# A BALANCED ACTIVE AND PASSIVE SAFETY CONCEPT FOR NEW VEHICLE GENERATIONS

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Paper No. 352

## ABSTRACT

For most of the current vehicles on the road – safety has been developed with the predominant focus of offering the best crash protection to occupants possible. With a soon to be introduced vehicle, a new philosophy has been applied. Additional options have increased performance of electronic devices. Concepts have been developed in which safety measures are applied throughout all relevant phases of the vehicle in traffic.
With future vehicles it is BMW`s intention to enhance safety in all relevant phases in a well-balanced way for drivers, passengers as well as other participants in real world traffic. Examples of relevant phases are: cruising and dynamic driving, critical situations and pre-crash phases, occupant protection in case of an accident and finally the post-crash phase.

## INTRODUCTION

Today and in the past, vehicle safety has mainly been associated with passive safety performance. It is the predominant discipline of safety and a matter of global competition. Although passive safety has improved tremendously over the last decades, fatality and serious injury rates are still high throughout the world (Figure 1, 2). Increasing traffic densities and total miles driven per year absorb the passive safety improvements in regards to accident figures.

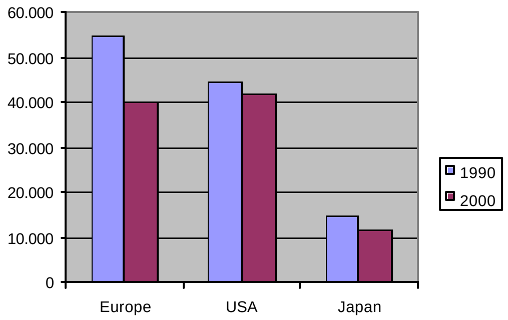


Figure 1. Fatalities in road accidents

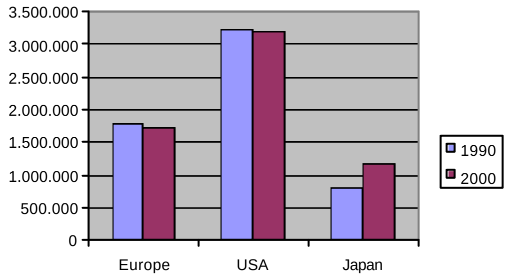


Figure 2. Injuries in road accidents

One should bear in mind: With established consumer tests like IIHS, Euro NCAP, US NCAP, Japan NCAP and Australian NCAP (which are well received by the public) the general vehicle passive safety performance considerably exceeds current legal requirements. For example, European legal requirements would receive a 1.3 star rating by Euro NCAP standards. However, current state of the art rating is a 4 star rating. Today more and more vehicles are even achieving the highest scores, with 5 stars. This shows one important trend in automotive business: it's not just legislation but mainly a private/public partnership, which paves the way to successful results. This proactive industrial behavior leads to intense collaborations between legislative parties, consumer organizations and the automotive industry.

The introduction of driver and passenger airbags in the 80's, thorax airbags and head protection systems as well as active roll-over systems for convertibles in the 90's lead to revolutionary improvements regarding passive safety. In the future it is expected that mainly evolutionary improvements will take place within this discipline. On the other hand legislators are striving to significantly reduce fatality rates: Europe 50% by 2010, Japan 1,200 (approximately 10%) by 2010 and the USA 9,000 (approximately 20%) by 2008.
It is doubtful that these challenging targets will be achieved through passive safety measures alone.

The prospects for this discipline are expected to be evolutionary rather than revolutionary.

However, there is some chance to move significantly towards these targets by changing the focus from passive safety to overall vehicle safety. Improved sensors, processors and general electronic capacities lead to a wide range of possibilities to fight the causes of accidents. The ultimate target of the future should and will be the assistance given to the driver in order to avoid critical situations in daily traffic.

## PHILOSOPHY OF VEHICLE SAFETY

Vehicle safety does not merely start when the accident occurs. Future philosophies should take measures for accident avoidance and accident mitigation into consideration. A phase model, which covers all situations of vehicle use, provides a basis for this concept:

1. prior to driving
2. driving phase (cruising as well as dynamic driving)
3. warning phase (critical situation in progress)
4. correction phase (assistance of the vehicle given to the driver in order to correct the critical situation)
5. pre-crash phase (make use of the milliseconds prior to a potential crash)
6. crash phase (passive safety discipline)
7. post-crash phase (assistance to rescue services and operations)

Results from accident research (source: BMW Accident Research) lead to the following main accident contributors of fatalities and severe injuries (Figure 4):

- accidents due to lack of distance
- coming off the road including roll over
- exceeding physical boundaries
- intersection accidents

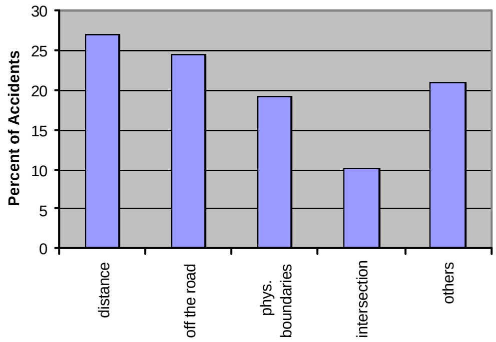


Figure 4. Contribution of accident types

These four main root causes for accidents exceed 80% of the accident scene in Germany. These categories can be sub divided into second source categories in order to evaluate potentials of detailed active safety counter measures.

In combining phases and fatality/injury contributors, several counter measures can be highlighted:

**Phase 1: prior to driving**

- an array of information regarding the target route, traffic situation, general vehicle status information
- assistance regarding optimum seating position, mirror adjustment and seatbelt use
- potential theft and car jacking notices

**Phase 2: driving phase**

- a variety of stress release suggestions, Human Machine Interface issues
- concentration on the main task – the driving process
- advanced visibility
- automatic cruise control and heading control
- brake and suspension support

**Phase 3: warning phase**

- a variety of assistance possibilities to make critical situations predictable – priority setting information fed
- feed-back of critical vehicle and driving configurations

**Phase 4: correction phase**

- active vehicle support (suspension, breaks, steering) while keeping the driver autonomous

- consideration of light control (blinding by light, drastic light changes entering and leaving tunnels etc.)

**Phase 5: pre-crash phase**

- prepare passengers and vehicle for a potentially up coming crash (amongst others re-adjustment of seating position and belt configuration)

**Phase 6: crash phase**

- all structural and passive vehicle safety device measures protect passengers and other road users

**Phase 7: post-crash phase**

- useful information passed on to rescue services for higher efficiency in the rescuing process.

Balancing all phases thoroughly, and not merely focusing on a single phase, vehicle safety will exhibit the best possible overall performance. The future will be in an advanced combination of active and passive safety. Taking into consideration the real world critical situations and accident scenarios by the frequency of their occurrence, the before mentioned governmental targets might be achieved even without strict enforcement by legal regulations.

Some advanced technologies to manage frequently occurring critical real world situations (defined in the phase model above) will be evaluated in the following paragraphs.

## ACCIDENT AVOIDANCE

### Human Machine Interface

HMI - Human Machine Interface, includes all incoming and outgoing media systems within the interior of the vehicle. HMI encompasses the operation of all primary functions (e.g. steering guidance, driver assistance), secondary functions (e.g. entertainment, navigation, communication, climate control) as well as their feedback signals. Operating the vehicle should not overload the driver, nor should it be undemanding due to high automation of the interior functions. If this is taken into consideration the HMI will add an important contribution to active safety.

For the first time the BMW-distinctive driver oriented operating system has been changed from the ground up with the introduction of the iDrive. A decisive reason for this has been to create a sound operating-concept. Despite an increase of individual features within the dashboard, the actual control elements for the system have not increased.

The main external iDrive characteristics are the high position of the monitor on top of the dashboard as well as the rotary-/push controller found in the center console of the vehicle. The display is easily visible for the driver, who therefore is not forced to take the eyes off the road to receive information from the display. Due to ergonomically optimal positioning of controls and displays, a clear spatial division is created between the primary functions ("driving") and secondary functions ("comfort"), see figure 5.


Figure 5. Spatial division of controls and displays

To follow the philosophy "eyes on the road, hands on the wheel" BMW will implement an optimized version of the intuitive iDrive-concept in its new generation of vehicles. This will further reduce the danger of distraction due to operating dashboard controls. The new system permits operation of the internal functions via voice control. Enlarging the text font and changing the display layout create visual improvements. This is made possible by the so-called trans-reflective technologies, which utilize the incident light to heighten the contrast.

### Adaptive Headlights

Adaptive headlights are currently being introduced to the market as an additional innovative driver assistance system. Pivoting headlights ensure a clear safety advantage during night cornering and poor visibility.

Today's Bi-Xenon headlight systems have a light distributor, which achieves a compromise for different types of roads. Particularly on country roads, long-distance visibility is a foundation for good visual guidance and thus safe driving. The immediate recognition of objects and other traffic members is consequently a contribution to active vehicle and road safety.

Pivoting headlights will provide additional safety benefits. In comparison to the so-called turning light, which merely offers an additional static light distribution, the adaptive headlight offers a flexible light distribution. This feature adjusts to the curving radius of the road. Via a control unit, which can symbolically be imagined as the "eye" of the system, the vehicle electronics constantly evaluate the steering angle, yaw rate and speed. Based on this information the pivoting Bi-Xenon-Modules are controlled by stepping motors (Figure 6).

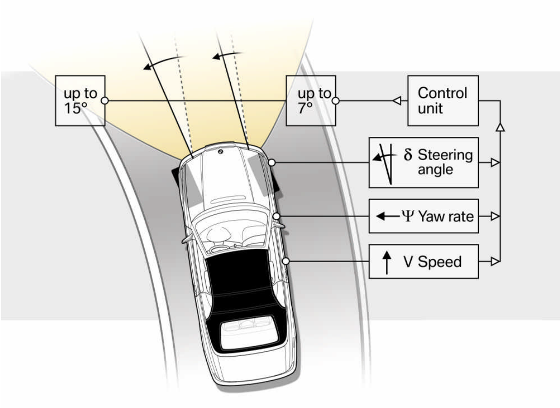


Figure 6. Control of Adaptive Headlights

The Bi-Xenon-Modules, which include low beams as well as high beams, represent the mechanical base component of the adaptive headlight. A turning mechanism enables the Bi-Xenon-Modules to rotate horizontally.
The modules are capable of directing the light distribution up to 15 degrees to either side and so adapt to the light- and speed situation- dependent on the steering commands of the driver.

The Adaptive Headlights are activated in the automatic driving light mode via the light sensor. In the manual driving light mode the pivoting function is deactivated and the low beams resume their original position, pointing straight.

The software and control algorithms needed for this technique are BMW inventions, which can be applied quickly and flexibly to different vehicle models and variations of headlights.
Xenon's well-known dynamic light range regulator ensures that the new Adaptive Headlights do not blind oncoming traffic.
Due to legal reasons the headlights of a parked vehicle with tires turned to roadside, must be aimed straight-ahead (this is due to the potential danger of blinding oncoming traffic). When backing a vehicle the adaptive headlights are also deactivated.

In summary, the Adaptive Headlights are based on horizontally pivoting Bi-Xenon-modules and function as low beams as well as high beams. Since the steering commands of the driver are directly transmitted to the control unit the headlights actively follow the curve and illuminate the routing of the road earlier. This feature provides the driver with significantly better road lighting within curves of the road (Figure 7). Consequently the driver can assess the segment of the lane ahead more safely. This is a visible advantage for active safety and vehicle control.

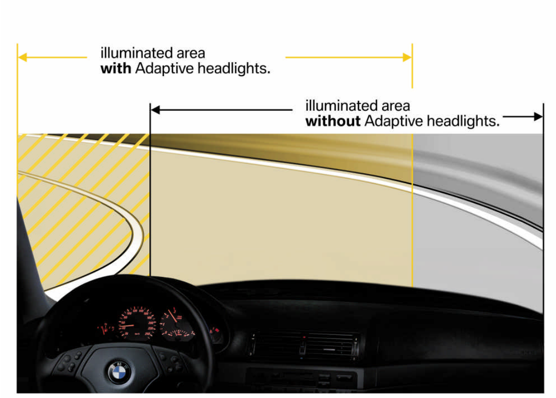


Figure 7. Road illumination in a curve

**Adaptive Brake Lights**

Many rear-end collisions could be avoided if the driver of the following car was offered an easy-to-interpret brake signal, which informs the driver of the intentions of the preceding car. As a result, BMW has scientifically developed a brake intensity display. This new display, called Adaptive Brake Lights, is a combination of size-, positioning and brightness changes within the tail light unit.

Available for all new BMW vehicle generations, the dual-stage display is offered in the US and Canada first. The introduction to several other markets is currently suffering from legislative restraints. The Adaptive Brake Lights enable the following driver to differentiate between normal braking- and emergency braking situations. This function is controlled by vehicle deceleration, speed of vehicle as well as the ABS-signal.

While braking, the brake light is illuminated in the tail light unit. During the braking process the vehicle speed is measured by the ABS-sensors, thus the vehicle deceleration is also measured. This information is accessible to the light controller via the internal bus system for processing and controlling the brake lights.

The evaluation of the vehicle signals leads to following two stages of the brake light display (Figure 8):

- Stage 1, regular braking: deceleration up to $5m/s^2$, conventional brake lights
- Step 2: emergency braking: deceleration of over $5m/s^2$ or ABS-activation, making use of the remaining taillights with a higher light intensity, so that a dynamic enlargement of the illuminated area is being generated.

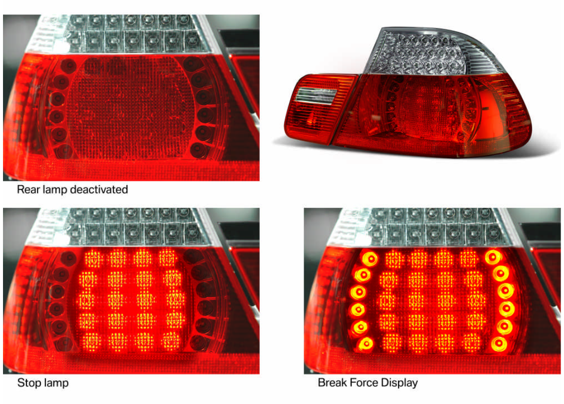


Figure 8. Two stages of brake light display

To summarize: the Adaptive Brake Lights are a new safety feature, which work as a preventative method to reduce rear-end collisions. It will offer benefits for the BMW driver as well as following members on the road. The Adaptive Brake Lights make use of the conventional signal shape and reinforce this function by adding the same function in a dynamic manner. The introduction of the system is currently limited to the US and Canadian markets. The date of implementation for European and other markets is currently unknown, however an approval for the European market is presently in progress.

**Active Steering**

BMW’s Active Steering system is a major step ahead in the steering system development. It consists of a conventional hydraulically supported rack and pinion steering gear. Apart from that, a planetary gear with an electric motor has been installed between power steering valve and pinion.

One of the main innovative Active Steering feature is the so-called variable steering ratio, which adjusts the actual steering ratio according to vehicle speed and steering wheel angle. The result is reduced steering efforts and significantly increased handling at any speed lower than about 120kph. Due to the fact that the steering wheel angle requirement in normal driving situations is less than 90° (see Figure 9), the gearbox shift paddles and any multi-functional switches integrated in the steering wheel are easier to handle.

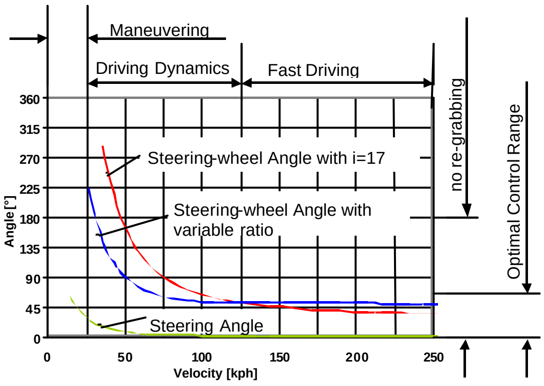


Figure 9. Variable steering ratio and steering effort

By means of this planetary gear, any steering angle can be added to the driver’s input transferred via the steering column. Consequently, the Active Front Steering will be able to increase or reduce the driver’s steering wheel angle and it could even apply a steering angle at the front wheels without driver interaction (e.g. parking maneuvers).

Figure 10 shows the load transfer from steering wheel (left) to the rack and pinion gear (right). Note that input and output shaft are not directly coupled to each other, but only by the planetary gear. In case of a severe system failure the spindle mounted on the motor’s drive shaft will be mechanically locked in order to maintain a sole mechanical steering mode.

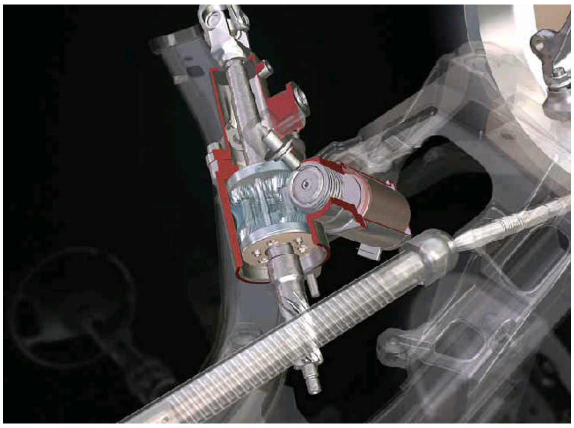

Figure 10: Active Steering planet gear (section)

Furthermore, the Active Steering system consists of a separate ECU containing a motor controller and a second controller, which runs the system's software. All software modules, which could cause a system failure, are being calculated continuously on both processors. The ECU is integrated into the vehicle's ACN network in order to communicate with other ECU´s such as the DSC vehicle dynamics controller and several signal transducers, which are commonly used by different systems.

All Active Steering functionalities are designed to support the driver and to increase vehicle safety and driving pleasure. The system is not intended (and not designed) to replace the driver and his responsibilities.

Finally, the Active Steering's driver-independent steering action can be used to stabilize the vehicle in transient driving situations such as severe lane change maneuvers. Naturally, a front axle steering input cannot compensate under-steer, but it can significantly reduce over-steering tendencies and dampen heavy yaw oscillations, which most drivers find hard to control.

The system's performance can be shown in a severe lane change proving that the driver's steering effort is being reduced both by the variable steering ratio and the yaw rate controller. However, the Active Steering's stabilizing effect is limited to a certain degree in order to avoid drivers feeling restricted while controlling their vehicle.

Consequently, the Active Steering cannot and is not designed to maintain driving stability in all situations. Therefore a vehicle dynamics controller based on individual wheel braking is still required. However, the Active Steering makes controlling the vehicle easier for the driver.

**ACCIDENT MITIGATION**

The systems described in the previous paragraph exemplify clearly BMW's measures to prevent accidents. There will be still situations in which traffic accidents are inevitable. In these situations, modern Passive Safety systems can help to avoid or to mitigate bodily harm to the vehicle occupants and other road users, during the crash and in the rescue phases.

In the future, Passive Safety will remain an important factor within the overall Safety Concept of BMW. Herein BMW's offer a maximum of occupant and partner protection, which reaches levels beyond the legal requirements. This goal has been set not only by standard crashes but also by experiences derived from research of real world accidents.

**Advanced Occupant Restraint System**

This requirement can be illustrated as an example of the development objectives dealing with the latest FMVSS208-demands.

The recently revised US legislative standard FMVSS 208 "Occupant Crash Protection" primarily addresses additional requirements for small adults as well as the minimization of injury risk due to airbags, especially for children. Also, it includes an intensification of crash conditions for belted and unbelted occupants. The biggest challenge of the front airbag development can be derived from the two last mentioned specifications: high airbag performance to restrain the unbelted occupant and low airbag performance to fulfill the Out-Of-Position requirements.

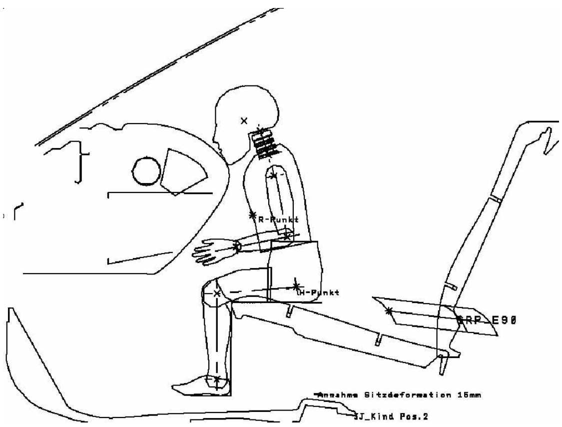


Figure 12. OOP situation (3yr.-child; head on IP)

In regards to the OOP-requirements, one thing was clear right from the start: an airbag cannot be made compatible to a rearward facing child seat (RFCS). Thus the development goal was to suppress the airbag deployment in such an OOP situation (12mth.-Crabi in RFCS). In the other OOP-configurations with the 3yr-child, 6yr-child, and 5%-female dummy, an ignition of the airbags with the lowest possible aggressiveness was the target (→ Low Risk Deployment; LRD). To avoid any risks of losing restraint performance due to the OOP specifications, the objective was set to provide for unbelted occupants an adequate restraint system even in low-speed crashes (dv<20mph). As a result of these new aspects, an innovative frontal occupant restraint system was developed. Its actuator- and sensor-based components are optimally adjusted to one another. Two examples out of these technological areas are described in the following paragraphs.

**LRD-Airbags**

The first OOP tests according to the 208-requirements have proven that a compliancy with conventional module designs is not possible. To closer isolate the major influencing factors many testing sequences were performed externally as well as internally. In the fact, 350 tests were conducted in the year 2001.

Two areas have to be taken into consideration within the range of these tests: airbag module design (Figure 13) and the airbag module surroundings (Figure 14). Both areas are equally important.

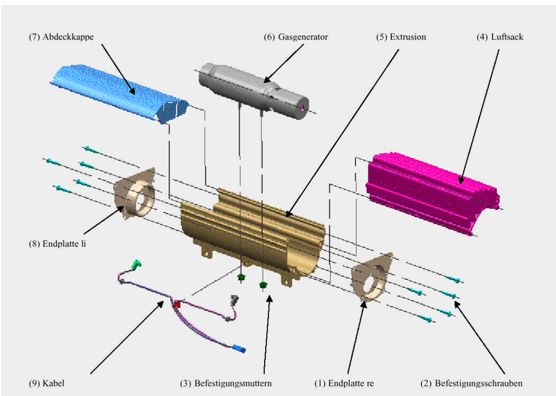


Figure 13. Airbag module design

A key factor in designing airbags is the bag folding method. At deployment, airbag modules with conventional folding method thrust forward a compact bag packet in the direction of the occupant. If the occupant's position is very close to the airbag module, a large amount of energy is transferred onto the OOP-occupant (so called punch-out effect). The advanced folding method, which will be implemented in future BMW airbag systems, reduces the chances of injury significantly in OOP situations. It enables the airbag to unfold laterally from the beginning thus reducing the transfer of forces and momentum noticeably.

Splitting and on-set characteristics of the gas generator were used as an additional measure, intended to reduce the aggressiveness of the airbag. The application of dual stage gas generators enables a reduction of the relevant LRD generator performance of up to 50%. Proportionally to this result the injury risk to the OOP-occupant is reduced. How adequate restraint protection (even when depowering in the low-speed crash range [dv<20mph]) for unbuckled occupants of different weight categories can be achieved, is explained in chapter OC-3.

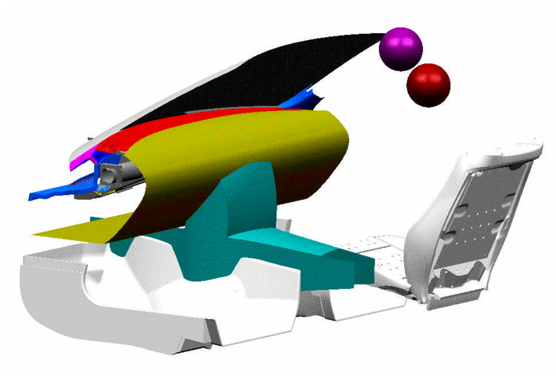

Figure 14. Airbag surroundings

An optimal LRD arrangement for both above mentioned factors still does not guarantee OOP-compliancy. To achieve this compliancy, the surroundings of the airbag module must be taken into consideration. Important factors are the module position (e.g. top mount of passenger airbags; Figure 15), the angle of airbag deployment, as well as the design of the airbag module cover For instance, a multiple tear-off solution avoids interaction between the cover flap an the occupant in extreme OOP situations. High load values can so be prevented.
These findings were first implemented in the new BMW Z4 design of the steering wheel and dashboard.

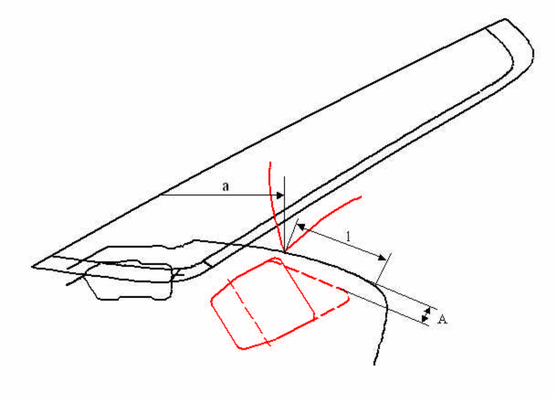


Figure 15. Top-mount position of airbag module

As mentioned before, of particular importance for the fulfillment of the new 208-requirements is the ability to guarantee automatic activation/ deactivation of the airbag dependant on the type of occupation on the passenger seat.

**OC-3 System**

This is the task of the OC-3 system. It enables a classification of the occupant in the front passenger seat for a safe deactivation of the airbag in presence of an infant in a RFCS and activation of the airbag for adults starting with the 5%-f. Accordingly the airbag-off warning lamp is activated.

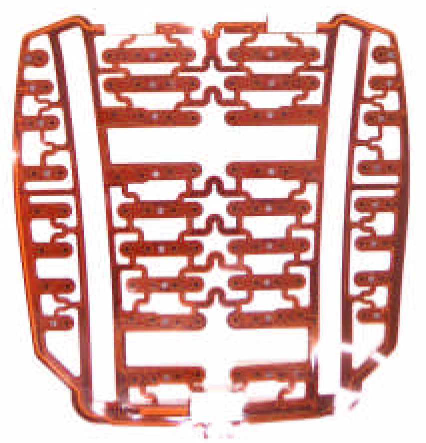

Figure 16: OC-3 mat

The underlying concept of the OC-3 system is a pattern recognition method. This pattern recognition uses a mat with a sufficient amount of sensor cells, which contain pressure sensitive ink. When force is applied to the seat surface the electrical resistance of the ink changes. The OC-3 mat (Figure 16) is integrated into the top and sides of the passenger seat. Resistance values in each cell are measured and processed with a suitable algorithm. The result is a pattern, which can be classified according to legal requirements (Figure 17).

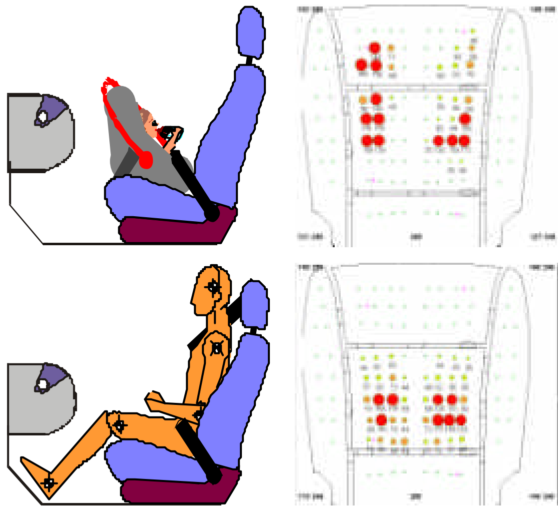

Figure 17: Pattern recognition (e.g. RFCS; 5%-f)

In addition, the OC-3 system opens another potential: it presents the possibility of differentiating between the occupant classes 5%-f and 50%-m. This function can be used to further improve restraint system of both unbuckled occupant classes in a low crash speed: LRD airbag performance for the 5%-f (as required by the FMVSS 208), higher airbag performance for the 50%-m percentile to avoid contact with dashboard or windshield (Figure 18).

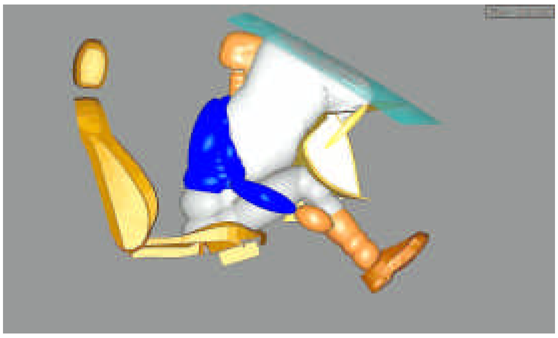

Figure 18. Simulation of low speed crash / 50%-m

Due to the crash-severity distribution (approx. 90% all frontal collisions are low-speed-crashes up to dv<20mph) and the partially low belt-use rate BMW is certain that this system development will bring enormous benefits in real-world crashes.

An additional and important topic within the overall safety concept of BMW is the evolution of today´s

ACN function. It supports the rescue services in the Post-Crash Phase.

**Automatic Crash Notification**

ACN is an automated emergency program to notify rescue personnel immediately after an accident. In the Post-Crash phase, time plays a major factor in reducing the rescue time for occupants. Experts often call this the “golden hour”. It is the hour after the occurrence of a serious car accident, in which immediate medical aid is most vital for survival.

One glance into the US accident databases FARS and NASS makes clear how crucial this topic is. Police registered approximately 6,279,000 accidents in the US in 1999. 3,236,000 of the occupants were injured, 250,000 suffered severe injuries, and 41,611 received fatal injuries. It is estimated that about half of the occupants with fatal injuries die before they reach a hospital. The time span between the accident and hospitalization takes longer than 45 Minutes for ca. 45% of all fatally injured individuals. 25% take even longer than 60 minutes (FARS 1999). This problem becomes more obvious in rural areas, where 60% of all fatal accidents occur (FARS 1999/2000). Based on these figures, the potentials for enhanced treatment of seriously injured individuals in car crashes were analyzed in several studies by the NHTSA. According to these studies, 17% of all trauma related deaths might be prevented, in rural areas even up to 27% of fatalities. A further potential means the reduction of painful and cost intensive long-term injuries. ACN can be of important assistance to these goals.

**BMW Assist**

BMW offers its customers the ACN function in all vehicles equipped with BMW ASSIST, a package including navigation and telecommunications. The ACN function is triggered by severe accidents with airbag deployment or heavy rear-end collisions (Figure 19). In a scenario such as this, automatically the vehicle identification number and the GPS position is transmitted to the BMW ASSIST emergency call center. An immediate voice link is created. Provided that the situation is confirmed to be serious, the BMW ASSIST emergency call center immediately alerts rescue services. Hence, the rescue measures can begin immediately.

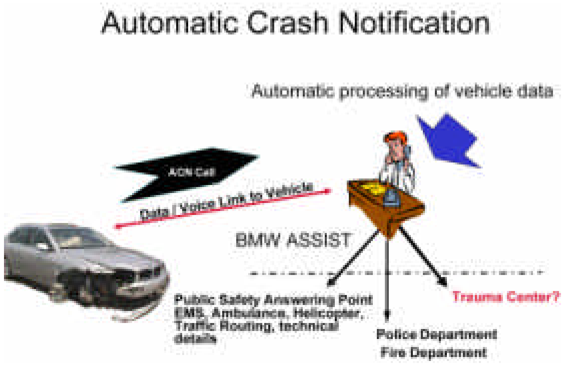


Figure 19: ACN communication procedure

An emergency call system only makes sense if it works reliably. Therefore, BMW vehicles with BMW ASSIST will be equipped with additional back-up components. This includes a crash-safe battery, an additional speaker, as well as an emergency call antenna mounted in the vehicle’s interior.

Based on the basic functions described above BMW continues to develop the ACN - Advanced ACN.

**Advanced ACN**

The objective of the Advanced-ACN development is to be able to transmit more vehicle data than has been done previously and so achieve higher efficiency in the rescuing process. Primarily this extra information should enable all rescue parties involved to further improve the decision making process in regards to rescue, transport and treatment of the injured individuals.

In the course of working with leading research institutes (William Lehman Injury Research Center in Miami as well as George Washington University) guidelines have been developed to closer define the new ACN system. Additional support has been given to this project by surgeons from the Ludwig Maximilian University of Munich.
A major part of this research was to identify relevant ACN data. The results can be divided into two groups: data for emergency workers to initiate appropriate rescue measures quickly and data for medics and orthopedic surgeons to predict probability of serious injuries.

During the course of this study a prioritization of gathered data was produced. Here is an excerpt of the most important data:

- Accurate information about crash location:
  GPS coordinates; direction of travel, …
- Vehicle status:
  Submersion, fire, fuel leakage, …
- Occupant status:
  No. of occupants, occupant ejection, …
- Risk of severe injuries:
  Crash severity/direction/type, belt usage, …

Concluding the study, the benefits of various scenarios of implementation were estimated based on real-world crash data. With the information deduced from these studies BMW will present in new vehicle generations with an expanded ACN-package.
The Advanced ACN transmits more supplementary crash related data than the basis data of the original ACN did, for example the severity of a crash or occupancy of the passenger seat. This is made possible by cross-linking the safety electronics with the telecommunications system. Once the data is received by the BMW ASSIST emergency call center the information is immediately evaluated and transmitted to the appropriate rescue services. A schematic representation of this sequence can be viewed figure 19.

BMW will continue developing the ACN in increments. The foundation to continue this research project with the William Lehman Injury Research Center has been already set. The utilization of the ACN data offers a vast potential to estimate the risk of serious and time critical injury to the occupant. An algorithm to make this possible is currently in its testing phase.

Naturally, to make use of the potentials offered by advanced ACN technology, an area wide infrastructure for rescue and treatment services must be established. This also includes nationally standardized data-protocols between the ACN service centers, 911 call centers and the emergency medical services.

## CONCLUSION

The contributions of Passive Safety, as well as already introduced Active Safety features, like advanced braking, suspension and visibility systems led to remarkable results in reducing the numbers of fatalities and injuries in daily traffic. Nevertheless, it is of major public and industry interest to achieve further significant reductions of these figures throughout the world. The increasing performance of affordable electronics, like processors, sensors (e.g. infrared systems) amongst several other developments of accident avoiding features, opens the door to additional and statistically noticeable contributions. While vehicle safety has mainly been perceived to be Passive Safety in the past, an overall safety approach covering all phases from prior-to-driving to post-crash will be the new measure for evaluating vehicle safety performance in the future.

## ACKNOWLEDGEMENT

The authors wish to express their appreciation to Dr. Jeffrey Augenstein and his team at the WLIRC for the cooperation involved in developing the basics of the Advanced ACN system.

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