Driver Assistance Systems in Oncoming Traffic Situations

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ABSTRACT

In Germany, every fourth fatal road traffic accident takes place in situations with oncoming traffic. Two out of three fatal accidents occur on two-lane rural roads. Overtaking maneuvers and loss-of-control situations are responsible for many of these accidents and they usually result in serious injuries or fatalities.

This paper

- analyzes the basic accident mechanisms in oncoming traffic collisions,
- focuses on human error that leads to the collisions,
- deduces target requirements for assistance systems,
- addresses safety benefits in terms of mitigating the severity of injury of occupants and vehicle damage of those involved.

This paper presents the results of a driving simulator study that describes basic driver behavior in these situations. The paper also describes different variants of assistance systems that address these drivers behavior effectively by acoustic warnings.

INTRODUCTION

Worldwide the number of traffic fatalities has decreased in Japan, USA, Russia, European Union (EU), UK and Germany as shown in Figure 1. In its White Paper concerning the safety of road users, the EU sets as its common goal a reduction of 50 % in the number of fatalities among European road users by 2010. This EU-

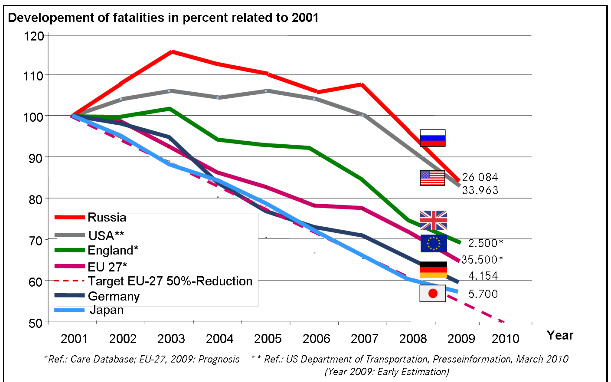

Figure 1: Trend of fatalities in road accidents from 2001 to 2009 in Germany, Great Britain, EU(27), USA, Japan, Russia

initiative has encouraged the introduction of more and more active safety measures as standard equipment or optional features in new cars. While in the past, systems for stability control and advanced brake assistance had been in the center of development efforts, the focus is shifting increasingly towards systems that can analyze environmental and situational conditions in complex traffic scenarios. They will increasingly contribute to an additional reduction of accidents. Using innovative sensor technologies and improvements in the area of situation analysis and assessment, even more complex traffic situations such as at intersections and involving oncoming traffic become usable for advanced driver assistance systems.

In 2009, a total of 2.31 million traffic accidents were registered by the police in Germany. In these accidents 4,154 people were killed and another 397,671 were injured. At an 8 % margin, oncoming traffic accidents take a middle position in accidents causing injuries. However, they gain importance when considering accidents with fatalities or severe injuries. Here, oncoming traffic accidents account for 22 % of accidents involving fatalities and 17 % of accidents involving severe injuries. Observing accidents that happen on rural roads, but not on divided highways, this type of accident accounts for 32 % of all people killed; 774 out of 2452 fatalities occurred in rural areas [1].

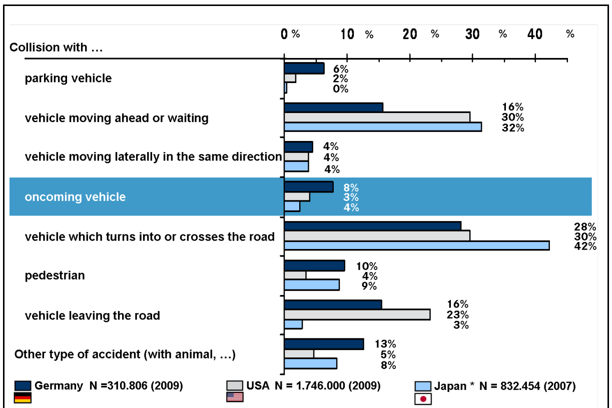

Figure 2: Distribution of the types of accidents involving personal injury. Figures for Germany (2009, DESTATIS), USA (2009, NHTSA) and Japan (2007, IATSS)

According to official accident statistics from the US and Japan, oncoming traffic accidents account for 4 % or 3 %, respectively, of all accidents involving injuries (see Figure 2). IIHS [1b] reports that the amount of fatalities in accidents with oncoming traffic is nearly 24 % of all fatalities in road traffic. The percentages in the severe injury and fatality categories, however, are similar to German statistics. Russian authorities report 10 % oncoming traffic accidents with injuries [2] and approximately 33 % are fatal [3].

Currently, the research regarding oncoming traffic accidents has mostly considered aspects like road design and traffic theory and has focused less on the design of advanced driver assistance systems. For example, Wang et. al. [4] examined the estimation of conflict probabilities in overtaking situations. Hegeman et.al. [5] have analyzed the individual phases of the overtaking process and divided it into various sub tasks. Hohm et. al. [6] have researched possible approaches for an overtaking assistance system. As part of the PRORETA 2 research project, in 2009, Continental and the Technical University of Darmstadt presented a prototype of an assistance system supporting the driver while overtaking on country roads. The prototype shows that the technical implementation is possible [7].

This paper uses a different approach. Our starting point was not a technical implementation in a vehicle, but an examination of driver behavior associated with oncoming traffic accidents that resulted from overtaking another vehicle. Variables under considerations were the behavioral, attentional, perceptual, and psychomotor facets of driver behavior and performance. The detailed understanding of the mechanisms how these human factors interact and their sensitivity is necessary when designing an effective and user accepted assistance system in this specific pre-crash situation.
The research was conducted in 2007 / 2009 in the Daimler AG (moving base) driving simulator in Berlin, effectively ruling out any risk to life or injury of the test persons. The experimental design was based on a detailed analysis of on-road accidents. In the first part of this study the human errors that lead to an accident were identified. Building on the test results, a second study was conducted analyzing the potential of a warning function and its user acceptance. The study also included a change in the test persons' perspectives in the situation. In one instance the test persons took the *"active"* part as the driver in the oncoming lane of traffic. In a different scene the drivers were placed in a *"passive"* role in which another vehicle in the oncoming lane of traffic started an overtaking procedure into *"their"* lane, facing *them* directly. Both situations showed significantly different patterns of behavior.

ACCIDENT MECHANISM AND RELEVANCE

The pre-crash situations, which most frequently lead to oncoming traffic accidents were first analyzed. The analysis based on the representative GIDAS database, which will be introduced briefly.

GIDAS database – a statistical representative sample of accidents for Germany

The analysis in this paper is based on accident data provided by the GIDAS project. GIDAS is an abbreviation for "German In-Depth Accident Study". It represents a cooperative project between the German Association for Automotive Technology Research (Forschungsvereinigung Automobiltechnik e.V., FAT) and the German Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt) (see [8, 9] for more details). In its current form it was founded in 1999. Since then data for in-depth documentations of more than 2000 accidents per year were collected in two research areas – the metropolitan areas surrounding Hannover and Dresden (see Figure 3).

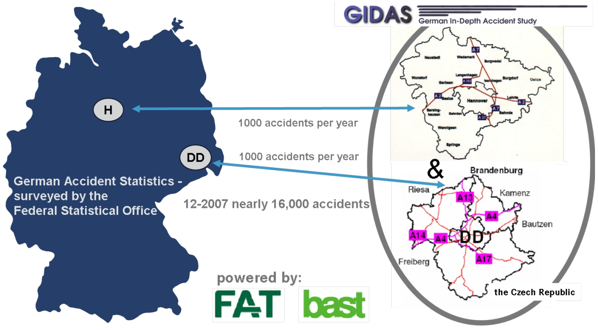

Figure 3: GIDAS - the research areas around Hannover and Dresden

The criteria for choice and collection are: (1) road accident, (2) accident in one of the research areas, (3) accident occurred when a team is on duty in a defined time frame, and (4) at least one person was injured in the accident, regardless of severity. For each accident a digital folder was created according to carefully defined guidelines and coded in a database. Depending on the type of accident, each case is described by a total of 500 to 3,000 variables, containing, e.g., accident type and environmental conditions (the type of road, number of lanes, width, surface, weather conditions, time of the day,…), surroundings of the accident scene, vehicle type, vehicle specifications (mass, power, tires, …) and configurations (primary and secondary safety measures), documentation of damage to the vehicles, and injury data for all persons involved and their medical treatment. The investigation of all cases is "on the spot" to ensure the best visibility of traces for the best possible reconstruction. Each accident is reconstructed in detail including the pre-collision-phase. Available information includes the reconstructed initial vehicle and collision impact speed, deceleration, as well as the speed sequence of the collision.

ACCIDENTS WITH ONCOMING VEHICLES

Selection of accidents for detailed examination

In the GIDAS database accidents are encoded according to the extended accident catalog of the GDV (German Insurance Association). The various accident types are derived from the situations from which the accident evolves. An oncoming traffic accident can be subdivided into the following five accident types:

- Type A „Driving accident in a left turn."
- Type B „Driving accident in a right turn."
- Type C „Driving accident on a straight road."
- Type D „Accident in parallel traffic with oncoming vehicles."
- Type E „Accident in parallel traffic involving the overtaking vehicle and oncoming traffic"

On the basis of about 1060 accidents belonging to type A to E selected from GIDAS 12-2007 it was found that the subgroup of traffic accidents (type A-D), which ultimately lead to an oncoming traffic accident, had the largest share of about 60 %. About 25 % take place in curves. About 35 % of oncoming traffic accidents are preceded by a lane change (Type E).

In the case of driving (or loss-of-control) accidents, with the ESC and the lane departure warning / protection / lane guiding system currently offered in the market, there are already assistance functions that address this accident type. The coming years will show how well these systems work in helping the driver to prevent these accidents. Accidents with oncoming traffic due to lane changes have so far not been addressed by a assistance system, which is why this type of accident was selected for being studied in the driving simulator.

On the basis of 325 representative accidents (selected from GIDAS-2007) that were caused by "overtaking into oncoming traffic" these accidents can be characterized as follows:

- The oncoming traffic accident preceded by a lane change is an accident that in 90 % of cases occurs on rural roads, usually well-developed trunk roads, typically with single carriageways.
- About 60 % take place on (typically long) straights and about 35 % around the exit or after (typically shortly after the end of) curves.
- At 6 %, it has an extremely high rate of fatalities.
- Involved in these accidents are 80 % passenger cars, 15 % commercial vehicles and 15 % motorcycles.
- Collision partners of the passenger cars are 70 % passenger cars, 17 % commercial vehicles and 13 % motorcycles.
- Passenger cars collide at 45 % fully covered head-on, 10 % partially covered head-on and 15 % side-on while evading the oncoming vehicle. 15 % collide at the conclusion of the maneuver with the vehicle they have overtaken.
- The driver of the overtaking vehicle overlooks the oncoming traffic or underestimates the distance required for the passing maneuver and/or the speed and its consequences.

From this data it can be estimated that the oncoming traffic accident preceded by an overtaking maneuver has a share of about 8 % of fatalities on German road traffic. This result fits well with current figures of the Royal Society for the Prevention of Road Accidents [13] for UK. They conclude that in 2007 175 people were killed in overtaking (into oncoming traffic) accidents, with a further 1,351 seriously injured. This means that in the UK around 16 % of motorcyclist fatalities. about 6 % of all car occupant fatalities, and about of 7 % of all road fatalities occurred in this kind of accident.

This GIDAS analysis was the basis for a representative routing and definition of the accident situation for the Daimler AG driving simulator experiment.

Derivation of the experimental design

The results of the study define requirements for the used test track and the scenarios for the experiment. Based on the results the goal was to create a test track that met the requirements for representative accident scenarios, thus the experimental design met these criteria:

- The track passes over country and represents a well-developed trunk road.
- The track has a long, easily manageable straight section that invites the driver to overtake vehicles
- Before the "active overtaking maneuver" there is a long curvy stretch with dense oncoming traffic. At the beginning of the curves the participants approach a vehicle (M-Class) that drove through the curves at about 100km/h. In the curves there is a speed limit of 100km/h.
- As in reality, traffic is simulated at irregular intervals on the entire stretch.
- The stretch has a length of 70 kilometers.
- The driver repeatedly experienced harmless scenes in order to convey a natural driving sensation. The individual events were evenly distributed over the entire stretch. On the drive they repeatedly went through sections with and without a lead vehicle.
- The participants repeatedly experienced overtaking in oncoming traffic. They were also able to overtake several times on their own.
- The order of "active" and "passive" is selected at random for each participant at the start.
- The participant is seated in an vehicle cabin of a C-Class with an automatic transmission.

SIMULATOR

Driving simulators are suitable - especially in the early phases of system design - for safe and repeatable tests of the interaction between "normal driver" and primary safety measures in critical situations. Results obtained with this method have the advantages over others because they offer a high degree of determinateness, reliability, objectivity, validity and therefore transferability - for instance in different set ups - and comparability - for example between different levels of development. On the other hand, there are a few drawbacks, such as extraordinary expense for hardware, software and operation, integrated simulation chain in the design process, as well as specific difficulties. for example in replicating the vehicle movements, graphical presentation and limited awareness of exposure.

The mechanical set-up of the Daimler moving base driving simulator in Berlin presented in Figure 4 and is described in detail in Käding [12]. This well established simulator provides a very realistic driving environment. The movement system is composed of a hexapod and a cross cylinder. It allows for a movement of ± 3.80 m in transverse direction and of 1.50 m in longitudinal direction. The dome includes a CRT-projection system of 230° to the front, 60° to the back and exchangeable standard vehicle. LCD displays were integrated in the side mirrors of the test vehicles.

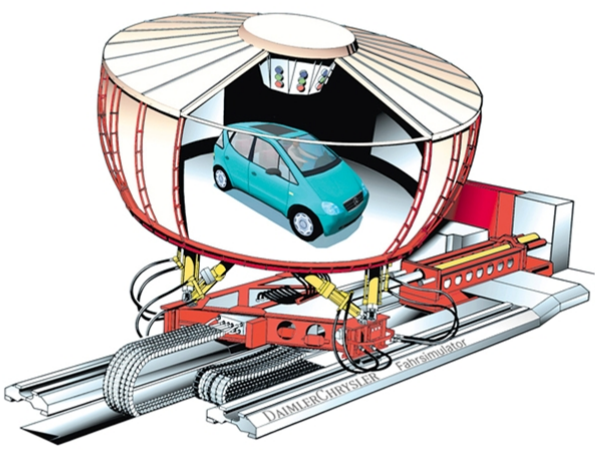

Figure 4a: Schematic diagram of the Driving Simulator of the Daimler AG in Berlin. Simulator was in use during 1985 - 2009.

Many studies have shown that results from experiments in this simulator are highly correlated with results from experiments on the test track. Participants were licensed drivers recruited from the public in the Greater Berlin area. Participants were not informed about the presence of assistance systems, and in the experiments they were not told what to expect in the course of the drive. Events were triggered when participants were familiarized with the simulator. However, there might have been participants who were expecting emergency situations, paid more attention and performed better as a result. But it can be assumed that this factor was potentially present within both groups.

Remark – The new DAIMLER Driving Simulator

The two studies presented here were carried through at the (old) moving base driving simulator in Berlin. This driving simulator was in use from 1985 to 2009. In September 2010 Daimler brought a new moving base driving simulator in Sindelfingen into service. This new driving simulator has a spherical CFK dome with a 360° projection system (8 projectors each 2048 x 536 pix.). It is shown in Figure 4b.

Figure 4b: New Driving Simulator of the Daimler AG in Sindelfingen. Simulator is in use since October 2010.

The movement system is composed of a hexapod and a linear rail of 12.5 m length. It can be moved with a velocity up to 10 m/s, an acceleration of +/-10 m/s². The hexapod has its own moving space of +/-1.3 m in longitudinal, 1.1 m in lateral and 1 m in vertical direction. This enables angels of +/- 38° around the yaw, 1+/-9 ° around the pitch and +/-20 ° around the roll axle. All actuators are electrical.

FIRST SIMULATOR EXPERIMENT

Sample of participants

Altogether, 84 fully licensed drivers took part in this (first) study. All had driving experience with Mercedes-Benz vehicles equipped with an automatic transmission. Their ages fell in the range between 23 and 72 years, equally distributed over the sub-ranges 25-40, 40-55 and 55-70 (mean: 48), with between 3 and 52 years of driving experience (mean: 18 years), and with between 5,000 km and 45,000 km yearly mileage (mean: 17,000 km). Thirty-five percent of the sample was female and 65 percent male. The participants were asked to provide a self-assessment of their driving style. In addition, their ability to react was evaluated by testing their basic four mental reaction times. These results served as a reference for evaluating the performance results.

Scenario 1: „Active overtaking“ - Definition

The “active” overtaking maneuver takes place on a long, straight road section that follows an approx. 4000 m curvy road section. Approximately 500 m in front of this curvy stretch a lead car is met, a SUV (M-Class) with a speed of max.100 km/h (the speed limit of this section of road). No other vehicle follows the participants vehicle.

After about 150 sec. of following, both vehicles drive up to a (red) vehicle driving ahead at approx. 70 km/h. The lead car is used to have comparable speeds of all participants while approaching the slower red car. As soon as the oncoming traffic allows, the lead vehicle begins to overtake the slower vehicle ahead of it. Once the lead car has completed its overtaking maneuver, the participant has a clear view of the entire stretch. The participant can now independently decide to overtake the slower vehicle ahead. An oncoming vehicle becomes visible from the time at which the participants commence their own overtaking maneuver.

The participant can now at any time choose whether to continue or abort the passing maneuver. The oncoming vehicle draws attention to itself by flashing its lights once the estimated time to collision (ttc) between the two vehicles falls below the critical value (ttc = 1.6 s).

If the participants' vehicle gets too close to the side of the car they have overtaken (red car in figure 5) it starts to honk. The participant should therefore be warned of a side collision, and perceive the situation as realistic and directly threatening.

As soon as a collision is unavoidable the oncoming and overtaking vehicles trigger an emergency braking so that the participant does not experience an accident (impending trauma). In addition the oncoming vehicle performs an evasive maneuver to the right. This results in a sufficiently large corridor in the middle of the road. The participant now has the opportunity to resolve the situation without a collision.

Figure 5: Critical phase of active overtaking

DRIVER BEHAVIOR THAT RUN TO DEFICIT

Typical behavioral strategies while overtaking

Three basic "typical" behavior patterns were observed and can be described as follows:

1. The participants follow the lead vehicle at a large distance or even falls behind. After reaching the slow vehicle (red vehicle in picture 6), they hesitate for a long time before they finally start the overtaking maneuver.

   - 27 % of this group abort the overtaking maneuver.

   - 42 % of all participants belong to this subgroup.

2. The participants follow the lead vehicle at an adequate distance (approximately 50 m). Both vehicles reach the slow vehicle at the same time. After the leading vehicle has (nearly) completed the overtaking maneuver, the participants start their own overtaking maneuver.

   - 25 % of this group abort the overtaking maneuver.

   - 19 % of all participants belong to this subgroup.

3. The participants follow the lead vehicle at a constant but very short distance. Both vehicles reach the slow vehicle driving ahead almost simultaneously. The participants initiate the overtaking maneuver at the same time as, or even earlier than, the leading vehicle. (In some cases, the leading vehicle is overtaken.)

   After having become aware of the oncoming traffic,
   - 30 % of this group abort the overtaking maneuver.

   - 39 % of all participants belong to this subgroup.

   (Note: Due to the modeling of the situation (curvy road; there is no safe way to overtake for some time) the participants obviously felt a high pressure to overtake. As a consequence, the first opportunity offered was used to overtake the vehicle ahead. This exactly corresponds to the behavior found in accident data.)

Characterizing overtaking maneuvers by their observed style (definition taken from Wilson et. al. [16]) gives:

- 48 % piggy-back overtakes (direct following another overtaker)
- 53 % flying overtakes (no adaptation to lead car velocity)
- 67 % accelerative overtakes (increasing velocity throughout the maneuver)

Further objective safety relevant criteria used for characterizing and evaluating a driver's behavior are:

- visibility of the oncoming lane / vehicle while initiating the overtaking maneuver;
- use of maximum acceleration and braking ability of the vehicle;
- discontinuing of overtaking maneuver;
- collision rate.

Observability of oncoming roadway while initiating overtaking

Due to the leading vehicle driving ahead – an all-terrain vehicle of the M-Class – visibility of the oncoming lane is temporarily severely obstructed. Was the participant able to see oncoming traffic or not during the overtaking maneuver? Has the participant checked whether or not the oncoming lane was clear of traffic or have they "blindly" relied on the vehicle driving ahead?

The analysis of the field of vision shows the following results.

- 43 % started the overtaking maneuver although there was no or very limited visibility of the oncoming lane (regarding the control of the oncoming lane, they "blindly" relied on the unknown driver ahead.)
- 57 % started the overtaking maneuver after the leading vehicle had completed its own overtaking maneuver. (Only these drivers have controlled the oncoming lane themselves.)

When the participant's vehicle is next to the overtaken vehicle (red vehicle, see illustration 5), the situation becomes critical. Up to that moment, 14 % have aborted the overtaking maneuver. Another 14 % abort the overtaking shortly after.

Use of the capabilities of the vehicle

The remaining participants accelerate more and willfully and continue the maneuver. How did these participants react under this enormous situational stress? Did they use the full range and spectrum of the dynamics for accelerating? They have two opportunities: the use of kickdown or at least drive at full throttle (apply the gas pedal with 100 %).

Those who did not use the kickdown used maximum throttle positions in the range of 60 % to 85 % of a scaled throttle position interval from 0 % to 100 %. The observed median was 80 %. No manual gearshift was observed.

Release of kickdown

An automatic transmission includes some means of forcing a down-shift into the lowest possible gear ratio if the throttle pedal is fully depressed. This is called *kickdown* and leads to an abrupt increase in engine power.

While overtaking, the driver's accident hazard is continuously increasing. Do the participants use the maximum acceleration by activating the kickdown in such stressful situation? In fact,

- 24 % used the kickdown prior to the oncoming vehicle flashing its lights (e.g. ttc in the range 3.5 – 2.5 sec);
- 6 % used the kickdown immediately after the oncoming vehicle had flashed its lights (ttc=1.6 sec);
- 10 % used it right from the beginning of the overtaking maneuver; and
- 60 % of participants who did not abort the overtaking maneuver did not use this option during the continuation of the overtaking maneuver, which means that they did not utilize the full engine power during the critical phase of overtaking.

Aborting the overtaking maneuver

One possibility of getting out of the situation without an accident means aborting the overtaking maneuver. How many participants chose this option and at which point in time?

> *28 % of the participants aborted the overtaking maneuver. They had no accident.*

Of the persons, who aborted their own overtaking maneuver

- 50 % did so at a very early point in time (before they were next to the vehicle to be overtaken);
- 40 % released the gas pedal directly prior to, or after, the oncoming car flashed its lights (TTC~1.6 sec.) and performed a hard braking;
- 10 % did something in between.

For those who aborted the maneuver the time they required to move the foot from the gas pedal to the brake pedal is below 0.5 sec. for 80 % of the participants.

Collision rate and collision constellations

The maneuvers ended in these collision combinations:

- 51 % without a collision, of which
  - 28 % aborted overtaking;
  - 23 % partly ended in a "near accident" situations with an extremely little distance to the overtaken and / or the oncoming vehicle (significantly less than 0.5 m).

  6 % head-on,
  6 % offside,
  11 % nearside, all cut in.
- 26 % with a (nearside) collision with the overtaken vehicle. The participant steered the vehicle into the right lane too early, which caused a collision with the vehicle intended to be overtaken.
- 23 % with a collision with the oncoming traffic;

  16 % head-on,
  7 % offside.

No loss-of-control or lane departures while carrying out the overtake and returning to the lane following the overtake or the break off were observed. But in about 28 % of all returns, ESC intervened.

Length of the overtaking maneuver

The participants, who completed the overtaking maneuver, were traveling in the oncoming lane for:

- 11 % less than 6 seconds;
- 73 % between 6 and 10 seconds;
- 16 % more than 10 seconds.

Evaluation by subsequent interview:

When questioned, 90 % stated that they had attentively observed the traffic situation. One third of the participants said that they had grasped the situation at an early stage. However, 60 % had underestimated the danger. More than 73 % assessed their reaction as very good to normal. The results are shown in figure 6. When asked, whether they had already experienced such a critical overtaking maneuver in traffic, 65 % of the participants answered „YES“. Over 95 % of the participants said, the situation was very realistic.

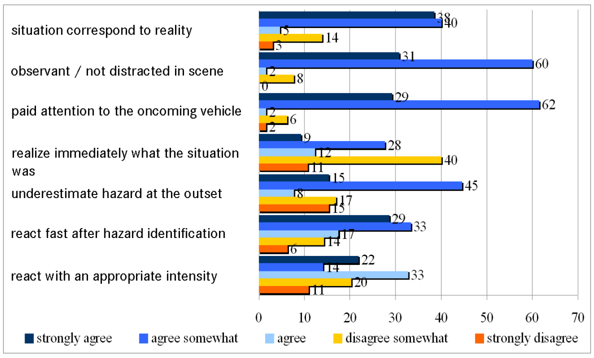

Figure 6: Self-assessment of response by the participants in the situation "Active overtaking"

Scenario 2: "Passive overtaking" - Definition

The "passive overtaking maneuver" took place at the end of a long straight road with a speed limit of 100km/h. The participant drove freely without following a lead car ahead or a vehicle following from behind. A line of traffic approaches in the opposite lane led by a truck. A vehicle driving behind the truck swings out and starts to overtake (see Figure 7).

The time at which the oncoming vehicle starts the overtaking maneuver and the speed of the two oncoming vehicles are such that the passing maneuver can just be completed in time even without reaction from the participant. Shortly before a possible collision the situation is resolved by an extreme deviation of the oncoming vehicle.

Figure 7: Critical phase of passive overtaking

Collision rate and driver behavior

The analysis of the measured data largely confirms the participants' statements. Hence, 55 % of the participants reacted to the oncoming vehicle by combined braking and steering maneuvers. Another 42 % performed a pure braking maneuver in order to clear the dangerous situation. One participant, tried to cope with the situation by a steering maneuver. The collision rate with the oncoming vehicle was 28 %. The rate of “near collisions” i.e. situations with extremely near distances, was about 20 %. 24 % of the participants left the road while evading and drove onto the shoulder.

Evaluation by subsequent interview

With regard to this situation, 95 % of the participants (see Figure 8) stated that they had been attentive and had observed the traffic situation. Nearly 80 % of the participants believed that they had grasped the situation at an early stage, and more than 70 % reported they had reacted appropriately. The conclusion of the participants was correspondingly positive – nearly all of them thought they had had a normal or good reaction.

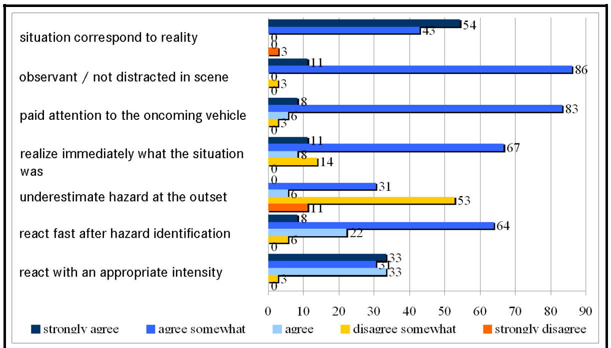

Figure 8: Self-assessment of response by the participants in the situation "Passive overtaking"

Requirement of assistance by questioning

Regarding the question, as to whether or not they have already experienced any of the critical scenarios on-road, more than 65 % answer "yes" in the context of "active overtaking", in the context of "passive overtaking" the share even amounts to more than 95 %.

The questioning as such showed that the acceptance of driver assistance systems is in total very high:

- 80 % believe that having an assistance system during an **active** overtaking maneuver would be helpful;
- 65 % believe that having an assistance system during a **passive** overtaking maneuver would be helpful;
- 50 % would accept direct intervention in the steering of the vehicle, while at the same time very few (<10 %) would be ready to leave control entirely to the vehicle;
- 75 % thought that an acoustic warning would be the best solution;
- 50 % thought that a visual warning would distract too much from the traffic situation.

DISCUSSION

In order to safely complete the overtaking maneuver the driver must ensure that the time required for completion of the maneuver is less than the time required for the oncoming car to reach the point where the maneuver will be completed. Otherwise the overtaking and the oncoming vehicles collide. In other words, the driver of the overtaking vehicle has to supervise two independent control tasks during his overtaken maneuver: an expected ***time to collision*** **(TTC)** with the oncoming vehicle and the ***time needed to perform a safe overtaking*** (**TSR – time to a safely return**) with no collision with the overtaken vehicle), stabilized during the maneuver and after the return to the nearside lane.

The estimation of the time needed to leave the oncoming lane safely is presumably based on the drivers' ability to ***estimate*** their current speed and the ***use of*** everything within the range of the dynamics of their vehicle (the maximum of its acceleration / deceleration capabilities), ***knowledge*** of the capabilities of their vehicles and ***assumptions*** about the actions of the driver in the overtaken vehicle.

The estimation of the time to collision with the oncoming vehicle is presumably based on their recognition of the oncoming vehicle, the ***estimation*** of its current speed and the distance to the oncoming vehicle, their use of the dynamics of their vehicle, their ***knowledge*** of the capabilities of their vehicle and their ***assumptions*** about the actions of the driver in the oncoming vehicle and especially their ***knowledge*** about the dynamics of the change in the distance between him and the oncoming vehicle in time.

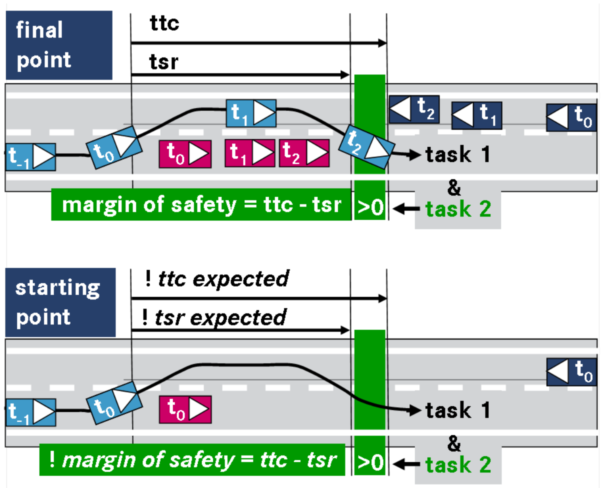

Figure 9: The two control tasks for for the driver while overtaking into oncoming traffic

These are two rather difficult, complex and linked ***control tasks*** -shown in Figure 9- for the driver that he has to carry out parallel under a lot of situational stress. The situational demand for the driver is comparable to those of pilots, which were classical research object in the context of situation awareness. Krüger [18] refers to Endsley and describes a related "switching problem" in multitask processing of pilots. In the case of an unexpected event (differing from their mental models) pilots have to learn to switch active goals that prime their mental models and hence their situation awareness. For example, while landing "*... the pilot has to switch between goal-driven processing (trying to land) to a data-driven processing that changed the (actual) goal to a goal-directed processing associated with the new active goal (aborting the landing)"* if there is an object on the runway. In simulator experiments a considerable amount (~25%) fail to react on them.. Pilots practice such situations to sharpen their situation awareness and thereby to improve decision making and performance.

To compound matters, there is a lack of on-road driver training in regards to overtaking maneuvers. Therefore, many drivers have not gained a lot of experience in carrying out these control tasks. Hence there are misjudgments in the dynamics of their own and other vehicle(s), misperception of visual and haptic information, faulty "go" or "go-on" decision and missing check of these decision or a missing calling them into question, lacking experience and knowledge gaps in appropriate control strategies as well as vehicle capabilities. Consistent with the results of the observed driver errors in the accident analysis, drivers in the present study made a considerable number of errors during simulated overtaking maneuvers.

The following behavioral patterns were predominant as to the two overtaking situations:

- faulty maneuver control, poor choices of timing or estimations of distances and speeds,
- dynamic capabilities of vehicle were not fully utilized,
- misjudging and missing calling whether or not it is safe to continue overtaking into question;

  (In this respect, the drivers seem to have been experiencing a kind of block, similar to "... a deer caught in the headlights …".)
- leaving the judgment whether or not it is safe to initiate an overtake maneuver to a stranger in the vehicle ahead.

Clark et. al. [10, 14] made some of the rare analyses on overtaking accidents. They examined 402 overtaking accidents and found by a retrospective analysis that for 272 (68 %) of these accidents the precipitating error was a wrong decision to start the maneuver made by the overtaker. They conclude that "*the problem stems from faulty choices of timing and speed for the overtaking maneuver, not a lack of vehicle control skills as such* ".

In this study about 49 percent made wrong choices on timing and speed – they had a collision. Another 23 percent had a "near collision".

The correct determination of the TTC by the driver needs exact estimations of distances and speeds or a mental model were both vehicles would meet. Björkman [15] and Bremer [16] found that drivers expect to meet an oncoming vehicle halfway, independent of speed. This causes a problem if the oncoming vehicle is much faster than their own vehicle. In this study none of the participants looked at the speedometer after initiating an overtake and when their vehicle was in the oncoming lane. It seems reasonable that all participants do not know their velocity exactly. The human limits in differentiation speeds of an moving object need at least an change of 0.2 degree per second in the angle under which the retina detects it. This causes errors in the estimation of objects´ velocities at long distances.

Wilson and Best [17] proposed the idea of the *"inertial drivers"* - one who is essentially unwilling to change speed, one who is maintaining speed to the last possible moment before braking to follow. Once overtaking is initiated, this inertial driver waits until the last possible moment before returning to the nearside lane. The authors observed collision-free maneuvers. The result of this study is that these "inertial driver" exist and that they continue in their *"stoic"* behavior until a crash occurs. These people seem to be mentally blocked; unable to react or check whether it is actually safe or not to continue the maneuver or unable to deduce an action out of a positive result. They behave like "a deer caught in the headlights" – facing the danger.

Can deficient driving behavior be positively changed through assistance?

The results of the present study suggest that a possible safety measure is a warning. The objective of the second study was the examination of the following questions:

Can the drivers' behavior be influenced by means of a warning while a overtaking maneuver is carried out to:

- improve judgment or query in judging whether or not it is safe to continue overtaking / passing;
- reduce the misestimation of the vehicle dynamics;
- increase the use of vehicles dynamic capabilities;
- and reduce the collision rate?

SECOND SIMULATOR EXPERIMENT

Sample of participants and test design

The participants were chosen in line with the first experiment. One hundred fully licensed drivers took part in this study. All off them had driving experience with Mercedes-Benz vehicles with an automatic transmission. They ranged between 23 and 76 years in age, equally distributed over the sub-ranges 25-40, 40-55 and 55-70 (Mean: 48), between 3 and 58 years of driving experience (Mean: 18 years), between 8,000km and 45,000km yearly mileage (Mean: 17,500). Thirty-five percent were female and 65 percent were male.

Three variants of assistance were derived from the findings of the first simulator experiment and examined on the basis of a subsequent experiment with participants. In 2009, a second simulator experiment was carried out by Daimler AG. The test track used in the first experiment and the scenarios examined were not changed.

A fictitious oncoming-traffic-assistance system helps the drivers to improve their judgment of the oncoming traffic with a warning; however, it does not actively intervene. Does it have an effect?
The following warnings were implemented:

- early acoustic warning,
- late acoustic warning,
- a cascade consisting of a combination of early and deferred acoustic warnings.

Operating principle of Oncoming Traffic Assistant in the Scenario 1: "Active overtaking"

The initial situation for the participants and the process are identical to the first experiment. When it is determined that the test person started an overtaking maneuver, a number of processes are initiated (see Figure 10), which correspond to the operating principle of an oncoming traffic assistant.

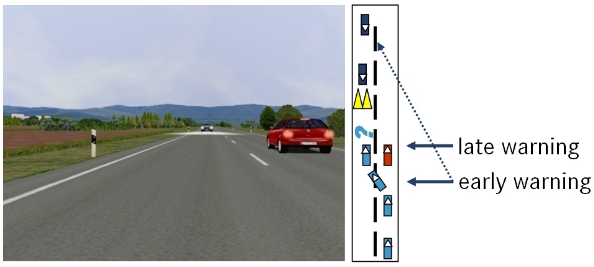

Figure 10: Operating principle of oncoming traffic assistant in the scenario "Active overtaking"

RESULTS OF THE SECOND SIMULATOR TEST

As a result of this experiment, the data of 85 participants were available for detailed evaluation. A brief summary of them is given below:

Effectiveness in decreasing the collision rate

The collision rate amounted to 49 % without the oncoming traffic assistant. (This was a result from the first experiment.) Aided by the assistant, this rate was reduced to:

- 15 % for cascaded warning (-70 %),
- 17 % for early warning (-65 %),
- 21 % for late warning (-58 %).

Effectiveness in increasing the discontinuing rate

The success of the three warning strategies in causing the driver to abort the maneuvers differed. Without the assistant, initiated overtaking maneuvers were continued in 72 % of all cases. Figure 11 shows the success rate of early warning, deferred warning and cascaded warning, with respect to causing the driver to abort the maneuver. Cascaded warning proved to be most successful in causing a driver to abort an overtaking maneuver. The aborting rate of 28 % observed during previous experiments was increased to 74 % (in absolute figures). Late or early warning resulted in an increase to 63 % and 52 %, respectively.

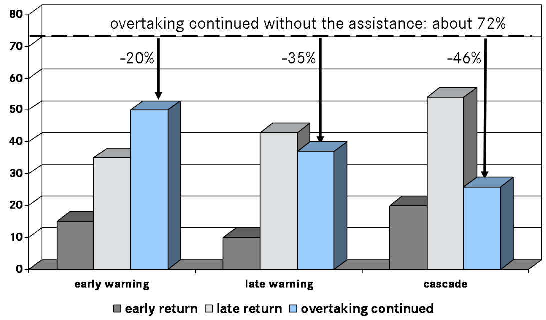

Figure 11: Analysis of overtaking rate with and without oncoming traffic assistant

Effectiveness in increasing the use of Kickdown

The following picture emerges with reference to overtaking maneuvers that are not aborted regarding kickdown: (reference to the earlier experiment of 30 % (without those who start the maneuver using the kickdown)):

- 30 % for early warning (analogous to the previous result),
- 50 % for late warning (+20 %),
- 90 % for cascaded warning (+60 %).

Overall significantly and positively it is found that both, the collision rate and the observed deficient driving behavior can be changed by means of an audible warning.

Evaluation of the findings based on subsequent interviews

Each of the three warnings had a clear influence on the driving behavior and the outcome of the overtaking maneuver. When interviewed, it was stated by:

- 65 % that early warning,
- 61 % that late warning,
- 62 % that cascaded warning

had been important and helpful to them in the situation.

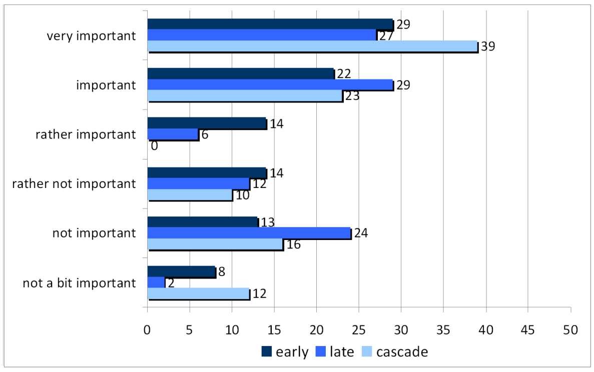

Figure 12 Provided by the participants to the significance of the warnings

Remark: Active overtaking against an oncoming vehicle generates an enormous level of stress in the participants. An significant amount of about 15 % of participants, aborted the test drive after they had experienced the active overtaking scenario although they had no collision.

Operating principle of Oncoming Traffic Assistant in the Scenario 2: "Passive overtaking"

The initial situation and the process are identical to the first experiment. When it is determined that the test person started an overtaking maneuver, a number of processes are initiated (see Figure 13) which correspond to the operating principle of an oncoming traffic assistant.

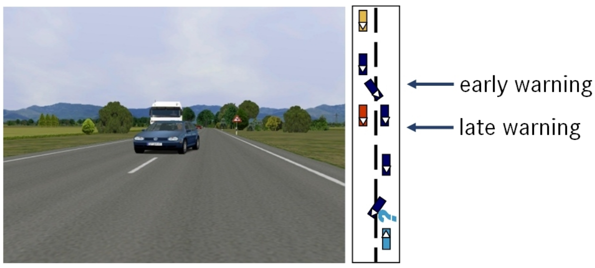

Figure 13: Operating principle of oncoming traffic assistant in the scenario "Passive overtaking"

Effectiveness in decreasing the collision rate

The collision rate amounted to 28 % in the previous experiment without the oncoming traffic assistant. Due to the three warnings this rate was reduced to:

- 8 % for cascaded warning (-71 %),
- 8 % for early warning (-71 %),
- 12 % for late warning (-57 %).

Close passing maneuvers, which accounted for a share of 20 % in the previous experiment, were not observed.

In general, it is shown that drivers can judge and assess situations significantly better because of the warnings. Hectic reactions, collisions, near misses and evading on the shoulder were considerably reduced.

Effectiveness in changing driver behavior

The warnings cause the drivers to change their behavior. In the previous experiment, there was a share of about 62 % of participants who steered or swerved. This share dropped significantly as shown in figure 14.

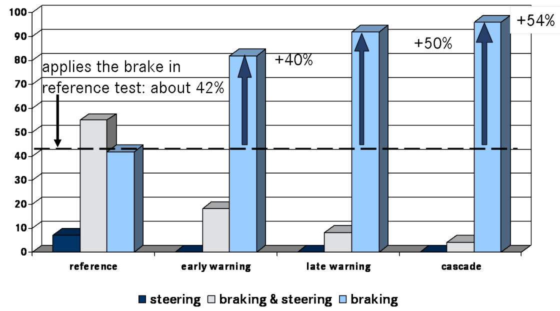

Figure 14: Analysis of the effect of the oncoming traffic assistant in the scenario "Passive overtaking"

The drivers were nearly all observed engaging in pure braking reaction. Start of braking and maximum delay changed at a clearly earlier start and at an average increase in decelerating of 2 m/s². None of the participants were observed swerving into the embankment (previously 24 %).

Evaluation of the findings based on subsequent interviews

Each of the warnings had a clear impact on the driving behavior and the outcome of the overtaking maneuver. When interviewed, it was stated by

- 90 % that early warning,
- 91 % that late warning,
- 96 % that cascaded warning

had been important and helpful to them in the situation. This corresponds with the observed braking behavior .

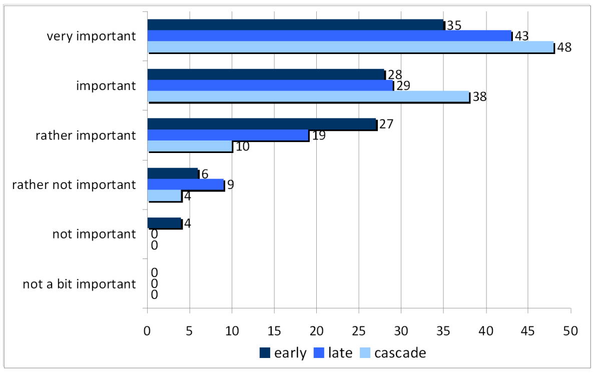

Figure 15: Provided by the participants to the significance of the warnings

DISCUSSION

In both – the active as well as the passive overtaking - situations it is shown that drivers can judge and assess hazard situations significantly better because of the warning. Hectic reactions, collisions, near misses and evading on the shoulder were considerably reduced. In both cases, no negative influence of the warning (e.g. a time delay of the reaction due to the warning, …) on the behavior of the driver was observed or reported in the questioning.
Overall it was noted that the warning had higher acceptance and impact levels when pointing out mistakes made by *the other road user* but not if they served to cause the driver to examine their *own previous decision*. These kinds of warnings had to be presented at the right time (in agreement with the inner mental model of the driver), repeated insistently to be recognized to release an appropriate action.

SUMMARY:

The study of accident statistics shows that a considerable number of people have lost their lives in collisions with oncoming traffic, as a consequence of overtaking maneuvers. In Germany, the share of people killed in such accidents is estimated to account for 8 % of all deaths in road traffic. Although there are initial approaches and systems that assist drivers in some aspects of overtaking maneuvers, the participant of oncoming traffic is hardly considered by current concepts.
This study was targeted at identifying deficient behavior of drivers, which occurs during overtaking maneuvers in oncoming traffic situations. To this end, representative overtaking situations in oncoming traffic situations were developed for the Daimler AG simulator and performed with 73 public drivers.
The following behavioral patterns were predominant in the two overtaking situations:

- faulty maneuver control, poor choices of timing or estimations of distances and speeds;
- misjudging and missing query in judging whether or not it is safe to continue overtaking / passing;
- only 30 % took advantage of the full dynamic capabilities of their vehicle;
- 43 % left the judgment whether or not it is safe to initiate an overtake maneuver to the driver of the vehicle ahead.

In a second simulator experiment the benefit of different warnings was tested with 83 valid participants. Warnings reduce the collision rate by about 70 %. It was shown that the drivers were in a significantly better position to judge and assess the situations when given elementary warnings. The number of hectic reactions, collisions or near misses was thereby clearly reduced.

At present, the technical realization is hindered by the system limitations of radar and camera sensors, as they do not yet allow for a reliable detection of oncoming traffic at any time.

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