50 years of Mercedes-Benz Accident Research - ready for the next level

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Abstract
Mercedes-Benz accident research has been working on product safety for 50 years. The idea to own an accident research investigation center was conceived due to the fact that in 1960s the number of accidents were increasing. The focus was on self-investigated accidents and affiliated data.
In 1969, the Ministry of the Interior provided the mandate for the legitimacy of such accident investigation. Under this mandate, in certain circumstances, the authorized police officials were entitled to report serious accidents involving current Mercedes-Benz vehicles to the accident research center and provide collected data.
One of the first investigated vehicles was a W113, so called Pagode. Required investigation methods were developed immediately. The goal of in-depth investigation was to identify the contributing factors for accidents and injuries and derive possible requirements for research and development. Until 2018, more than 5000 accidents were investigated and reconstructed. Today, some of the major tasks of the accident research are accident-data-analyses and the benefit estimation for future safety systems and innovations.
Accident investigation and reconstruction has changed significantly during the years. Measuring lanes and traces with a tape measure, like it was done in the past, isn’t possible anymore due to more traffic on the roads. A modern 3D-laser scanner is being used for this purpose today.
Not only investigating the accident scene has changed, the vehicles themselves have changed significantly. Today, accident research aims at assessing the impact of modern advanced driver assistance systems along with investigating the crash worthiness. Therefore, interpreting all system functions is a new and important task. Modern accident reconstruction software applications can visualize the accident sequence, which can also help to relate the restraint system deployments.
This paper will be discussing the progress of available methods and introduce new approaches for future automated driving applications in road vehicles.
50 years of accident research = 50 years of improvements

Introduction
On a cold, gray winter's day in January 1969, government officials and senior police officers from Baden-Württemberg met up with representatives of the then Daimler-Benz AG for several hours of talks at the state's Interior Ministry. The agenda contained an unusual request added by the automotive company- an appeal for police assistance in reconstructing and analyzing road-traffic accidents involving Mercedes models.
The idea of the development engineers was to use data from real world accidents in order to enhance vehicle-occupant safety. Daimler-Benz had already acquired initial experience in this field during a six-month pilot project held two years previously. During the period January- June 1967, company employees had worked together with police on
the investigation of serious road-traffic accidents that had occurred in the district of Böblingen and on the A8 highway.

The prime aim of the meeting at the Ministry was to place this research project on a broader and most important of all, permanent footing. The reaction was positive, and senior police officers once again signaled a readiness to cooperate. Therefore a communiqué, which was requesting for support, was dispatched to the various departments. The Accident Research Project was officially launched on April 29, 1969, after which the Interior Ministry issued a directive to all the relevant police departments. This directive was telling the police departments to inform Daimler-Benz by telephone of any road-traffic accidents, as well as to allow company representatives to inspect the accident report and question the duty officers on the actual sequence of events. The justification for this measure was as follows: "The Interior Ministry supports the research of Daimler-Benz AG because of its general impact for road safety."

Thanks to successful cooperation with the authorities and the police, the area covered by the Mercedes accident research has been expanded several times over the following years. Today, it stretches from Baden-Baden to Ulm, from Mannheim to Konstanz, and from Tauberbischofsheim to Lindau- almost 200 kilometers across at its widest point.

One of the first investigated vehicles was a W113, so called Pagode.

Accident researchers on call
50 years of accident research at Mercedes translates into 50 years of meticulous data acquisition and detailed analyses. Today, researchers are called out over 100 times a year to carry out first-hand inspection of serious crashes. Since being set up, Mercedes Accident Research has investigated and reconstructed more than 5,000 traffic accidents.
Examples of investigated Mercedes-Benz models in the 60s/70s

At the accident scene, work generally begins with a set of basic questions: How did the accident happen? What was the position of the vehicles after collision? Are there any traces or skid marks? Today researchers usually use a 3D-laser-scanner to scan the accident scene with all the marks and three-dimensional information of the landscape. During the investigation of the involved Mercedes-Benz vehicle, the researchers ask themselves some questions. How did the crumple zone perform? Is there any deformation of the passenger cell? Were airbags and seatbelt tensioners activated? Is there anything unusual about the interior of the crashed Mercedes model? Were the occupants injured- and if so, what were their injuries? These are some examples of the manifold questions.

The answers to all these questions and additional information is ultimately recorded in a database with more than 1,200 parameters per case. This database also includes dozens of photos, sketches and eye-witness accounts. Once the relevant information has been collected, researchers can systematically reconstruct the actual collision. Assistance is delivered by a computer system that converts the data and 3D-laser-scans gathered at the accident scene for visualization. The researcher is able to reconstruct the actual sequence of events by combining the length of traces or skid marks with design data and information on the handling behavior of the damaged Mercedes model. Researchers can then view onscreen how the vehicle moved before, during and after the collision. Furthermore, the computer simulation provides views of the accident scene from different perspectives.

The results are then compared with data from other accidents, thus enabling automotive engineers to gradually compile an exact picture of the typical injuries involved, and acquire the knowledge needed to develop new and even more effective safety systems. Furthermore, the findings of Mercedes Accident Research show the engineers that the brand’s longstanding and uncompromising stance on safety is already paying dividends. The analyses of traffic accidents shows, that the risk of being injured when traveling in a Mercedes has been consistently declining for many years now.
Technological edge through research
50 years of accident research at Mercedes-Benz have played a major role in preserving the brand's technological edge over rival automakers. That's because engineers are quick to apply this knowledge in a practical manner. Over the years, the findings of such research have repeatedly provided the basis for the development of new and pioneering safety systems:

Interior design
At the end of the 1960s, when Mercedes-Benz first began systematic accident analysis, experts initially focused on improving protection inside the passenger compartment. Although Mercedes models were already then fitted with seatbelts, very few people actually used them. For many front-seat passengers, this carefree attitude led to serious head injuries, resulting from an impact with the steering wheel, instrument panel or windshield. Accident researchers therefore set about identifying dangerous impact points inside the vehicle and suggested improvements to the design of various switches and handles responsible for severe injuries. Likewise, the instrument panel and interior trim materials were also reconsidered with safety in mind. Since then, design engineers have favored energy-absorbing materials.

Examples from the 90s: Footwell-Protection/Seat-Deformation elements, Flexible fuel lines
Accident evaluation are showing the need for further improvements for safety (interior and exterior)
- Footwell:
  energyabsorbing foams to reduce forces to the heel
- Seats:
  installation of deformable elements at the side of the frame to distribute the impact forces
- Motor:
  impact-safe fuel lines (flexible and protected)

Some examples of interior improvement in the 90s
Test procedures and body structure

Once the interior had been made safer, the attention of accident researchers and engineers turned toward improving the body structure. Once again, this was the consequence from initial accident analyses. When reconstructing typical collisions with oncoming traffic, accident researchers quickly realized that vehicles usually hit one another asymmetrically. The result for the front part of the body is that one side is more heavily impacted than the other. Experts describe this type of crash as an offset collision. In around half of all so-called head-on collisions on German roads, the impact actually affects only 30 to 50 percent of the left-hand side of the vehicle front. In a further 25 percent of such collisions, the impact occurs on the passenger side of the vehicle front.

This discovery had major consequences for automotive design. Given that a full front-end collision against a flat wall was legally required as a safety test for passenger cars, but only represented a fraction of real world accidents, Mercedes-Benz decided to go further. On the basis of results from the company's own accident research, engineers introduced the first offset crash tests as early as 1974 and went on to develop a design principle that provides high occupant safety even when the vehicle front is subject to extreme partial loads. The solution was realized in form of forked members- rigid longitudinal sections on both sides of the front part of the body structure. Each of these forks in the front of the front wall and toward the side skirts and the drive shaft hump. These cause the force of impact from a collision to spread equally between the hump, floor and side panel, with the result that the passenger compartment remains largely undamaged. The S-class sedans of the W 126 series, as launched in 1979, were the first Mercedes models to feature forked members designed specifically to protect against offset front-end collisions. Today, a new design principle provides an even more effective protection for vehicle occupants - not only in the event of an offset crash.
Years of continuous accident observation later revealed the need for a further modification of the test procedure, whereupon Mercedes-Benz developed the offset crash test against a deformable barrier. In this test an aluminum structure serves to replicate the crash crumple zone of the opposing vehicle, thereby enabling a more realistic analysis of how the body deforms during impact than is the case with a collision against a rigid concrete or steel barrier. Jointly developed by Mercedes-Benz, the crash test with a deformable barrier is now part of Euro NCAP (New Car Assessment Program) and, as such, compulsory for all new passenger cars in Europe.

Further analysis of real world accidents in the 1970s and '80s led to the development of additional pioneering safety features. The most important of these was the three-point seatbelt, which was first introduced by Mercedes-Benz in 1968 and, along with headrests for the driver and front-seat passenger, became standard equipment in all the brand's models in 1973. The seatbelt remains the most important element of occupant safety and has saved hundreds of thousands of drivers and passengers from death or serious injury over the years. Once again, however, accident research showed Mercedes engineers that there was still space for improvements. This included enhanced seatbelt geometry as well as fixing the lower mounting point to the frame of the seat. This ensures optimal positioning of the
seatbelt irrespective of the seat's position. In 1971, the Mercedes-Benz 280 SL debuted as the world's first car to feature this important safety feature.

Mercedes-Benz 280 SL, 1971
Seatbelt tensioner, 1992

**Seatbelt tensioners**

It was in the early 1970s that accident researchers first realized that conventional seatbelts were not sufficient to protect vehicle occupants from impact with the steering wheel or instrument panel in the event of a severe front-end collision. The reason for this was the slack in the seatbelt, which results from the design principle of the component, and which Mercedes engineers were able to offset with the invention of the seatbelt tensioner. In the event of a crash, the tensioner tightens the seatbelt in a matter of milliseconds. Development of this practical component began in 1970. After that it was only with subsequent advances in microelectronics, which are required to trigger the mechanism, that the seatbelt tensioner achieved a realistic chance of entering series production. Mercedes-Benz first introduced seatbelt tensioners for the front seats in 1980, and they have been standard equipment in all the brand's passenger car models since 1984.

Today, there is no doubt as to whether this complex development was worthwhile. In the event of a front-end collision, the seatbelt tensioner not only prevents the head and upper body from tilting dangerously forward but also reduces the overall stress load on vehicle occupants.

**Front-Airbag**

The quality of occupant restraint systems was further enhanced by the development of the airbag—another flash of inspiration on the part of Mercedes engineers and a milestone in safety technology. Development of this pioneering piece of equipment began in 1967. It was patented by Daimler-Benz in October 1971 (DE 2152902 C2) and first introduced into series production at the end of the 1980s, following full 13 years of development and testing. The airbag inflates within milliseconds in the case of a front-end collision to
prevent the driver's head from hitting the steering wheel or instrument panel, thus substantially is reducing the risk of serious injury. Mercedes-Benz has fitted a driver airbag as standard equipment since 1992.

With the launch of the S-class (W220 series) in 1998, Mercedes engineers showed that the airbag can be adapted to deal with different accident situations. The engineers developed an innovative two-phase gas generator that enables the airbag to be inflated in line with the severity of the impact: If the sensor system registers a medium collision, it activates merely the first phase of the gas generator, with the result that the airbag is only partially inflated. If, however, a more severe impact is detected, the first phase is followed by a second phase milliseconds later that further inflates the airbag. This adaptive control system for both the driver and front-seat passenger airbag is today a standard feature of all Mercedes passenger cars.

Mercedes engineers had designed the airbag to supplement the three-point seatbelt. The primary function of which is to provide protection in the event of a front-end collision. Accident research at Mercedes-Benz confirms the wisdom of this approach. Back in the 1970s, around 30 percent of Mercedes car drivers involved in a severe front-end collision suffered life-threatening injuries despite wearing a seatbelt. Today, however, injuries of such a severity are a thing of the past, thanks to the excellent interplay between airbag, seatbelt, seatbelt tensioner and other safety systems.

If these Mercedes accident research results are extrapolated to cover all passenger cars fitted with this technology, it means that the airbag has helped save the lives of more than 2,500 people in Germany alone since 1990. The National Highway Traffic Safety Administration in the United States has ascertained that airbags protect one in three car occupants against serious injury in the event of an accident. Moreover, around one in six drivers and front-seat passengers involved in an accident owe their lives to airbags. Indeed, the airbag has saved the lives of more than 14,200 vehicle occupants in the U.S. since 1987.

**Seatbelt force limiters**

In the mid-1990s, the analysis of accident reports revealed that standard fitting of airbags and seatbelt tensioners for drivers and front-seat passengers had created scope for further fine-tuning of the restraint system as a whole. In response, Mercedes-Benz developed the seatbelt force limiter, which reduces the restraining force of the seatbelt as soon as vehicle occupants are cushioned by the airbags. This significantly lessens the load on the upper body of front-seat passengers.

**Sidebags and windowbags**

Mercedes-Benz's longstanding commitment to enhancing occupant safety has had a huge impact: By early 1998, accident researchers were already able to confirm that the risk of suffering life-threatening or fatal injuries in the event of a front-end collision had been substantially reduced over the preceding two decades. Indeed, fatalities among passenger car occupants wearing a seatbelt were almost exclusively limited to extremely severe front-end collisions.

The focus therefore shifted to another type of accident: the side-on collision. The proportion of such collisions among all accidents resulting in serious injury to vehicle occupants had risen continuously since the 1990s. Although only 14 percent in 1985, it had risen to 30 percent by 1995. Similarly, side-on collisions were becoming an increasingly significant cause of fatalities among vehicle occupants: A study by Mercedes Accident Research actually revealed the proportion of all road traffic fatalities involving this type of collision to be 44 percent.
In response to this trend, safety engineers put together a package of measures that included not only stronger door locks and hinges but also special deformable elements and foam padding in the interior trim of vehicle doors. In addition, Mercedes passenger cars were fitted with protective reinforcement in the lower part of the doors. This protection against side impact was further enhanced with the introduction of sidebags in 1995 and windowbags (curtain airbag) in 1998.

The development of the windowbag was based on intensive research at Mercedes-Benz, which had shown that side-on collisions can lead to serious head injuries. Either because occupants are struck by foreign objects entering the vehicle or because the force of the impact causes passenger heads to move outward. A large windowbag, which is inflated along with sidebags and covers the inner surface of the side window, provides effective prevention against this type of injury.

**Sideprotection: Benefit of Side- and Windowbags in DBCars**

- Evaluations of accident data revealed a continuous increase in the proportion of side collisions in accidents involving injured car occupants at the end of the 1980s
- After the frontal collision, the side impact became increasingly the focus of safety development:
  - 1995: Sidebags as protection pad for chest and abdomen
  - 1998: Windowbags as a suitable head protector
- In side collisions the share of uninjured occupants could rise up to 30% (-20%)
- The seriously injured persons could be reduced to 7% (-13%)

S-class W220 which was hit by a tram (left and middle) and benefit calculation (right)

Mercedes-Benz also developed a similar safety system for its roadsters and convertibles. These models are fitted with special head/thorax sidebags and special headbags to protect the upper body and head of front-seat passengers.

Real world accident, E-class convertible A238 side impact into a tree

Several accidents have shown that there is also a benefit from windowbags in rollovers to protect the occupants. Since 2004, such rollover-sensing sensors are available in many
models. The first model which was standard equipped was the S-Class W221 followed by the E-Class W211.

PRE-SAFE®
Thanks to automatic seatbelts, seatbelt tensioners, airbags and many other innovations, Mercedes models have reached such a high level of safety in recent years that it is hard to find room for significant improvements using available technology. In other words, new ideas and approaches are required to achieve further advances in occupant safety. Once again, accident research has provided the necessary impetus: Some time ago, experts determined that over two-thirds of all traffic accidents are preceded by a critical driving situation such as skidding, emergency braking, or sudden evasive action—situations that already indicate an imminent collision. In the past, these precious few seconds before the crash could not be utilized for the benefit of passive occupant safety. That's because established protection systems such as seatbelts, airbags and seatbelt tensioners would only engage after impact.

Such insights from accident research led to the development of PRE-SAFE®, an innovative occupant protection system that ushered in a new era in vehicle safety at the end of 2002, and which has since then won a number of awards for Mercedes-Benz. PRE-SAFE® is a preventive system that can anticipate an impending accident and immediately start to prepare the vehicle and its occupants for a possible collision by initiating a precautionary tightening of the seatbelts, for example. It thus makes the best possible use of the brief period before a collision to initiate a variety of preventive safety procedures. A comparison with nature is apt here: PRE-SAFE® gives the car "reflexes." PRE-SAFE® is able to recognize an impending accident because it offers a unique synergy of active and passive safety features. It is connected to the Active Brake Assist and the Electronic Stability Program (ESP®) - standard safety systems which use sensors that can recognize potentially dangerous driving situations and then transmit this information to their control units within milliseconds. Mercedes-Benz also uses this data for the purposes of anticipatory occupant protection, thus creating a new dimension in automotive safety.

PRE-SAFE® has been continuously developed and has now been extended with the functions PRE-SAFE® Sound and PRE-SAFE® Impulse Side, which gives additional safety for the vehicle occupants in real life accidents.
One of the latest PRE-SAFE® functions: PRE-SAFE® Impulse side

**Beltbag**

The inflatable webbing of the belt, so called beltbag, may reduce the risk of injury to rear passengers in a severe frontal impact by distributing the load on the chest over a larger area. If the crash sensors detect a severe frontal impact, the airbag control unit triggers the deployment of the pyrotechnical seat belt pretensioner along with the beltbag. A gas generator inflates the webbing to almost three times of the width. The larger area of the webbing (contact area) now reduces the pressure on the thorax of the outer rear occupants. This helps to reduce the risk of injury. The system has proved its effectiveness in real world accidents investigated by the Mercedes accident researchers.

**S-class W222 after a frontal collision with beltbag deployment on the left rear seat**

**Post-Crash functions**

Another idea in the 90s was to shut off the motor. No further acceleration due to any issues during and after the crash. After this first Post-Crash function many others were introduced over the years. Only the accident research team is able to validate these functions in the field. An overview of Post-Crash functions in the field is given in the next picture.
Investigation Methods
Over the years, the effort of manually creating sketches from the scene was replaced by using a laser scanner and/or satellite-maps with high definition resolution. The more detailed sketches resulting from this method enable more accurate reconstruction and further analyses. This is particularly important for assessing the active safety system functions in the pre-crash phase. Another advantage of the laser scans is the ease of measuring the deformation: the device can overlay the shape of the examined vehicle with the dimensions of a new car and easily determine the deformation.

Using a laser scanner device to investigate the scene requires skilled personnel. Some of the necessary preparation work includes the correct usage of reference points. For that matter, special white and reflecting ball type elements need to be positioned in a way that various scans can be oriented in the post processing phase. At the end, the researcher can decide what type of sketch is most beneficial for his analysis. Either a 3D cloud with all parts of the road and uneven pavement or a simple sketch as a JPG-file for plain sights and easier calculation.

Both methods are used for reconstructions and are more accurate than any handmade sketch.
Examples for laser scan usage, vehicle scans and mostly measuring accident scenes

International investigations
Results from different databases around the world show differences in configurations, participants and share of accident data. Due to this issue, a harmonized dataset was created. The project for this standardized data was iGLAD [1]. However, iGLAD currently is not able to fill all the gaps of the worldwide data. The biggest gap is the data from the car itself. To close this gap, it is necessary to also investigate in other markets to identify differences. With this in-depth data from the car, there will be sufficient data for research and development available.

The biggest challenge is the communication and the education in different locations. For that reason, AR technique will be used in the future. With these VUZIX M300 glasses, real-time communication with researchers in different locations can be facilitated. Fast and direct contact with live-video-stream and audio as well as additionally specific data and other important information can be established. Data can quickly be transferred between all participants.

Direct communication between experts around the globe in real time using new AR technology

Conclusion
A wide range of technical innovations contributes to the exemplary safety of Mercedes passenger cars. Many of the patented developments are what set Mercedes models
apart from other cars, thus underlining their role as safety pioneers. And most of them resulted from the findings of 50 years of Mercedes accident research, which helped to safe a significant number of lives. New technologies like the laser scanner or AR will also change the investigation and reconstruction techniques of real world accidents in the future. This will not only allow to obtain more accident data, even in emerging markets. It will also provide a better chance to find the right solutions to mitigate or even avoid more and more crashes in the future. The need for more safety is documented in the current WHO-status report [2] with 1.35 Mio. of road traffic related fatalities in 2018. The amount of different datasets from several countries brings the opportunity to develop an optimized unique vehicle which can address the most accident-configurations and - severities worldwide.

References:
[2] WHO, Global status report on road safety 2018