EMERGENCY STEER & BRAKE ASSIST – A SYSTEMATIC APPROACH FOR SYSTEM INTEGRATION OF TWO COMPLEMENTARY DRIVER ASSISTANCE SYSTEMS

Alfred Eckert
Bernd Hartmann
Martin Sevenich
Dr. Peter E. Rieth
Continental AG
Germany
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ABSTRACT

Advanced Driver Assistance Systems (ADAS) assist the driver during the driving task to improve the driving comfort and therefore indirectly traffic safety, ACC (Adaptive Cruise Control) is a typical example for a “Comfort ADAS” system. “Safety ADAS” directly target the improvement of safety, such as a forward collision warning or other systems which assist the driver during an emergency situation. A typical application for a “Safety ADAS” is EBA (Emergency Brake Assist), which additionally integrates information of surrounding sensors into the system function. While systems in the longitudinal direction, such as EBA, have achieved a high development status and are already available in the market (e.g. “City Safety” from Volvo), systems in the lateral direction are still in the predevelopment stage. The next logical development step in this case will be the system integration of the Emergency Brake and Steer function.

This paper presents an approach to systematically combine longitudinal braking assistance and it’s complementary lateral dynamics into an integral advanced driver assistance system for collision avoidance or mitigation. The system assists the driver during emergency brake and/or steer maneuvers based on driver input, physical aspects and surrounding sensor information. The robust detection of the surrounding and the analysis of the driving situation play a major role regarding the discrimination of a hazard situation from normal driving.

The level of assistance is based on the ability and robustness of the sensor to display the picture of the real surrounding and driving situation. The discussed system approach assists by preconditioning the chassis for the oncoming brake and/or evasion maneuver and – in the case of an emergency evasion maneuver initiated by the driver - gives a recommendation utilizing steering torque overlay to help the driver to steer along a calculated optimized trajectory. In this respect and beside all technical and physical aspects, the human factor plays a major role for the development of this integral assistance concept. Basis for the development of this assistance concept were subject driver vehicle tests to study the typical driver behavior in emergency situations. Objective was on the one hand to analyze the relevant parameters influencing the driver decision for brake and/or steer maneuvers. On the other hand the evaluation should result in a proposal for a preferable test setup, which can be used for use case evasion and/or braking tests to clearly evaluate the benefit of the system and the acceptance of normal drivers. Definition of assistance levels, warnings and intervention cascade, based on physical aspects and an analysis of driver behavior using objective and subjective data from vehicle tests with untrained drivers are presented.

INTRODUCTION

The volume of traffic has noticeably increased within the last 10 to 15 years but the improvement in both driving and transport safety has led to a significant reduction of traffic fatalities in the EU. Beside traffic-based political and educational steps, major improvements in active and passive vehicle safety systems have shown their effectiveness.

Continental has demonstrated with ContiGuard® that further development in traffic safety must include – in addition to the individual active/passive safety domains – in particular the complete network and the integration of vehicle surrounding specific information as well as the human-machine interface. Further development and integration occurs more and more according to different platforms and levels of automotive guidance, i.e. the stabilization level, the maneuver level and the navigation level.

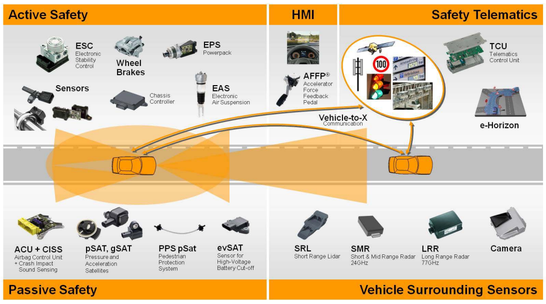

Figure 1. ContiGuard® - The Five Cornerstones & their Key Components

ContiGuard® covers all safety functions by integration of Active Safety, Passive Safety, Vehicle Surrounding Sensors, Human-Machine-Interface (HMI) and Safety Telematics, including driver assistance.

Driver assistance systems shall reduce the driver's operational work load. This not only under normal driving conditions, where they mainly contribute to enhancing driving comfort, which will be described as "Comfort ADAS", but especially in challenging driving situations where safety of the occupants and other road users is endangered ("Safety ADAS"). A typical "Safety ADAS" application is represented by the Emergency Brake Assist EBA, which assists the driver in the vehicle's longitudinal control in hazardous or emergency braking situations. EBA was the first spin-off out of the research program "PRORETA" [1], where Continental together with the University of Darmstadt (2003-2006) performed an interdisciplinary research project, which later led to several market introductions, e.g. EBA-City from Volvo. Lateral guidance in facing a hazardous situation out of "PRORETA" needed more concept work and resulted in a stand-alone approach of an Emergency Steer Assist, which is still under development.

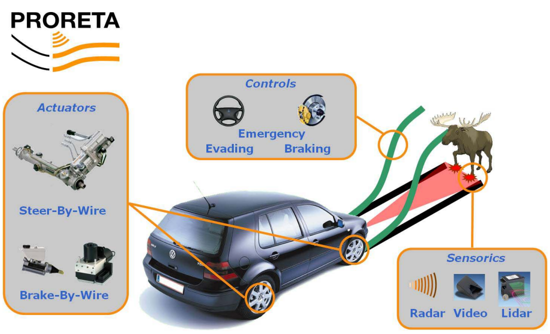

Figure 2. Overview PRORETA project

Following the work carried out within PRORETA and the basic concept of ContiGuard®, a conceptual integration of EBA and ESA is the next logical step in creating an overall "Safety ADAS" for hazard situations.

BASIC USE CASE

The typical use case for systems in the area of lateral & longitudinal guidance leads to the challenge to find the optimum brake and steering control in order to overcome a critical situation if an obstacle suddenly appears in front of the vehicle.

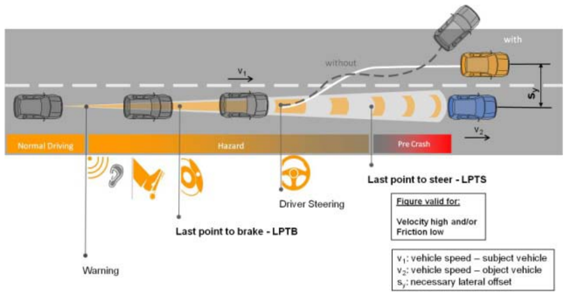

Figure 3. Collision avoidance by braking/ steering

The generally preferred measure to avoid a collision at low velocities e.g. in urban situations is a braking maneuver. Thus in numerous driving situations, collisions can be avoided or at least the impact can be mitigated. At higher velocities, the stopping distance increases with the square of the relative velocity and therefore evasion with a linear behaviour in respect to the relative velocity becomes a meaningful alternative for the driver to avoid a collision. According to the two equations in figure 4, the physically necessary minimum distances - last point to brake d_b / last point to steer d_e – are determined by three parameters, the closing velocity v_{rel}, the necessary lateral offset s_y and the average longitudinal acceleration a_x , respectively lateral acceleration a_y, which are determined by the available tyre/road friction value µ.

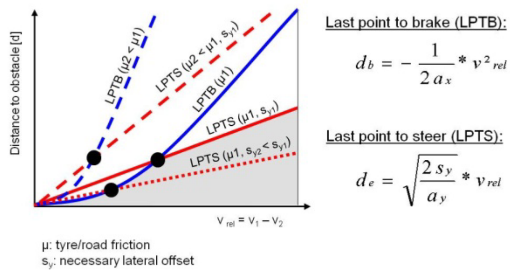

Figure 4. Necessary distances to avoid a collision by braking or steering

The diagram shows that braking is the right decision for low velocities but for higher velocities evading can be much more efficient than braking. For higher velocities, if the driver has missed the last point to brake, there is still the opportunity to evade the obstacle and to avoid a collision. Compared to a singular Emergency Brake Assist function, which is utilized in different applications preferably in urban traffic scenarios or to mitigate collision in the last milliseconds before crash at higher speed, the preferred use case for an Emergency Steer Assist function exists at higher velocities on non-urban roads such as main roads and preferably highways.

Lower tire to road friction coefficient μ and smaller obstacle width affect the range of speed where evading is becoming more effective also at lower speeds and the area of urban traffic will be entered. This implies that besides mastering vehicle dynamics, the quality of surrounding sensor information and interpretation is essential for the effectiveness of the overall function. An assistance concept covering both braking and steering actuation together with high quality of surrounding sensing has to overcome the "warning dilemma" of stand-alone solutions while interacting with the driver.

EMERGENCY BRAKE ASSIST

In recent years, Emergency Brake Assist functionality in different specifications can be found on the market. Goal is to avoid or at least mitigate an accident by automated braking intervention. Basic principle of this system is to analyse the proximity in front of the ego vehicle, based on application and specific sensor configuration, perform driver warning and stepwise intervention starting with moderate deceleration of 0.3-0.5g up to full brake apply if a collision can not be avoided (collision mitigation). The system is interacting with the driver in such a way that driver reaction and environmental situation is combined to support drivers wish to brake. So if the system is pre-filling the brakes or braking in a moderate way, driver brake application will lead to significant stopping distance reduction e.g. EBA-City within the use case in city driving scenarios. Situation interpretation is a key element to reach more and more use cases and leads to taking lateral dimensions and reactions into account.

EMERGENCY STEER ASSIST

The stand-alone emergency steer assist function warns and supports the driver in the lateral driving task. The driver remains in control and has the complete responsibility of the vehicle. Surrounding sensors provide just a limited or reduced picture of the complex surrounding. The driver can overrule the system at any time.

The assistance concept is based on information content and robustness of at least one surrounding sensor due to the functional definition, e.g. a long range radar sensor. The system permanently monitors the driving situation dependent on surrounding information and vehicle driving state. Based on the actual driving situation and driver demand, an electronic controller unit analyses the criticality of the situation and decides for optimized driver support when entering a hazard situation. From this point assistance will be applied in two different respects. On the one hand the vehicle will automatically be prepared best for the oncoming emergency maneuver in respect to driving stability (stabilization level) utilizing sub-systems and actuators such as ESC (Electronic Stability Control) and optional rear wheel steering system ARK (Active Rear Axle Kinematics). On the other hand the maneuvering task of the driver will be facilitated by path optimized steering support of the EPS (Electric Power Steering) when the driver has initiated the steering maneuver. Without directly controlling the course, the system will support the driver to steer along a calculated optimized trajectory e.g. by EPS torque overlay and/or torque vectoring by brake. In doing so, the driver remains in complete responsibility and can always overrule the system.

Further improvements in surrounding sensing lead to increased knowledge of the driving scenario as a basis for functional improvements and for further guidance of the driver to partly take over responsibility by the system as well as handling of the complete longitudinal and lateral reaction of an integral function approach.

DRIVER BEHAVIOR IN EMERGENCY SITUATIONS

Active Safety and Advanced Driver Assistance Systems are gradually becoming more and more practical with advances in surrounding sensing and vehicle control technologies. Analyses of traffic accidents have shown that human errors are involved in almost 93% of all accidents and in almost 75% of the cases, the human mistake is solely to blame [European Commission Paper COM (2006) 59 FINAL], however those errors can be grouped into three categories; cognitive errors (e.g. errors caused by inattentiveness or oversight), judgment errors (e.g. wrong judgment that the other vehicle will stop) and operating errors (e.g. failing to apply the brakes strongly enough). That is the reason why research and development of advanced driver assistance systems focuses strongly on driver behavior to develop real driver support technologies, which take naturalistic driver behavior into account.

Literature Review

Crash statistics have shown that drivers involved in crashes prefer to brake in front of an obstacle and resist lateral maneuvers. Lechner & Malaterre (1991) studied the collision avoidance driver behavior, using the Daimler-Benz driving simulator. Their relevant scenario was an intersection scenario with a single no right of way vehicle, stopping at a stop sign, accelerating for 1.9 seconds and stopping again, blocking the subject´s lane. In total 49 subject drivers were participating the simulator test with an equal number of men and women at three different time-to-collision conditions (2.0, 2.4 & 2.8 seconds). Looking at the collision avoidance potential of all different maneuvers across all three time-to-collision clusters, only 10 out of the 49 participants successfully avoided the collision, six subjects by braking only, three by steering only and one by combined braking and steering. The further analysis showed, that braking was the most preferred measure to avoid collision (88% attempted braking), if there is sufficient time (TTC). The researchers also found out, that drivers start swerving in front of the incurring vehicle for shorter TTC. Drivers did not use any lateral avoidance maneuver even though those maneuvers would have been able to avoid collision. 57% of all subjects, who collided, could have avoided the incurring vehicle by swerving. This study gave a good indication about driver behavior in emergency situations according to different time-to-collisions.
Within the scope of "NHTSA Light Antilock Brake Research Program Task 5" in 1999 [5] an examination of driver´s collision avoidance behavior on the Iowa Driving Simulator was conducted. Amongst others the study focused on the examination of driver imminent crash avoidance behavior as a function of the vehicles brake system and various other effects such as speed limit and time-to-collision (TTC). The scenario was set up to answer some open questions in the literature and to better understand driver´s emergency avoidance behavior. An emergency maneuver to avoid collision with another vehicle crossing an intersection at different time-to-collisions had to be carried out by the subjects. The Iowa driving simulator used four multi-synch projectors to create a 190° forward field-of-view and a 60° rear view. It incorporated recent technologies to achieve a highly realistic driving behavior. The simulator dome featured a fully instrumented vehicle cabin.
In total 60 females and 60 males between 25 and 55 years of age participated in the test program. A 2 x 2 x 2 x 2 experimental test design was used to investigate amongst others the factors speed limit (45 or 55 mph) and TTC (2.5 and 3.0 sec.). TTC was defined as the time it took the ego-vehicle to reach the intersection at its current speed as measured from a trigger point in the road. The purpose was to examine if and how subject drivers varied their crash avoidance strategy based on the time available to respond to the event (TTC). Evaluation criteria were grouped into three categories: initial responses, emergency steering/braking behavior and final outcome. The following findings are interesting in this context. Regarding the emergency Steering/braking behavior all participants used some form of braking and steering input to avoid collision with the incurring vehicle. 79% applied the brakes as their first steer-brake-response before steering, 4% initiated braking and steering at the same time and 17% attempted to steer before applying the brakes.

Effects of TTC:

Generally, the farther back a driver begins an avoidance maneuver the more the brakes will be applied and the closer the driver is to a collision event the more likely he will steer. Subjects in the shorter TTC condition (2.5 sec.) were 240 msec. faster on the time-to-first-steer measure. This emphasizes the hypothesis that driver´s steering is more relevant in extreme avoidance actions. There was also a significant effect on time-to maximum-brake-pedal-force. The average time was 321 msec. faster for the shorter TTC group than for the longer (2.042 sec. vs. 2.363 sec.). TTC, of course has a strong effect on crash outcome. Only 10% in the 3.0 sec. group crashed, compared to anyhow 61% in the 2.5 sec. group.

Effects of speed limit:

The statistical analysis found no main effect on initial response time as well as on the different steering and braking variables. Regardless of the speed, subjects tend to brake first and steer later when attempting to avoid collision. 42% crashed in the 55-mph speed, only 28% in the 45-mph speed, but the differences were statistically not significant.

Subject driver vehicle tests

Methodology The imminent crash avoidance behavior study was an on-road vehicle test program conducted on the Continental proving grounds in Frankfurt, Germany, where subject drivers drove an instrumented vehicle along the test track as shown in figure 5. Participants were recruited mainly from non-technical support functions at the same location of the company. In total 41 licensed drivers participated in this experiment. Sixteen drivers were within the ages of 20 and 30, twelve were within the ages of 30 and 40, 9 within the ages of 40 and 50 and four between 50 and 60. In total 32% of all drivers were female and 68% were male.

Approximately half of all participants reported a minimum annual driving mileage of 20.000 km/a. There were just 7 participants with less than 10.000 km per year . The majority of all drivers had in average a total driving experience of more than 10 years. There were just 4 with less than 5 years driving experience and 9 with less than 10 years. Before starting the three-phase driving session the co-driver as the experimenter had to check that all participants adjusted the seat, the steering wheel and the rear-view mirrors and also fastened their seat belts. All subjects were given a short vehicle briefing as well as detailed instructions concerning the driving task and the track conditions. In driving phase 1 participants had to familiarize themselves with the BMW 530i test vehicle, which was equipped with different state of the art measuring systems (e.g. DGPS system , strap down platform, measuring steering wheel, etc.) to be able to precisely evaluate driver actions as well as vehicle reaction. During the experimental drive, vehicle motion data (yaw rate, longitudinal & lateral velocity & acceleration), DGPS data (abs. position, heading, velocity) and driver activity data (steering wheel angle & torque, brake pressure, pedal activities) were recorded. Subjects were asked to drive some laps to familiarize themselves with the specific driving behavior of the vehicle and also with the track layout. During this time participants had to carry out driving maneuvers such as accelerating, decelerating and braking as well as evading maneuvers. This was to ensure that all participants had experience controlling the vehicle prior to an unexpected obstacle appearance. All maneuvers were concentrated in section A only. The co-driver informed the participants about the communicated purpose of the driving session to subjectively evaluate different steering wheel interventions caused by different types of steering torque overlay in straight driving as well as in steady state cornering situations. During phase 2 subjects had to continue their test ride, for each driver two different types of steering torque overlays with variation in amplitude, shape or latency were emulated in the straight line driving as well as in the curve. All interventions were exclusively conducted in section A of the test track only; this was to ensure that drivers should focus only on section A. They should not care for any other parts of the track. During the entire test ride participants were asked by the co-driver to communicate their subjective impressions regarding the different types of steering torque overlay and the impact on vehicle reaction and driving situation. Goal was to involve them into some discussions, to ensure they would be somehow distracted if something unexpected occurs.

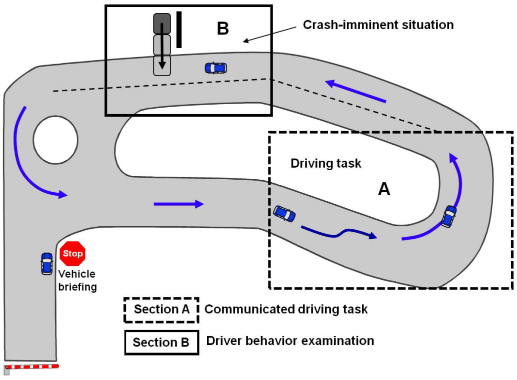

Figure 5. Map of the used test track

All subject drivers were unaware of what would happen in phase 3 in section B of the track. The scenario in this part of the track was a right-side construction area along a two-lane main roadway. All subjects had passed this section several times before and nothing out of the ordinary occurred. This was to give the drivers a certain confidence in what was going on during their driving event. The crash-imminent driving scenario as shown in figure 6 was a 500 m long two-lane main roadway scenario. The single lane width was 3.7 m. Both sides of the road were marked-off with pylons as they are normally used during road repairs or painting activities in construction areas. The appearance of the whole scenario should look very natural and normal for all participants. In front of the camouflaged obstacle, approximately 2 m beside the right side traffic lane marking, there was a static distracter vehicle with warning lights. The co-driver had explained in the very beginning of the drive that actually some repairs of the surface and new paintings of the driving lanes are taking place. Due to this construction area the speed limit in this part of the track was 60 km/h. It is important to say, that subjects never faced any oncoming traffic during phase 1 & 2. The obstacle used in the crash-imminent hazard situation was a light weight balloon car, which was pushed into the right driving lane by a special designed automatic catapult. The activation of the catapult was controlled by a control unit, using a light beam as an external trigger. The trigger was activated as soon as the vehicle crossed the line between the light beam and the reflector. At this point the vehicle speed was taken, time-to-collision (TTC) was calculated to activate the catapult accordingly. The stored energy of the catapult could be adjusted for pushing the balloon car to a defined end position in the driving lane (full or half overlap).
At the time of the incursion event, there was no oncoming traffic. Time-to-collision was defined as the time it would take the subject vehicle to have a collision with the incurring balloon car at its current rate of speed. Of course, any decelerating or

accelerating would influence the TTC directly. The real use-case scenario rebuilt here in this examination is a typical pull-out or intersection incursion situation. The driver of the pulling-in vehicle did not realize the preferred vehicle due to any objects in his field of view, pulled out into the driving lane and stopped immediately when recognizing the other vehicle.

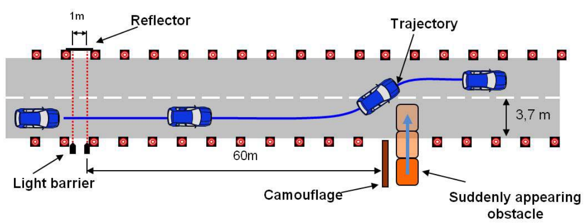

Figure 6. Two lane main road with incursion object from the right

Goal of the examination on the one hand was to evaluate relevant parameters influencing the driver behavior in crash-imminent collision maneuvers. On the other hand the results should be used to find a realistic test scenario where subjects would prefer steering instead of braking to be used for subject driver use-case testing for Emergency Steer Assist functionalities. The investigated, relevant parameters within this examination were:

Time-to-collision (TTS):
1,5s – 2,0s - 2,5s

Obstacle overlay in vehicle driving corridor:
full & half overlap

The explanation of full and half driving corridor overlap is given in fig. 7. Overlap defines the end position of the obstacles left side when it came to a standstill in relation to the actual driving corridor of the vehicle.

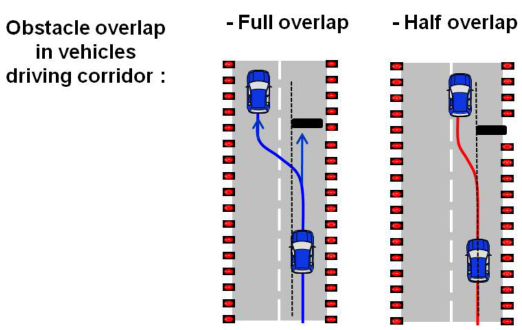

Figure 7. End position of obstacle after stop

For the full overlap position the obstacle stopped with its left side 0.9m in front of the lane centerline and for the half overlap position 1.85m in front of the lane centerline that means just in the middle of the right driving lane. For both scenarios there was enough room for the subject vehicle to evade around the incurring obstacle. The overlap of the obstacle directly influenced the necessary lateral offset to be realized by an evading maneuver. The full overlap scenario made it necessary for the subject drivers to make a complete lane change on the left driving lane, the half overlap allowed the subject vehicle to stay on the right driving lane as it could fit between the centerline and the incurring obstacle.

Results Directly after the practical driving portion, all subject drivers had to fill out a dedicated questioner. A majority of 92.7% of all drivers reviewed the simulated emergency scenario as highly realistic and anyhow 41.5 % of all drivers stated that they have been really frightened and 53.7% were at least irritated by the suddenly and unexpected pulling-out obstacle. These figures are a good indicator that the following results, which give an overview concerning the different collision types and influences of the two parameters TTC and object overlap, are pretty reliable and a good base for further development.

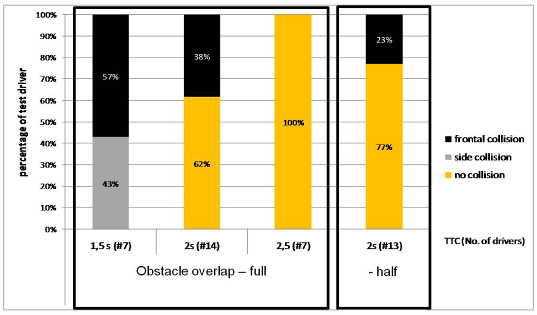

Fig. 8. Collision type evaluation

Within the full overlap group there is a significant influence of TTC on collision avoidance potential. The shorter the time-to-collision and the more critical the situation, the more likely a collision becomes with the incurring vehicle. It can be clearly seen that a long TTC of 2.5 seconds allowed all 7 subject drivers to avoid a collision at all. Of the 14 participants within the 2.0 seconds group there were 9 drivers, who could avoid a collision and 5 that had a frontal collision with the obstacle. There was not any subject driver in the 1.5 seconds TTC group, who could avoid a collision. Four drivers had a frontal collision, whereas 3 drivers had a side impact. This is a clear indication of the fact that the incurring obstacle was still moving when the collision occurred; drivers did not take that into account.

The influence of overlap position can be seen from the right half overlap column in relation to the middle column of the full overlap group. Both driver groups with 14 and 13 participants experienced a TTC of 2.0 seconds and are directly comparable to each other regarding the influence of absolute overlap which corresponds to necessary lateral offset for an evading maneuver. There is a tendency that more drivers could avoid a collision with the obstacle in the half overlap group compared to the full overlap group. The explanation will be given in the next figure, where driver behavior regarding the two variables was evaluated.

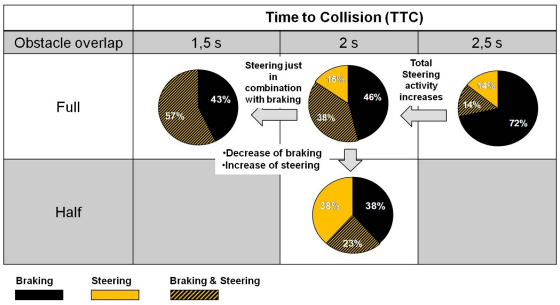

Fig. 9. Driver behavior evaluation

The figure illustrates how driver behavior depends on time-to-collision and lateral obstacle overlap. Again the influence of TTC can be observed within the full overlap group. At TTC of 2.5 seconds there is a majority of 72% of all subject drivers applying the brakes to successfully avoid a collision. Additionally, in each case, there is one subject driver avoiding collision by steering only or by a combination of braking and steering. The preferred measure to avoid collision at long time-to-collision is obviously the braking maneuver, because there is time and room enough to come to a controlled stop in front of the obstacle. This is what drivers are normally doing day-by- day in normal traffic scenarios.
It can be observed that total steering activities increase with shorter TTC. At a TTC of 2.0 seconds the majority of all subjects used steering wheel intervention during their maneuver. Whereas the ratio of pure steering activity stays in the same magnitude, there is a significant increase in the group of combined braking and steering. The ratio of this category almost triples from 14% to 38%. If TTC is decreasing once again from 2.0 to 1.5 seconds the ratio of those participants with steering activities stays the same on the relatively high level of almost 60%. But it could be observed that all drivers that utilized a steering activity simultaneously combined steering with some kind of braking. It is interesting to see, that subject drivers with steering only are not represented in the 1.5 seconds TTC category anymore. It can be considered, that accelerator release together with braking is an intuitive reflex behavior in high risk emergency situations.
Regarding the influence of lateral obstacle overlap in the driving lane the two categories with full and half overlap at TTC 2.0 seconds can be compared. The effect of less lane overlap within the two TTC 2.0 seconds groups is exactly opposite to the effect of reduced TTC from 2.0 to 1.5 seconds within the full overlap category. This time a significant increase of drivers, who used a standalone steering maneuver could be observed, the ratio of steering maneuvers increased from 15% to 38%. This is obviously the reason why more subjects could avoid a collision, the ratio of successful avoidance maneuvers increased from 62% to 77%. Drivers intuitively decided for the evasion maneuver, which was considered to be the more successful maneuver compared to a brake maneuver. Steering away from the suddenly incurring obstacle seems to be a reflex reaction, which is objectively the right decision. The share of all forms of steering activities (steering and steering & braking) in all three categories TTC 2.0 and 1.5 seconds with full overlap and the TTC 2.0 seconds with half overlap is approximately the same, there is no significant difference to be observed.

Comparison with the Iowa Driving Simulator

In principle both crash scenarios look very similar and therefore the results are pretty well comparable. Both scenarios are derived from real crash accident target scenarios. Subject drivers were confronted with suddenly appearing obstacles as right-side incursion scenarios to initiate a crash-avoidance response from the driver. In both cases the speed limits with 45 mph for the Iowa driving simulator and with 60 kph for the Continental vehicle examination were nearly the same. Goal of both examinations was to evaluate the typical driver behavior in crash-imminent situations under variation of the variable “time-to-collision”. Whereas the driving simulator test varied as a second variable the speed limit, the Continental vehicle test varied the lateral lane overlap. This can be seen as enhancement of the Iowa Driving simulator study.

<u>Both examinations were consistent in the following results:</u>

- TTC has a strong effect on crash outcome.
- When there is enough time at a long TTC, braking is the preferred avoidance response.

- The shorter the TTC, the more likely drivers are to swerve around the incurring vehicle.
- Driver steering becomes more relevant in extreme avoidance maneuvers.

Additionally the Continental vehicle examination showed the following findings:

- Driver steering becomes more time relevant with less necessary lateral offset.
- This emphasizes the hypothesis that steering away from a suddenly incurring vehicle seems to be a reflex action of the driver.

ASSISTANCE CONCEPT OF INTEGRATED FUNCTIONALITIES

The assistance concept of the integrated Emergency Steer & Brake Assist on the one hand has to be based on physical aspects (e.g. last-point-to brake, last-point-to-steer) and on the other hand it should consider typical human behavior in emergency situations. A good system performance and driver acceptance is based on two major cornerstones:

- Robust detection and interpretation of the driving situation by surrounding sensors
- Precise detection of driver intension

Generally a hazard situation can be divided into three fundamental phases (warning, imminent-crash & pre-crash).

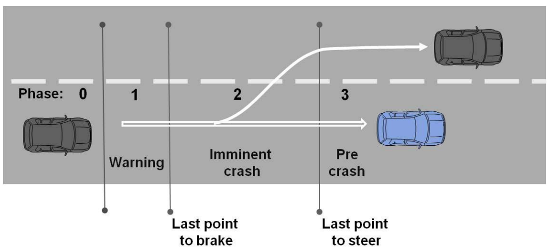

Fig. 10. Definition of the three fundamental hazard phases at high speed

Several investigations have shown that the main accident causes are inattentiveness, misinterpretations and line-of-sight obstructions. A publication of the Insurance Institute for Highway Safety in 2008 [6] analyzing the National Automotive Sampling System General Estimates System (NASS GES) and the Fatality Analysis Reporting System (FARS) from 2002 -2006 identified the forward collision warning system as the one with the greatest maximum potential out of five analyzed driver assistance systems and therewith underlines the importance of driver warning for those, who are inattentive or distracted. The author resumed, that based on early driver warning (fig. 10, phase 1) this “Safety ADAS” system could prevent or mitigate up to 2.3 million crashes in the United States each year.

Co-ordination and integration of Emergency Steer & Brake functionalities take place in phase two, the imminent crash phase, where the driver has to take latest action to avoid or mitigate a crash. Usually the emergency situation is characterized by the fact that the driver can avoid or mitigate the crash by braking, by evading or by a combined braking & evading maneuver. According to fig. 3 & fig. 4 the outcome of this is a “warning dilemma”. At higher speeds and even at low TTC the driver has the opportunity to avoid a collision by swerving around the obstacle. Based on enhanced sensor information displaying a reliable and precise picture of the real driving situation the warning dilemma can be eliminated. Beside the recognized obstacle in the ego driving lane, the system has to evaluate also the general evading opportunity. If free space recognition of the sensor fusion system comes to the conclusion that alternative driving lanes are occupied by other vehicles the warning and intervention can be applied earlier because evading is no alternative and the criticality of the situation is increasing.
According to the results of the internal driver behavior examination subject drivers decide for braking, steering and combined braking/steering dependent on time to collision (TTC) and lateral obstacle overlap. Both values can precisely be derived from advanced sensor fusion technology, this leads to the fact that the system has a good chance to be ahead of the driver´s action and will be well prepared waiting for driver intention detection to assist according to the driver´s decision.

Market introduction will start in the lowest assistance level, the so called “support level”, where interventions are driver initiated and the system supports the driver’s action. The driver has the lead and can always overrule the system. For those who decide for a solely braking maneuver at higher TTC in front of the obstacle, the system will assist by early and efficient brake application (e.g. pre-filling & boost). Those who decide for a steering maneuver will be supported by chassis parameter adaptation and steering recommendation along an optimized trajectory in order to stabilize the vehicle in high dynamic situations and help the driver to steer in a smooth, efficient and controllable way around the obstacle. And those who intuitively decide for a combined braking/steering maneuver will be supported by a driver intention dependent and situation adapted optimization of longitudinal and lateral vehicle performances during the steer-in phase (e.g. by reduction of under-steering) sequentially followed by measures of the emergency steering assistance with a smooth and controllable transition from braking to evading.

The third phase (pre-crash phase) of the ContiGuard® cascade becomes relevant as soon as the so called "point of no return", which is represented by the physically last point to steer (dependent on relative speed, friction and necessary lateral offset for evasion), is passed. If a driver misses this point, a collision will be unavoidable and system initiated automated full braking will be applied as well as the passive safety systems will be preconditioned for the oncoming crash.

CONCLUSION & OUTLOOK

Development of the Emergency Steer & Brake Assist represents the next logical step to integrate the Emergency Brake Assist with its lateral assistance complement, the Emergency Steer Assist function. As subject driver examinations show, drivers intuitively combine braking and steering activities dependent on time-to-collision and object overlap in emergency situations. Key factor for the improvement of the overall function is the surrounding sensor concept. The ability and robustness of the sensor system plays a major role to display the precise picture of the real surrounding. This is the basis for the assistance system to make the right decision, how to assist the overstrained driver in the crash-imminent situation. The integration of the longitudinal and the lateral assistances opens literally a new dimension. On the one hand this second dimension increases the complexity of the total crash scenario with the already described challenges for an enhanced sensor system. On the other hand, however, the integral function approach gives the opportunity to address more use cases and with that it will help another time to reduce accident rates and to support the vision zero, traffic without serious injuries and fatalities.
A very interesting and important deliverable within the further development of the integral assistance system is the examination of use-case subject driver tests. Objective is to quantify the benefits of different integrated system functionalities by EPS, ESC and ARK and to receive feedback regarding the overall acceptance by normal drivers. Beside further developments in sensor technology functional improvements, also under consideration of functional safety aspects, will be the next important development milestones.

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