the market long enough to provide a sufficient market penetration. Before and during the introduction of a new Active Safety system only prospective methods are helpful.

IN-DEPTH STUDIES OF REAL WORLD ACCIDENTS

If a retrospective accident analysis is not successful for given systems or not possible for new systems, in-depth studies of real world accident can be very helpful. Real world accidents can be reconstructed and re-analyzed considering the assumed effect of a specific Active Safety system. For that purpose the accident data needs to provide detail (including driver behavior). The German GIDAS data base [7] is a good source for this purpose. As an example, it was possible to recalculate to positive effect of Brake Assist on pedestrian accidents on the basis of GIDAS data [8]. This study and similar other studies formed the basis for the European legislation on pedestrian protection that includes the mandatory fitment of BAS on passenger cars [9].

A different example is the recently published prognosis of the efficiency of BAS PLUS on real world accidents [10].

Figure 5: Efficiency - Prognosis on Basis of Real World Accident Analysis (GIDAS)

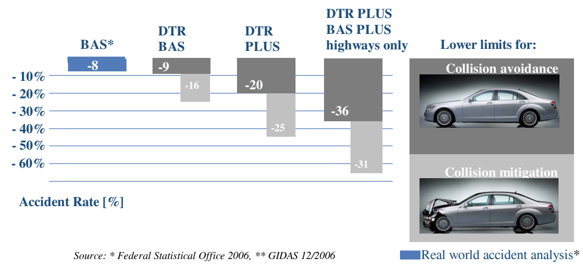


Figure 5 shows that the predicted efficiency of BAS on the basis of GIDAS data is very similar to the value that was obtained in retrospective statistical accident data analysis. BAS PLUS, a system launched in 2005, shows a prognosis of 20% accident reduction and additional 25% of accidents with mitigation effects. Values for highway- and Autobahn-scenarios only are even higher.

This approach is associated with significant analysis effort, but will gain importance in future for system development and optimization as well as for creating positive public awareness of modern safety technologies.

CASE BY CASE EVALUATION: REAL WORLD ACCIDENTS AND/OR FIELD STUDIES

Real world accidents can also deliver very valuable information when analyzed case by case.

Mercedes-Benz has a long tradition in real world accident analysis. Mercedes accident engineers have been systematically evaluating severe accidents with occupant injuries on-site since 1969. An extremely detailed database, only comprising Mercedes-Benz passenger vehicles and – more recently – light commercial Mercedes-Benz vans, has accrued over time. Even though comprising a comparatively small number of ca. 3,800 cases, the underlying database is an invaluable resource for product real world performance monitoring and improvement that no accident other study can offer.

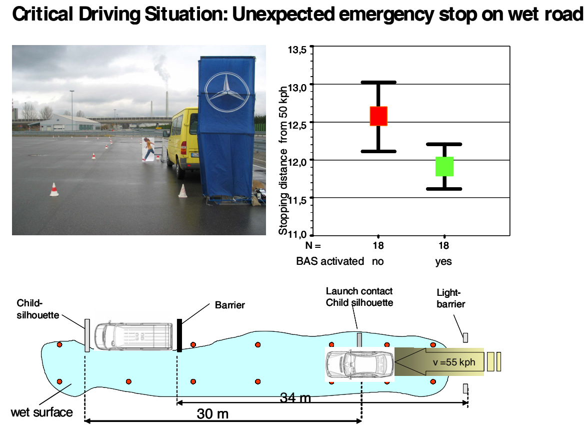
But such studies of real world accidents cannot only show optimization potential for Passive Safety. Accident reconstruction delivers inspiration for innovative Passive and Active Safety systems. The idea of exploiting the PRE-SAFE® phase, a time between departure from safe driving and the actual accident, was directly derived from the Mercedes-Benz accident research. Accident analysts showed that the PRE-SAFE® phase was of considerable duration, exceeding the time available for crash-activated devices by orders of magnitude. This marked the advent of reversible safety systems, most prominently the reversible PRE-SAFE® seat belt tensioner.

The reconstruction of the accident scenario under the assumption that a specific Active Safety system was present allows a prediction of the systems effect on the specific case.

Additionally, the reconstruction of real world accidents can be used to create artificial or virtual scenarios for field tests with normal drivers on test tracks or in the driving simulator.

An example for a typical critical driving scenario that can be used for field studies on test tracks is described in Figure 6. A driver who is not prepared for the event experiences an unexpected emergency braking situation when an obstacle crosses his driving path. The emergency bracing reaction of the driver and the resulting stopping distance can be measured. The results with BAS and without BAS can be evaluated and compared.

Figure 6: BAS Efficiency on Test Track



In this case a significant enhancement of braking performance and reduction of stopping distance was observed for test runs with BAS.

Most of the relevant accident scenarios that can be derived from accident analyses are of a much more complex type, including other traffic and more sophisticated driving situations. In these cases a driving simulator can be used to gain repeatable results under complex conditions without risk for the test persons.

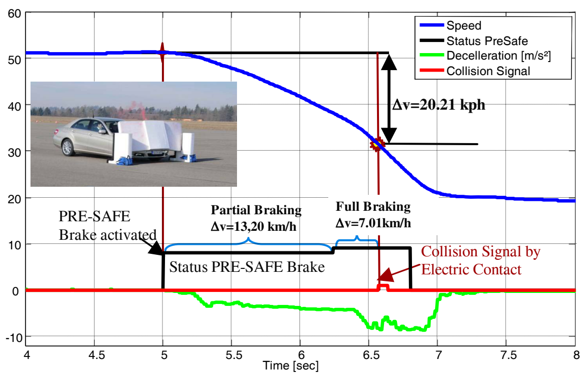
Figure 7: BAS PLUS Efficiency in Driving Simulator

Figure 7 shows the result of a study in the Daimler driving simulator in Berlin. 110 drivers experienced typical critical situations derived from accident research. BAS PLUS lead to a reduction of the accident rate of 75% in these specific situations compared to the conventional BAS.

PERFORMANCE TESTS AND MEASUREMENTS ON TEST TRACKS

All the effects that Active Safety systems have in real world accident scenarios as well as in field studies on test tracks or in simulators are of course related to their specific functionalities and objective performance. Functionalities and performance of the Active Safety system are usually well known to the OEM and are used as input parameters for all of the above described evaluation methods. Nevertheless, objective tests are necessary for demonstration and especially for validation purposes, e.g. in combination with ratings or with homologations. Objective tests and minimum performance levels have been defined for Electronic Control Systems [11] and also for BAS [9].

Figure 8: Measurement of Speed Reduction by PRE-SAFE® Brake



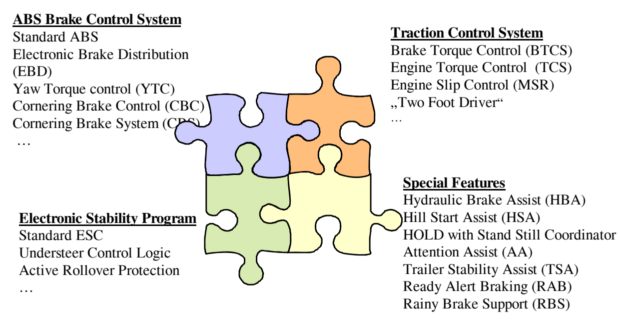
The result of a typical performance test of the recently launched PRE-SAFE® brake stage 2 is shown in Figure 8. The diagram shows the result of a critical approach to a stationary obstacle that simulates a vehicle. Even without any driver reaction the vehicle speed is reduced from 54 km/h to 34 km/h. Partial braking of PRE-SAFE® brake reduces the speed by 13 km/h, PRE-SAFE® brake stage 2 delivers an additional 7 km/h reduction under these circumstances. This translates into an energy reduction of almost 63% which is not only beneficial for the occupants of the car equipped with PRE-SAFE®, but also for the passengers of the other vehicle.

LIMITATIONS

Although the functionality and the performance of Active Safety systems form the basis for their real world efficiency, they are not sufficient to describe all relevant effects and will not allow an efficiency prediction. Active Safety systems interact with the driver, they support the driver, they help to avoid mistakes and they interact with the vehicle and the environment. A full forecast of their potential is only possible with respect to the complete relation of driver-vehicle-system-environment (Figure 2). Statistical methods or field tests can be an approach to that aim, but a test track test alone will not be sufficient.

Even the inviting opportunity to at least compare different Active Safety systems with similar functionality is questionable. Active Safety systems are very complex; they usually contain a variety of sub-functionalities. As an example, figure 10 gives a rough overview of the functions that are contained within a current Electronic Stability Control system.

Figure 9: ESP® Functions



All these sub-functions are optimized and developed during a development phase that takes several years. Each function is tested under numerous test conditions and situations [12, 13, 14]. It is not realistic that this overall functionality and performance be evaluated on basis of a limited number of tests.

This is even more important with respect to real world accident scenarios, since it is not clear in most cases which sub-function had the greatest real world effect.

Finally, even systems that more or less autonomously react without driver interaction cannot be evaluated completely with simple tests. The test result of PRE-SAFE® brake in Figure 9 may serve as an example: Evaluating the performance of this system on the basis of a “positive test” can be very misleading. In case of the PRE-SAFE® brake the “positive-false” performance is by far the greater challenge.

“Positive-false” implies that the system may not activate in non-critical real world situations. It is not sufficient to create a system that brakes as often and as hard as possible. The challenge is to overrule system activation in all non-relevant real world situations that might occur, and to activate it only when really necessary. To verify this, Mercedes-Benz tests new systems under realistic traffic situations (Figure 10).

Figure 10: Mercedes-Benz Real World Testing of Active Safety Systems

Normal drivers use specially equipped cars in real traffic in several countries on different continents to evaluate the system performance under real world conditions. In a first step the test cars are equipped with the system in a passive state, i.e. the sensors, controllers and algorithm are on board and active, but do not lead to a vehicle system intervention. The cars are equipped with several sensors and video cameras that allow the evaluation of driving situations, driver actions, and system reactions. In a second phase the system is active when driven on public roads. PRE-SAFE® brake for example experienced a total test volume of more than 1 Mio. km in real traffic. The collected test data is stored and used to recalculate and optimize the effect of different algorithms offline.

SUMMARY AND OUTLOOK

The evaluation of the effectiveness of Active Safety systems is possible on several levels of abstraction. Basic tests are functionality and performance tests on test tracks that can be used for development or demonstration purposes. A broader view of the system's performance, including the driver-system interaction, can be gained by field tests on test tracks or in a driving simulator, ideally on the basis of scenarios derived from real world accidents. Statistically more significant are accident reconstructions on the basis of in-depth accident data analyses. The probably most accurate efficiency evaluation is the retrospective statistical accident data analysis that delivers the most reliable results, but is not viable in most cases and not feasible for new systems.

The effectiveness evaluation of Active Safety systems has shown huge impact in the past, especially with respect to ESP®. It can be expected that in future, the importance of these kinds of evaluations will continue to increase. Motivation of this is the demand to raise consumer awareness by manufactures, authorities, insurance companies and others.

This consumer information is required to increase the acceptance and market penetration of effective Active Safety systems for the achievement of the overall goal: To increase traffic safety, i.e. to reduce the number and severity of accidents and to save as many lives as possible.

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