CRASH WARNING INTERFACE METRICS: EVALUATING DRIVER-VEHICLE INTERFACE CHARACTERISTICS FOR ADVANCED CRASH WARNING SYSTEMS

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ABSTRACT

The Crash Warning Interface Metrics (CWIM) project addressed issues of the driver-vehicle interface (DVI) for Advanced Crash Warning Systems (ACWS). The focus was on identifying the effects of certain warning system features (e.g., warning modality) and on establishing common methods and metrics that may be generally applied for evaluating DVIs in different vehicles. The project did *not* have the goal of proposing standard interfaces for particular warning functions, but it did consider implications for design. The project included analytical activities and five experiments. Each experiment investigated the effects of ACWS DVI on driver behavior or comprehension using a different methodology. An objective of these studies was to determine the appropriateness of the various methodologies for use in subsequent human factors research on ACWS DVIs. Implications were discussed for methods to evaluate DVIs including driving scenarios, research participant characteristics, pre-familiarization with the warning system, the distraction task, the participant's task and associated expectancies, accommodating user settings and options, the use of comparison benchmarks, and issues in the treatment of data. Key research needs were identified for carrying the work of this project forward, including research related to ACWS modality, ACWS design, and CWIM assessment methods.

INTRODUCTION

Background

ACWS use sensors to assess potential or emerging hazard situations and provide warning information to drivers. Example systems include forward collision warning (FCW) and lane departure warning (LDW). ACWS are increasingly common in passenger vehicles and the characteristics of these systems vary considerably among vehicle manufacturers. In particular, the means by which the warning information is conveyed to the driver – the DVI – varies in many respects, including the warning sensory modality, display location, information content, coding, sensory attributes (e.g., intensity), temporal aspects, and active intervention in vehicle control. Given the potential diversity of DVIs for analogous ACWS functions in different vehicles, the question arises as to whether all of the alternative implementations are reasonably effective and also whether this diversity may cause safety problems.

The National Highway Traffic Safety Administration (NHTSA) initiated a program to provide for systematic evaluation of the DVI for ACWS functions. This paper gives an overview of Phase 2 of the CWIM project, conducted as part of this programmatic effort. Three broad issues related to the ACWS DVI were encompassed within the project: (1) a consideration of alternative display modalities for conveying the warning (specifically for FCW and LDW applications); (2) methods for a common evaluation procedure for assessing a DVI; and (3) implications for DVI conventions.

Warning mode A variety of alternative display modes may be used to present ACWS messages to the driver. Auditory alerts and visual displays (lights, icons, text) are the most common modes. However, haptic signals of various sorts have received recent attention and are now found in some vehicles. Haptic signals include seat vibration, steering wheel vibration, brake pulse, seatbelt pre-tensioning, and accelerator counterforce. Acoustic icons and voice messages are alternative acoustic displays that may be used in place of beeps and other sounds that do not have inherent meaning. In addition to display modes, some ACWS include an active component. An "active" warning includes automatic partial control of a vehicle's behavior (e.g., direction, speed) through steering/braking. This automatic action may itself serve as a warning cue, and may promote driver responses that aid in crash avoidance, in addition to any direct safety effects from the vehicle response itself. Examples of active systems include an FCW system that applies crash-imminent braking and an LDW that applies a steering correction when the vehicle is drifting out of lane. Knowledge about driver response to such active interventions is limited. Furthermore, current commercial examples are typically moderate in terms of vehicle control aggressiveness, and they appear intended as aids to driver actions rather than autonomous collision avoidance. Active warnings are of particular interest both because of their potential to promote improved driver response and because of the possibility that they may induce inappropriate driver reactions or poor consumer acceptance (e.g., if a system is incompatible with users' expectations). Examples of inappropriate driver reactions include overcorrection in steering, strong lateral acceleration, severe braking, startle responses, and driver confusion. In order to devise evaluation methods and design guidance that remain appropriate as active systems evolve and become more common, it is important to understand how drivers respond to these types of ACWS. Therefore, the CWIM project included empirical evaluation of passive and active warning modes.

Methods for DVI evaluation While it is important to have effective DVIs for ACWS functions, a consensus means of *evaluating* a given system does not exist. The field lacks a valid, practical, consensus method for determining the efficacy of a DVI for a particular ACWS application. A set of specific research methods, dependent measures, and analysis methods could provide valid, reliable, and repeatable assessments. Such a consensus set of methods is what is meant by CWIM. The metrics considered in this project are directed at the evaluation of operational (commercial or prototype) ACWS, rather than as techniques to be used in earlier design stages. The metrics might be applied in various ways, such as evaluating the performance of the ACWS DVI (quantitatively and/or against established criteria), comparing the performance of alternative systems, providing a basis for consumer information (e.g., the type of information useful for the New Car Assessment Program), or supporting regulatory or safety actions.

This project developed initial suggestions for a range of CWIM factors. The process of developing and establishing consensus for CWIM is complex. Various manufacturers use different modalities and display types, so a common metric must be able to encompass any type of interface. Since a particular ACWS may be integrated as part of a system of warnings, the method must have a reasonable means of testing a given function in isolation, without penalizing the system by removing important context. Not all nominally similar safety functions operate in the same manner; for example, some warnings may only operate within certain speed thresholds. Some vehicles may provide advance information or alerts, prior to the situation in which the actual crash warning occurs; the means of incorporating this aspect into a test protocol is not obvious. Some ACWS include limited active intervention in some aspect of vehicle control (e.g., partial braking, counter-steering). This complicates the use of vehicle control or driving outcome measures as indices of the effectiveness of the DVI. Any evaluation method will have to specify the driving scenario(s) in which the warning occurs, yet the relative effectiveness of two interfaces may depend on the specific scenario used. Finally, the metric is intended to be applied to operational systems, and these may not be readily available or may employ proprietary algorithms not easily adapted to test methods such as driving simulators. Thus while there are important advantages to a common evaluation method, there are challenges in accomplishing this.

Design convention considerations Although the goal of this project was not to standardize any particular warning interface, there may be some benefits of conventions. Drivers may come to be familiar with the DVI in their personal vehicles, but as ACWS become more ubiquitous, drivers may confront unfamiliar interfaces when they use rental vehicles, share vehicles, or acquire a new vehicle. They may have false assumptions about vehicle functions and displays or may react slowly or inappropriately to emergency events. However, design conventions for a DVI may also have significant drawbacks and should not be proposed without a strong basis. For this reason, the CWIM project included empirical research that investigated design convention issues.

Project Overview

The project involved a combination of empirical research and analytic activities. The initial efforts of the project were analytical. This work examined research literature, crash analyses, current practice for DVI design and evaluation, and expert/stakeholder feedback. This defined needs, options, and preliminary suggestions for use in the subsequent project activities. Subsequently, five empirical experiments were conducted. These included three experiments that compared various crash warning interface modes and examined the methods used to evaluate them. There were also two experiments that addressed various aspects of DVI comprehension and potential issues related to display variability. Each of the five experiments used a different methodology. One objective of this project was to determine the appropriateness of the various methodologies for use in subsequent human factors research on ACWS DVIs. While each experiment was developed to provide findings that could stand alone, some comparisons can be made between the various study methodologies. The findings of the analytical and empirical efforts were then considered in the development of suggestions for ACWS DVI evaluation, crash warning interface design, and design convention needs. This project overview paper focuses on the empirical studies and the implications for DVI evaluation. Greater detail on all aspects of the work may be found in the project final report (Lerner et al., 2011).

LDW WARNING MODE EXPERIMENT

The objective of this study was to determine how readily drivers are able to use LDW to improve lane recovery and crash avoidance, and in particular how this is related to warning modality and active warning strategies used by the LDW system. Active warnings (e.g., active countersteer) were of particular interest, both because they presumably have greater potential to promote rapid vehicle control responses and because their potential to induce inappropriate driver reactions is not well understood. The study also addressed driver acceptance issues. A system that is not well accepted by drivers may be disregarded or disabled and would therefore not be effective. Finally, through development of the experimental protocol, this study addressed issues surrounding the best approaches for evaluating the driver interface of LDW systems.

Method

The experiment was conducted in the National Advanced Driving Simulator (NADS-1) at the University of Iowa. A two-lane bi-directional rural highway with 3-meter lanes used in the study was representative of the most common roadway departure crash scenarios according to Najm, Koopmann, Boyle, and Smith (2002). The roadway database was designed so that it had both long two-lane highway straight-aways as well as a variety of left and right curves. The drive was approximately 30 minutes in duration.

The most common crash types and ones that are generally the most injurious and fatal were chosen for examination in the study: a) Vehicle drifts off road to the right, b) Vehicle drifts over the centerline, with oncoming traffic, and c) Vehicle fails to keep lane in a left curve entry. Each participant was exposed to these three scenarios while they were periodically distracted by a secondary task. Participants were also exposed to a false alarm in which the LDW alert activated while driving through a construction zone.

This study compared driver responses to passive and active LDW warnings and to a control condition in which no warning was given about an impending lane departure. Passive LDW warnings included an acoustic alert and a tactile alert (steering wheel vibration). Active warnings included a weak active countersteer and a stronger active countersteer. The form and magnitude of all alerts tested were within the range of alerts on production vehicles now sold in the United States or elsewhere, and on pre-production vehicles tested by NHTSA. Data were obtained from 90 participants (18 participants in each of five different LDW system groups, including one control group that did not experience any LDW).

Participants were instructed to perform a variety of secondary tasks while driving including a visual/manual “bug task” which distracted them from the forward roadway long enough that a lane departure could occur unnoticed. The bug task required that the participant turn and reach into the back seat to trace the path of a simulated insect on a touch screen display. To ensure that an LDW was obtained, a bias in the steering was triggered to nudge the car to the desired side of the lane during a distraction event. This was initiated based on driver engagement with the bug task. To mask the drift, no motion cues were provided.

Results

Although specific findings varied somewhat across the range of dependent measures included in this study, the general outcome was that all four warning conditions were superior to the baseline control condition and that frequently the "weak torque active LDW" condition performed best (although not always statistically significantly so). For example, the weak torque warning was significantly better than all or all but one other treatment for measures of maximum lane exceedance, severity of initial steering angle, total amount of time spent out of lane, and number of inappropriate behaviors elicited.

Overall, the impact of the warning modes on the number of inappropriate behaviors observed from driver showed that the highest number of inappropriate behaviors was observed from those participants who did not have an LDW. There were significantly fewer inappropriate behaviors for participants who experienced either of the active systems. The number of subjects who fully departed their lane, or ran off road, was significantly less for the strong torque warning and significantly greater for the auditory warning.

For the false alarm scenario, in which there was no actual lane deviation, the strong torque differed from the other warning conditions in that drivers with this system responded with greater, though unnecessary, vehicle control actions. The strong torque group had significantly earlier steering responses, greater peak steering rates, acceleration, and jerk.

Even though the active torque LDWs appeared to be more effective than passive alerts in minimizing lane departures, participants felt that they were more problematic. Participants were not asked to directly compare different warnings in this study. However, those participants who experienced the weak torque rated that warning as less effective in capturing their attention as compared to other participants' ratings of other LDW warnings. The group experiencing the auditory warning found it more effective at capturing attention as compared to other participants' ratings of either of the active warnings. Furthermore, the passive systems were viewed by the participants as being more helpful than the active systems. Participants who experienced a passive warning felt that the system was more easily interpreted than those who experienced an active warning. Participants who experienced a passive warning also felt that the system was more reliable than those who experienced an active warning.

FCW WARNING MODE EXPERIMENT 1

This experiment compared driver responses to two different FCW systems (passive versus active) on two different crash scenarios and a false alarm event. The passive FCW driver interface incorporated a head-up display (HUD) and an auditory alert. The active FCW used a brake pulse to alert the driver by exerting momentary activation of the brakes. Specifications for these warnings were developed in consultation with NHTSA. The two crash scenarios used in the study were a decelerating lead vehicle and a stopped lead vehicle. The experiment was conducted in the NADS-1 simulator. The roadway environment was similar to that used in the LDW study.

Method

To support this research on the effectiveness of FCW system warnings, it was necessary to use a distraction task that would reliably and repeatedly insure that the driver's eyes are off road for several seconds prior to the forward collision events. Because drivers can use peripheral vision to monitor the roadway, it was essential to direct the driver's gaze away from the forward view. To achieve this, the same simulated bug task used in the LDW study was used here.

Thirty-two participants experienced one of the two FCW systems; 16 other participants in a third group (baseline) did not have any FCW system. For each forward collision event, measures of initial vehicle control, inappropriate responses, and lane recovery were recorded. Following the drive, the driver's acceptance of the FCW system was assessed.

Results

There were no statistical differences (at the $p<0.05$ level) in response time among the conditions, although there was a trend across the reaction time measures used. When looking at initial response to the event, drivers in the baseline condition took longer to release the accelerator than drivers in the warning conditions relative to their initial engagement in the distraction task. There were also trends towards faster performance for responses relative to the time the alert was issued. On average, drivers responded by releasing the accelerator and applying the brakes 375 ms sooner with a warning than without. When applying the brakes, there were significant differences in both the level of braking and the maximum decleration achieved by the driver. Peak brake pedal force was less forceful for drivers with the brake pulse than for drivers in the baseline and auditory/visual warning conditions. Also, these drivers achieved a maximum brake pressure that was

36% less than was achieved in the other conditions. Drivers in the brake pulse condition achieved a peak deceleration level that was 15% less than for drivers in the other two conditions. These differences in braking response did not translate into differences in collisons. Overall, there were no differences between groups in the number of participants who avoided collisions for either crash scenario.

Participants in each FCW group with alerts reported that they easily understood why the alert was presented, that the system successfully caught their attention, and that the alert was easy to see-and-hear or feel. The passive auditory/visual alert was rated significantly easier to interpret than the active brake pulse.

FCW WARNING MODE EXPERIMENT 2

This experiment, conducted on a test track at NHTSA's Vehicle Research and Test Center, compared driver responses to FCW systems that used either a HUD visual alert, an auditory beeping alert, a seatbelt tensioning device, or a some combination of two or all three of these alerts. See Forkenbrock et al. (2011) for the complete technical report on this experiment.

Method

Each of 64 participants was randomly assigned to one of eight groups. Participants in the first group experienced no FCW alert while participants in the other seven groups experienced one of seven different possible combinations of FCW alerts. The primary objective of the study was to develop a protocol suitable for evaluating FCW DVI effectiveness on the test track. A second objective was to compare the effectiveness of a small set of FCW alerts using the protocol that was developed.

Adult participants were recruited from the general public. Each participant experienced only one FCW event and had no exposure to the FCW system prior to experiencing the event. Each participant was asked to follow a lead vehicle while attempting to maintain a constant headway. Feedback on current headway was provided to the driver on a visual display. The participant was also asked to perform a secondary task which involved diverting their attention away from the forward roadway toward a visual display mounted near the back of the front passenger seat. After performing this task several times and driving back and forth across a straight test track, the distraction task was performed for a final time. During the final distraction task, while the participant was looking away from the roadway, the lead vehicle was abruptly steered out of the travel lane, revealing a stationary vehicle (a realistic-looking, full-size, balloon car) in the immediate path of the participant's vehicle. At a nominal time-to-collision of 2.1 seconds from the stationary vehicle, the FCW alert was presented to the driver.

Results

All eight participants in the baseline group with no FCW alert collided with the balloon car. Similarly, all eight participants who received only the HUD alert collided with the balloon car and 7 of 8 participants who received only the beeping alert collided with the balloon car. Among the various FCW alert combinations tested, it was apparent that FCW systems that included the seatbelt pre-tensioner as an alert were more effective in helping drivers avoid a collision than other FCW driver interfaces that did not include this alert. Approximately half of the participants who received the seatbelt tensioning alert (alone or in combination with other alerts) avoided colliding with the balloon car. The results of this study showed that the seatbelt pre-tensioner was effective at causing the driver to disengage from the secondary task (ending their visual commitment to the secondary task) and directing the driver's eyes back to the forward roadway in time to respond to the stationary vehicle in their travel lane. The timing of the protocol was such that many participants collided with the balloon car even though they had initiated some evasive maneuver. In addition to the outcome variable (collision/avoid) several other dependent measures were recorded in this study, such as timing variables (e.g. time from FCW activation until the driver's eyes were back on forward roadway), brake application timing and force, steering responses, speed of participant's vehicle at time of collision, etc.

IMPLICATIONS OF WARNING MODE EXPERIMENTS

The results of the three studies show that warning systems that included active and haptic warnings generally were more effective than systems that did not include these features (e.g., auditory and visual warnings). The FCW test track experiment showed that a haptic seatbelt pre-tensioning alert may be effective by helping to physically reorient the driver toward the forward roadway. Results from the LDW study suggests that there may be an optimal balance between having an active torque warning that is too weak and one that is too strong. A strong active warning signal will not necessarily be as effective as a weaker active warning and may lead to greater inappropriate driver responses to false alarms. Also, based on the results of the LDW study it is important to note that there may be a mismatch between driver perception of effectiveness and effectiveness as measured by the performance measures.

FCW NEGATIVE TRANSFER EXPERIMENT

This experiment on negative transfer in auditory FCW addressed whether driver response to a FCW alert during simulated driving suffered when the participant switched from a familiar vehicle with one acoustic alert to a different vehicle with a different acoustic alert. A substantial decrement in response times after the vehicle change would suggest that there is a lack of transfer from one warning system to the other. The method and findings of the experiment are briefly described below. Additional details are in Robinson et al. (2011).

Method

A total of 60 licensed drivers completed the study. Of these, 28 were male. The average age was 27.5 with a range of 19 to 64, SD=9.1. The average driving experience was ten years and the minimum driving experience was five years.

The experiment consisted of two phases: the learning phase and the test phase.

- The *learning phase* was used to create the association between a particular auditory alert and various FCW events.
- The *test phase* was used to assess whether participant reactions to FCW events changed when exposed to a different auditory alert.

In the learning phase, half of participants were familiarized with one alert and half were familiarized with a different alert. In the test phase, half of participants received the same alert again (control groups) and half of participants received the alternative alert (treatment groups). Table 1 summarizes the four experimental conditions.

Table 1.
Summary of experiment conditions

Control	Treatment
Learning: Light Test: Light n = 15	Learning: Light Test: Heavy n = 15
Learning: Heavy Test: Heavy n = 15	Learning: Heavy Test: Light n = 15

Two auditory-only alerts, one designed for light vehicles (Light) and one designed for heavy vehicles (Heavy), were selected for use in this study. The Light alert had a fundamental frequency of 1500 Hz and a fast pulse rate. The Heavy alert had a fundamental frequency of 600 Hz and a slower pulse rate. The alerts were developed as part of the Integrated Vehicle-Based Safety Systems (IVBSS) project (Green et al., 2008). These warnings were selected because they were proven effective in field tests and were representative of the types of warnings that might be used in a collision warning system, yet sufficiently distinct in sound and acoustic parameters to give the impression that they were from two different automobiles. Both FCW alerts were presented at 85 decibels (dB) against a background road noise average of 62 dB (modulated by traffic present in the driving scene).

Participants completed a total of six simulated drives over the course of three experimental sessions (two drives per day). Each drive took about 20 minutes and consisted of rural highway and suburban/commercial segments with various traffic control devices and contexts (e.g., stop signs, traffic signals, curves, construction zones). Other traffic was present at low density throughout. Participants were instructed to obey the posted 45-mph speed limited drive in a safe manner as they would normally. The three scenarios were matched in terms of key components of proportion rural highway and suburban/commercial, number of traffic control devices, number of turns, etc. Participants were guided through the drives via turn-by-turn guidance presented aurally and visually through an in-vehicle display.

Throughout each drive, participants were required to perform a subsidiary task on an in-vehicle touch screen device, which was designed to increase the likelihood that participants' eyes would be directed at the touch screen rather than the roadway when a FCW event occurred. The task was a variation of the "Simon" task in which participants listened to a sequence of directions presented aurally (e.g., "Up, Down, Left, Left, Up") and then were required to repeat the sequence with button presses. Fifteen seconds after each Simon task was completed, participants were cued to begin the next Simon trial. This pattern continued throughout each drive.

Four FCW events based on those used in the IVBSS project (Green et al., 2008) were used in this experiment:

1. Lead vehicle (LV) suddenly brakes with another vehicle blocking a steering evasive maneuver.
2. Work zone lane reduction with LV sudden braking.
3. LV evasive maneuver to reveal stalled vehicle with another vehicle blocking a steering evasive maneuver.
4. Cut-in and sudden brake. Another vehicle coming up behind the cut-in vehicle blocks the participant's option to swerve.

Mirrored versions (e.g., cut-in from right rather than left) of each of the four event types, plus an additional lead-vehicle sudden braking event were used to generate a total of nine FCW events across the six drives.

Participants were instructed that the experiment was designed to investigate safe driving in the midst of various in-vehicle devices and tasks along with different driving situations. Prior to the first experimental drive (on Day 1), each participant was seated in the simulator and was introduced to its features and capabilities (including the "systems" in the vehicle for the purposes of the experiment (i.e., navigation system, FCW system, etc.). Participants were also introduced to the environmental sounds they would encounter while driving (e.g., car horn, cell phone ring) and the FCW alert that they would hear during the learning phase of the experiment. Participants were also introduced to the distraction task and route guidance instructions that they were to follow. Participants then completed a 10-minute practice drive to gain familiarity with the simulator and experimental procedures.

Two drives were completed on each day. For the first two days, participants experienced one of the two FCW alerts (Light or Heavy) whenever a FCW event occurred. On the third day, participants in the treatment conditions experienced the alternative FCW alert, while participants in the control conditions again experienced the same FCW alert that they experienced during the first two days.

Results

Although each participant was exposed to nine potential forward collision events, the data from about half (52%) of staged events were discarded because participants either may have begun to respond to the developing collision event before the FCW alert was triggered (i.e., participant began braking less than 200 ms after alert activation) or because they responded to the alert without braking (i.e., by swerving into another lane). Using the remaining data, three critical FCW event exposures were defined for each participant, and these critical exposures were used for all analyses. The critical events were the first exposure (the first time a participant heard the FCW alert), pre-switch exposure (the most recent event during which the FCW alert sounded before it was switched), and post-switch exposure (the first event in which the collision warning sounded after the switch). The terms "pre-switch" and "post-switch" are inclusive of both treatment and control condition participants, even though participants in the control conditions received the same alert in both time periods.

Brake response time (RT) was defined as the time between FCW alert issuance and the participant's first brake input. Figure 1 shows the mean brake RT for participants in each experimental condition by alert exposure period. The figure shows that while participants in the control conditions improved their performance in each successive period, participants in the treatment conditions displayed impaired responding, particularly in one of the two conditions. A mixed repeated measures ANOVA of brake RT was conducted with warning condition as a between-subjects variable and alert exposure (pre- and post-switch) as a within-subjects variable. The main effect for exposure was not significant at the $p<.05$ level, $F(1,9)=4.37$, $p=.066$. However, the main effect was subsumed by a significant interaction between warning condition and exposure, $F(3,9)=9.62$, $p=.004$. Participants exposed to the switch from the Heavy warning to the Light warning took significantly longer to respond to the post-switch event, relative to the time they took to respond at the pre-switch exposure and relative to the other three groups.

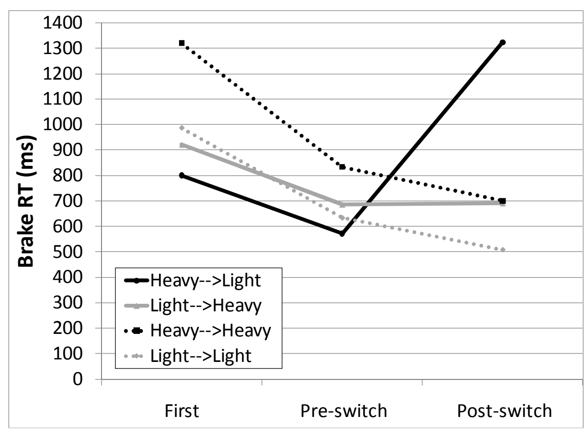

Figure 1. Mean brake RT as a function of warning condition and exposure period.

Following completion of all six drives, participants were asked to rate how similar pairs of sounds were on a scale of 1 to 7, with 1 being "very dissimilar" and 7 being "very similar." The similarity ratings were generally low, and the Heavy and Light warnings were both rated fairly consistently when compared to other sounds in the experiment, with the exception that the phone ring tone was perceived to be more similar to the Light warning than the Heavy warning. The relative similarity of the Light warning and the phone ring could have led to some confusion between these sounds, and therefore have played a role in the significant performance decrement observed among participants who switched from the

Heavy warning to the Light warning, though there is no direct evidence to support this interpretation.

ACWS STATUS DISPLAYS EXPERIMENT

This experiment focused on investigating whether people were able to identify and comprehends status displays for ACWS systems. The systems investigated in this experiment were LDW, FCW, blind spot warning (BSW), and adaptive cruise control (ACC). The main goal was to assess whether individuals understood what systems were present or operational in a vehicle and whether prior exposure to that vehicle's operational manual (or another vehicle's manual) affected that knowledge. Participants were presented with high-resolution images of a vehicle's interior, and then asked about system presence, operational status, and control button locations. The vehicle interior also was presented in several states of operation (e.g., pre-drive). Additional details are in Robinson et al., 2011.

Method

Participants viewed high-resolution images of a vehicle interior and answered questions regarding the presence or status of various vehicle safety systems. Data were collected regarding the following variables:

- *Comprehension* was defined as a correct response to a question about system presence or status.
- *Decision time* was defined as the amount of time (in seconds) taken by a participant to answer a question about system presence or status.
- *Confidence* was a participant's subjective rating (on a scale of 1 to 10) of their confidence that their response to a question about system presence or status was correct.
- *Location* was the position within the image of the vehicle interior that a participant indicated he or she sought the information that was used to determine whether a particular system was present or to determine its status.

The experiment was a fully crossed three-factor experimental design, with the following factors:

- *Vehicle (between-subjects)*: Each participant viewed the interior of one of three vehicles: 2010 Infiniti FX 35, 2010 Buick Lucerne, or 2010 Volvo S80. These vehicles were selected in part because they used different display strategies from each other (e.g., icons, text, acronyms). The vehicle models also ranged in number of safety systems.
- *Owner's manual familiarity (between-subjects)*: Prior to the experimental session, participants read sections of the owner's manual or related manufacturer-provided material for one of the three vehicles, or did not read any manual. This resulted in cases where the participant had familiarization (through the manual) with the vehicle they subsequently viewed in the experiment, cases where the participant had familiarization with a different vehicle than the one they saw in the experiment, and cases where the participant had no familiarization with any of the vehicles. Participants were not informed until they arrived for their sessions which vehicle interior they would experience.
- *Scenario (within-subjects)*: During the experimental session, data were collected in three phases, for which the images of the vehicle interior represented three situations: prior to starting the vehicle, after starting the vehicle (but before driving), and during driving. The state of the displays and the particular questions asked were appropriate to the particular scenario.

A total of 111 licensed drivers from the general population participated in the experiment. To ensure that participants had limited familiarity with the features of interest in this experiment, individuals were only selected to participate if they did *not* currently or recently drive a vehicle of model year 2006 or later, and if they did *not* currently or recently drive a Buick, Infiniti, or Volvo vehicle of any model year.

Participants viewed high-resolution photographs of vehicle interior displays shot from the driver's perspective. The monitors through which the photographs were displayed had a 30-inch diagonal display area and 2560x1600 pixel native resolution, which allowed near-full size projection of the images and good legibility of text and symbols. Participants used handheld touch pads to select answers to yes/no questions, to select ratings of confidence, and to indicate where in the interior of the vehicle they looked for particular features.

Up to three individuals participated per session. If participants were assigned to read vehicle instructional material before their session, they first completed a five-question multiple choice quiz to assess whether they read the assigned materials, and how well they remembered them. Each participant sat at a computer station facing away from other participants' screens. The experimenter then introduced participants to the experiment task and guided them through two practice trials.

The experimental trials were organized into seven blocks. Each block of trials was based on a particular image of the vehicle interior. The first block was for the scenario where the vehicle was turned off (prior to vehicle ignition). The next three blocks were for scenarios where the vehicle was started, but not yet moving. Each of these three photographs showed a different configuration in terms of what ACWS features and displays were on, off, or not functioning properly. The final three blocks were for scenarios where the vehicle was in motion. Again, each of the three photographs showed a different configuration in terms of what features and displays were activated.

There were a total of 40 questions across all seven blocks. The questions and answer options appeared on the participant's touch pad. For the pre-ignition scenario, all of the questions asked about the presence or absence of a particular system in the vehicle. The participant selected an answer ("present" or "not present"). Participants were asked to respond to each question as soon as they decided on an answer. The data collection system recorded the response time from the presentation of the question to the answer selection and confirmation. Once the answer was selected, the participant then rated their confidence that their selected answer was correct using a 10-point scale. Following that, the participant was asked "Where did you look for this information?" A photo of the vehicle interior was displayed on both the large monitor and the touch pad, and the participant used the stylus to point to the location on the touch pad. Figure 2 shows a participant viewing a vehicle display and responding on the touch pad.

Figure 2. Participant using stylus to indicate information location on touch pad.

Results

The primary dependent variables analyzed using mixed repeated measures ANOVAs in this study included accuracy of responses to questions, confidence in answers, and decision time. This section highlights some key findings of these analyses. Detailed results and statistical analyses are presented in Robinson et al. (2011).

Overall, individuals were not particularly accurate in assessing whether an ACWS was present (more than 40% of these responses were incorrect). This was consistent across all vehicles, systems, and whether or not the participant read a manual (same or different vehicle's manual). There was some variation by vehicle: Volvo and Infiniti participants were better at identifying system presence. Also, there was slightly better accuracy in identifying system presence (for some systems) when a participant read the appropriate manual, rather than no manual or another vehicle's manual. Mean percent correct responses across all questions as a function of vehicle and manual condition are shown in Figure 3.

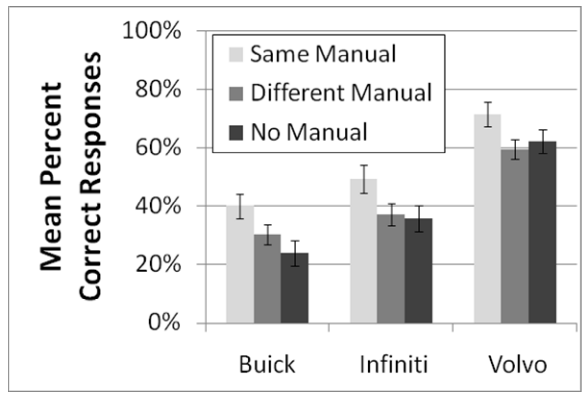

Figure 3. Mean percent correct responses for all systems (with standard error bars).

Individuals took considerably longer to respond to questions about system presence than system status across vehicles and manual conditions. Participants were always asked about system presence first, so much of this extra processing time may have been the result of the need to gain overall familiarization with the displays. Participants in the Infiniti condition took the longest to respond about system presence. Also, as expected, having the same vehicle's manual resulted in shorter decision times in all conditions.

As with system presence, participants were not particularly accurate when assessing system status (about 60% of responses were incorrect). In fact, participants were less accurate when determining system status than system presence. Participants in the Volvo condition displayed better comprehension of safety system status than those in the Buick and Infiniti conditions.

In addition to the low overall accuracy levels, participants also took a relatively long time to recognize the status of a safety system, even under static display conditions. Although participants were already familiar with the layout due to earlier trials asking about presence of a system, decision times were long (about 15 s for startup scenario and 11 s for en-route scenario, on average) when asked about system status regardless of vehicle or whether or not there was prior exposure to the vehicle's manual. Participants tended to be very confident in their responses despite a high rate of errors and long response times.

Participants were somewhat more accurate when asked about the presence or status of a system if they had prior exposure to that vehicle's manual. Having a manual led to improved accuracy, but even with a manual, overall comprehension, as indicated by accuracy, was still rather low. In particular, participants in the Volvo condition who were given the manual had significantly higher accuracy than the other two vehicle conditions. Familiarity with the vehicle's manual led to somewhat more accurate and faster responding in the pre-startup phase, but not other phases. There was no finding of a systematic trend toward either positive or negative transfer based on the manual that participants read.

Results indicate many participants who answered questions correctly did not select the correct location where they should have looked to determine the correct answer, which suggests that some participants who answered correctly may have done so by intuition or chance, may have recalled some information from a manual without being aware of location, or may have been led to the correct answer by an irrelevant cue. When participants selected the wrong location, it was often on the dashboard, which suggests that when in doubt, participants expected to find status information in this area. Conversely, some participants who answered incorrectly actually did look at the correct location to choose their answer, which suggests that these participants found the correct cue, but misinterpreted it.

Having a clearly labeled button (e.g., LDW or an LDW icon for all three vehicles) helped individuals identify the presence of a safety system. In contrast, not having a clearly labeled control button but rather a generic menu button can make system identification much more difficult (e.g., BSW in the Buick, which is discussed specifically in the fifth example case in the next section). In addition, using icons or full-word text instead of acronyms appeared to improve understanding substantially. Volvo and Buick both used icons for LDW systems, and as a result seemed to produce faster recognition of system presence than was observed in the Infiniti, which used acronyms. It should be acknowledged, however, that this experiment was not designed to formally address this.

Presenting system status information in full-word text form seems to be more effective in facilitating understanding than using color coded icons if the color coding is not intuitive to drivers. The Volvo vehicle used the most text to communicate information, and also had the highest overall understanding by participants. In contrast, the Infiniti relied on color coded icons, and showed the lowest performance, perhaps because the meanings of colors were in some cases ambiguous or counterintuitive to participants. In addition, the presence of text messages seemed to ameliorate the effects of not having a manual or having another vehicle's manual. The opposite was true for icon color codes.

The Infiniti's placement of control buttons in the lower left hand corner below the steering wheel may be problematic for participants to notice. Decision times were longer for the Infiniti in the pre-startup phase, indicating longer search and recognition times.

IMPLICATIONS FOR DESIGN CONVENTION

The FCW negative transfer experiment and the ACWS status display experiment were drastically different in approach, presentation medium, design, and analysis. Regardless, there was a common theme focusing on the implications for design convention in auditory alerts and visual displays of ACWS systems. The first experiment focused on auditory alerts and potential transfer effects from one alert to another. Similarly, the second experiment investigated understanding of visual displays and potential transfer effects. Design convention implications are discussed separately for each experiment.

FCW Negative Transfer Experiment

Transfer problem There is potentially a transfer problem with FCW auditory alerts as presented in the current experiment, but its dimensions and conditions are not clear. In one direction of shift (heavy to light warning), the slowing of the brake response was more than 700 ms, which is quite large. In the other direction (light to heavy warning), the response time did not change, whereas participants in both control conditions improved their reaction times to the already-familiar warning by about 130 ms.

Familiarity There was a large familiarity effect in the experiment. The brake response time reductions across successive sessions, from first exposure to the post-switch trial (for the control groups), were about 500-600 ms. Even from the session 2 pre-switch to the session 3 post-switch conditions, the difference was approximately 130 ms. This indicates that if people come to recognize a familiar sound from general experience, their responses are faster the next time the alert is presented. This also indicates a potential benefit of consistency of auditory alerts in ACWS.

Potential design convention benefits Participants experienced FCW alerts up to nine times over the course of a three day experiment, whereas in the course of actual on-road driving, these alerts are likely to be experienced much less frequently, which is likely to result in very different patterns of learning and familiarization. Under normal driving conditions, it may not be reasonable to assume that familiarization will occur quickly, so it is important to ensure that alerts lead to quick and proper responding regardless of prior experience.

Further research questions The transfer and familiarity effects suggest that some form of design convention could improve driver response time. The finding of a very large effect for only one transfer direction indicates that transfer effects may be highly dependent upon alert characteristics. For example, the asymmetry in transfer effects may be related to the similarity of the warning to other sounds that occur in the environment or perhaps to reactions to particular features of the alerts (e.g., spectral characteristics). However, this is an empirical issue that cannot be resolved with the current design and data. Several potential research questions are:

- What factors or components cause some auditory warnings to be more effective when there is a shift from the expected sound?
- What sound features could be used to maintain transfer (e.g., temporal pattern, primary frequency, tonal quality)?
- Would there be a better understanding of transfer effects and familiarity if individuals were recruited who actually drove one vehicle versus another?
- Would negative transfer effects occur in naturalistic circumstances (e.g., if the participants had become familiar with ACWS by driving an equipped vehicle over an extended period of time)?

ACWS Status Display Experiment

Overall comprehension There is the potential for a comprehension problem with vehicles containing unfamiliar ACWS systems, indicated by low comprehension rates and slow response times across all three vehicles used in the status display comprehension experiment. People unfamiliar with the systems had difficulty identifying system presence, operational status, and location.

Manual information Reading manufacturer-provided information was somewhat helpful, but the problems remained. Also, having read information about a *different* vehicle did not generally provide benefit. The limited improvement was vehicle-specific. It should be noted that the information read by participants, and the context in which it was read, were not typical of how individuals read owner's materials (if typically read at all), so the effects of manual information on ACWS comprehension should be interpreted with that caveat.

Potential design convention benefits Given the comprehension problems seen in this experiment, limiting the variability of some aspects of the vehicles' status displays may provide benefits. Potential areas for design convention are noted below:

- Use of standard terminology for particular warning functions, so that text or acronyms based on them are consistent.
- Use of standard icons and color coding for status. Color codes or icons should be congruent with drivers' mental models (e.g., green indicating activated or properly functioning systems).
- Status information should be located where people expect to see it. It is not clear to what extent this expectancy will be related to other aspects of the DVI, so location might have to be empirically determined/performance based for each vehicle, rather than there being a single preferred location for all vehicles.
- Effective quick-overview materials that convey what safety systems are in the vehicle, how status is indicated, and how they operate could help to enhance comprehension. Visual demonstrations might be appropriate and could be provided through web sites or other digital means. Because many drivers do not read owner's manuals, it might be beneficial to develop materials that are enticing or interesting to drivers, or to provide a demonstration or tutorial at the point of vehicle purchase. It may be reasonable to provide some criteria for such materials to help ensure system comprehension. Manual materials could be streamlined and presented in a way that is an easy reference (similar to the tabular format used in the drug industry).

DVI EVALUATION METHODOLOGY

Objective and Scope of the CWIM Application

In considering CWIM procedures, it is important to keep in mind the intended role of CWIM testing. The methods are intended to assess the DVI for a particular warning function in commercial or near-production systems. The intent is specifically to have a common method for evaluating the DVI of a commercial system.

Evaluating the DVI is not the same as quantifying or rating the performance of the safety system itself. The DVI is only one component of the system.

Therefore CWIM is not specifically concerned with how well a system addresses a crash situation, but more narrowly with how well the DVI conveys its status and the relevant crash-imminent information to the driver. How quickly and accurately does the driver perceive the threat and respond to the warning display, and does the interface elicit appropriate actions? The CWIM suggestions are focused on this goal.

Other issues related to scope include the following:

- Currently, CWIM is focused on the immediate driver response to warnings in potential crash situations. Not addressed are longer term influences on driver behavior and performance, such as automation complacency.
- Related to the concern above, the focus is also on the response to a particular warning function display, not on broader aspects of safety system performance. For example, driver response may be influenced by the frequency with which false alarms or nuisance alarms occur. This is important for assessing a system, but is not part of the DVI evaluation. Likewise, the effectiveness of a specific warning may depend on how well the particular function is integrated into the broader system of functions and information displays within the vehicle.
- The CWIM suggestions also must be tempered by practical considerations. It would not be feasible for a common evaluation procedure to experimentally manipulate all of the many factors that might interact with ACWS DVI performance (e.g., number of event scenarios included, roadway types, driver impairment, weather conditions, types of distraction). Some narrowing to a common set of conditions that will be practical for ACWS DVI assessment is required. Also, requirements in terms of unique facilities, costs, and practicality must be considered.

Specific Methodological Issues and Suggestions

Ten key factors were addressed in consideration of a testing protocol. For some of these, preliminary suggestions could be put forth. For others, resolution is not yet achieved and there is disagreement over potential approaches. Greater discussion of the issues and options related to each of these factors may be found in the project final report (Lerner et al., 2011). A brief presentation of the ten factors follows:

Driving scenario Two general aspects of the driving scenario must be kept consistent if common results are to be expected across testing sites. One is the general character of the roadway, such as the number and width of lanes, speed limits, presence of other traffic, type of setting (e.g., urban, rural), environmental conditions, and so forth. The other aspect is the dynamics of the potential crash event(s) under which driver response to the DVI will be evaluated. To some extent, the decisions about the driving scenario will be determined by whether a driving simulator or test track facility is used, since safety and practicality considerations limit what might be done on a test track. As a general principle, the general character of the roadway should not be more complex than is required by the event scenario. For LDW and FCW events, as with most other warning functions, there are a limited number of pre-crash scenarios that account for a large portion of crash outcomes (e.g., Najm, Smith, and Yanagisawa, 2007). Specific criteria for event scenarios are described in Lerner et al. (2011), but the general suggestion is to include a limited number of scenarios based on their prominence in crash statistics. Exceptions to this may be required on pragmatic grounds for test track procedures.

A related concern is the number of ACWS activations that research participants are exposed to. In naturalistic driving, ACWS activation is likely to occur very rarely, but in an experimental context it may be necessary to induce an artificially high number of activations, exposing participants to one or more activations over a relatively short period of driving. It is not clear how the absolute number of activations, or the rate of activations over time, influence participants' expectations, driving behavior, or reactions to warnings. There are, however, some principles of simulation study design that may mitigate the effects of an unrealistic ACWS activation frequency. Based on recent ACWS simulator research studies with relatively high rates of ACWS activation, Green (2008) provides five recommendations for maintaining validity: 1) use real world crash data as a basis for crash scenarios; 2) use a large number of potential crash scenarios; 3) include between three and five other vehicles in surrounding traffic that require the participant's attention; 4) use real on-road data to select crash parameters (e.g., closing rate); and 5) design scenarios to minimize the number of unusable trials (e.g., warning not issued or participant not sufficiently distracted).

Participants There are various alternative strategies as to how the sample of research participants should be composed. The approach favored here is that the participant sample be based on a relatively stable and homogeneous portion of the typical driving public. It specifically excludes special groups based on diminished capabilities or risky actions or populations defined by consumer attributes. This is most consistent with the goal of a common CWIM methodology, which is to compare DVI "A" with DVI "B" in a stable, repeatable manner. Additional criteria for participant selection are provided in Lerner et al. (2011).

Distracting the driver ACWS are intended to support the driver in recognizing emerging hazards. The primary purpose of systems such as LDW and FCW is to alert the driver who is distracted or otherwise unlikely to detect the event on their own. Evaluating the DVI for these systems therefore should include an appropriately distracted driver. The means of distracting the participant is a key part of any common CWIM methodology. In normal driving for most people, relatively long glances away from the road are quite rare and are difficult to predict. Therefore the experimental method must have some means of inducing appropriate visual distraction at known times. Distraction is a complex issue and there are many forms of distraction. The choice of a distraction task is currently an issue in research and standards efforts and is a matter of some contention. The CWIM project (Lerner et al., 2011) identified ten criteria for defining an ideal distraction task. In practice, there are tradeoffs and it may not be possible to optimize all of them.

Warning system context An ACWS functions within the context of the particular vehicle that it is designed to support. The warning occurs in the context of other safety functions, displays, and communications within the vehicle, and may occur as part of a progressive warning strategy or be related in some way to a parallel safety-relevant system (e.g., adaptive cruise control). Therefore the question arises as to how to deal with the warning system context. The purpose of the CWIM evaluation is not to quantify the effectiveness of the safety system in crash avoidance, but more specifically the ability of the DVI to convey the appropriate information and induce the appropriate driver response. Therefore a particular DVI may be evaluated on a stand-alone basis within the framework of a given vehicle and driving context, even if it may occur in a particular vehicle within the context of earlier informational messages or lower level alerts. Obviously, performance might be better if these related messages were present. However, the earlier alerts might not always be sufficient; if they were, the imminent crash warning would not be required. Therefore the CWIM protocol should test the worst-case situation where the driver has not taken account of other messages and is responding only to the imminent crash warning itself. If resources allow, it may be of interest to include within-context testing as well, but the primary context for evaluating the warning display should be a stand-alone presentation.

Familiarity with the technology Driver response to a warning depends to some degree on the driver's familiarity with the ACWS. At one extreme, a person may not realize the technology for a particular warning capability exists. Or, they may not realize that the particular function is present in the vehicle they are driving. Or, they may understand that it is present but have no idea what it looks, sounds, or feels like. They may or may not have familiarity with other commercial products that fulfill a similar function. At the other extreme, they may be highly experienced with the specific system present in the vehicle they are driving. The experiments described above on FCW negative transfer and status display comprehension suggested that familiarity may influence response time or accuracy. Therefore, the question arises as to what degree of familiarity with the technology participants should have under CWIM procedures. One perspective is that a totally naïve driver represents the "worst case" and therefore should be the basis for the evaluation. Another suggests that this is neither a representative nor fair basis for testing a particular DVI. According to this view, drivers may be assumed to at least be aware that a warning function is present in their vehicle; furthermore, they will only be totally naïve to the look, sound, or feel of the display once, and after that, all future driving will be done with some awareness of the system. Some types of ACWS warnings may be expected to occur with some frequency (e.g., lane departure or blind spot warnings) while others could be quite rare, so drivers may have less familiarity with the ACWS DVI in their own vehicles. While the most appropriate degree of system familiarization remains open to debate, and may depend upon specific research objectives or methods, our general suggestion is to provide a limited and controlled degree of pre-exposure, particularly if the study design includes repeated exposures to an ACWS. Ideally, a study might incorporate both naïve and familiarized participants. Further research investigating the effects of various familiarization schemes (including no-familiarization) may help to refine this recommendation.

Participant expectancy The nature of the participant's driving task and the expectancies engendered by the procedures are a critical concern. The intent is to impose the potential crash situation on drivers who are driving in their normal manner and are not anticipating the probable occurrence of an emergency event. The instructions defining the purpose of the experiment *from the participant's perspective* are critical. Participants should not have any indication that the researcher's interest is specifically with crash warning systems. Instructions to participants and associated materials should not promote this perception. As much as possible, the procedure should foster the feeling that drivers can simply behave in their normal manner. Lerner et al. (2011) describe a general procedure to meet these needs, based on the premise that participants believe they are going to experience a new prototype vehicle that includes a variety of innovative design features. This allows some familiarity with the ACWS alert without focusing participant attention specifically on crash warnings.

Accommodating user settings and options Manufacturers may design systems that allow the user to select or program various aspects of the system response, or systems that adapt to the characteristics or performance of the driver. Thus there may be user-controlled or dynamic variance in DVI characteristics such as display intensity, display type, triggering criteria, or timing of displays. If a display attribute is adjustable in some dimension, what setting should be used for CWIM testing? Should the procedure use the most conservative setting, the least conservative, a mid-point, a default setting, a setting selected by the research participant, or some combination of these? The recommendation here is to use the default or mid-point setting, because it carries the implication that this is the "normal" option and any deviation from this is the user's responsibility.

Comparison conditions If CWIM methods are meant to evaluate the effectiveness of a DVI, there is the question of "effective compared to what?" Is comparison made to a benchmark value, control condition, or "standard" interface? Is the evaluation to be taken in absolute or relative terms? Is the assessment quantitative or a pass/fail decision through comparison with some criterion? Our recommendation is that CWIM evaluations include a relevant control condition(s) and that pass/fail outcomes result from comparison to that condition. Ultimately, it would be most desirable to define some absolute performance levels for a particular dependent measure, based on a sufficiently large study to define this threshold empirically. However, this is not feasible until some standard metric is agreed upon, a threshold is established through adequately large empirical efforts, and the measure is shown to be highly reproducible across different evaluation sites. Until absolute metrics have been adequately demonstrated, the performance of a given DVI must be made on a relative basis, compared to a benchmark condition included in the same evaluation study. The suggestion here is that CWIM evaluations of a DVI include two benchmark conditions within the same study. One of the benchmarks is a "no warning" control condition. The other is a fully-specified "basic" DVI. These two benchmarks would define thresholds for three levels of performance: (a) no benefit; (b) basic effect (adequate); (c) superior. The comparison with the no warning control condition is desirable because poorly designed DVIs may have no appreciable beneficial effect and in some cases may even prove worse than no warning at all. Furthermore, the control condition may provide a confirmation of the appropriate urgency of the potential crash scenario and the distraction procedures. The comparison with a basic standard comparison DVI is useful because merely showing an improvement relative to a no-warning control condition is a very minimal basis for evaluating a DVI. If a simple and common type of warning is shown to have some beneficial effect, the CWIM procedure should determine whether a given DVI is similar to, worse than, or superior to this basic display. We suggest a comparison signal be drawn from major previous research (e.g., CAMP) or from a detailed survey of parameters in current warning signals in production vehicles. The "basic" DVI should be an exemplar of typical vehicle warnings, but should not be identifiable as uniquely the display of any specific manufacturer's product. An additional advantage of having these benchmark conditions is that it will permit "calibrating" comparisons across testing locations or testing times.

Treatment of data Lerner et al. (2011) recommended that common analytic methods not rely solely on comparisons of central tendency. Example data were provided to illustrate how differences may be more pronounced in the tails of response distributions, and these might be obscured with a focus on central tendency.

General test method Because CWIM requires a highly repeatable measurement system, this implies the use of either driving simulator or test track methods. Actual on-road driving with the ACWS may be valuable, but it does not provide the control needed for a formal assessment tool to compare DVIs. Both driving simulators and test tracks have advantages and limitations and both are potentially useful for CWIM testing. Simulators provide the flexibility to program a wide range of potential crash scenarios and environments without exposing participants to any real hazards. However, test track driving provides a real driving environment and does not require the use of advanced simulation facilities.

CONCLUSIONS

The five experiments described in this paper investigated human factors issues related to ACWS DVI warning mode, comprehension, and warning variability between vehicles. Each experiment used a different methodology, and the methodologies themselves were assessed to determine their appropriateness for future human factors research on ACWS DVIs, and to define the key issues and decisions that must be addressed.

The three studies on ACWS warning modes generally found that haptic and active warnings led to quicker and more appropriate responding than visual and auditory alerts, when participants were visually distracted. The simulator study on DVI variability found that participants' responses to a FCW warning are slowed when they switch from a familiar auditory warning to an unfamiliar auditory warning. The laboratory study on ACWS DVI comprehension found generally low comprehension of ACWS presence and status among naïve participants, and only a slight benefit when provided with some familiarization through owner's manual materials.

While each experiment was intended to provide findings that could stand on their own, some comparisons can be made between the various experiments' methods. On the whole, the study found that there was no one best method, but rather many options, each of which has advantages and limitations depending on the objectives of the research. When considering a CWIM test method that could be generally applied to investigate various ACWS DVIs, research methods must balance internal and external validity with considerations such as practicality, repeatability, and cost

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ASSESSMENT OF BEHAVIORAL ASPECTS IN INTEGRATED SAFETY SYSTEMS (EU FP7 project ASSESS)

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ABSTRACT

Integrated vehicle safety systems that combine elements from primary and secondary safety have a high potential to improve vehicle safety due to their ability to influence crash conditions and/or to adapt to these crash conditions. The value of pre-crash sensing systems that employ remote exterior sensors (in combination with on-board sensors) to detect dangerous situations and activate primary and secondary safety devices was clearly shown in projects like TRACE, APROSYS, eIMPACT and SAFETY TECHNOPRO. Joint R&D efforts (e.g. PReVENT, CHAMELEON, SAVE-U) have resulted in Pre-Crash Safety systems that are already on the market or close to market introduction.

In previous and current projects, the development of test and evaluation procedures was considered to be merely a secondary objective. So far, no procedures have been developed and implemented. Moreover, all the research into test procedures was based on research systems and not on commercially available systems.

Because of the above, a project specifically devoted to the development of assessment procedures is required to enable widespread introduction of integrated vehicle safety systems such as pre-crash sensing systems into the vehicle fleet. The main goal of the ASSESS project [1] is to develop harmonized and standardized assessment procedures and related tools for commercially available pre-crash sensing systems. Procedures will be developed for:

- Driver behavior evaluation
- Pre-crash system performance evaluation
- Crash performance evaluation
- Socio-economic assessment

This paper will present the activities related to the “driver behavior evaluation”. The objective is to provide a tool box for the specific evaluation of behavioral aspects of pre-crash systems and the contribution of the overall system performance.

The paper will include the complete test design: test scenarios, measurements, key performance indicators (objective/subjective data) and questionnaires. In addition, needs of behavioral aspects for “system performance evaluation” in test tracks will be discussed (e.g. driver reaction times).

The following aspects will be investigated and taken as a first approach towards assessment criteria:

- Driver reaction for intended system performance (especially for semi-autonomous systems)
- Validation of driver behavior regarding inadequate system reaction or possible side effects due to a FALSE trigger of the system

In order to carry out the experimental studies in driving simulators (6D moving based) and tests tracks with real vehicles and subjects, a common and harmonized test design, including the complete story book, will be presented. Possibilities and limitations of the methods will be also discussed.

This paper summarizes the results corresponding to the stability assistance domain of the European project ASSESS (Assessment of Integrated Vehicle Safety Systems for improved vehicle safety, FP7 – SST 2nd call, grant agreement no. 233942)

INTRODUCTION AND MOTIVATION

ASSESS mobilizes the European research community and car industry to develop a relevant set of test and assessment methods applicable to a wide range of Integrated Vehicle Safety Systems (IVSS). IVSS that combine elements from active and passive safety have a high potential to improve both the comfort and safety of vehicles and their occupants. Methods will be developed for driver behavioral aspects, pre-crash sensing performance and crash performance under conditions influenced by pre-crash driver and vehicle actions. The acquired expertise will be implemented in proposals for test and assessment procedures that will be evaluated on the basis of actual systems currently offered to the market. ASSESS aims to stimulate the introduction of new crucial technologies in vehicles to further reduce road fatalities and injuries to car occupants in Europe and to make the traffic environment safer for road users.

To realize the project goals while taking into account results from previous projects, a structure of seven work packages (WP) has been defined. WP1 deals with defining the test scenarios as well as developing the final overall assessment methods, WP2 with legal and socio-economic aspects, WP3-4 and 5 with the development of evaluation methods for driver behavior, pre-crash performance and crash performance respectively. Management and dissemination are performed in WP6 and 7. The diagram in Figure 1 shows the work packages, their output and interaction. It is important to note that driver behavior, pre-crash and crash feed each other sequentially in time with respect to relevant parameters (as in a real accident situation) but also have its own contribution to the overall assessment.

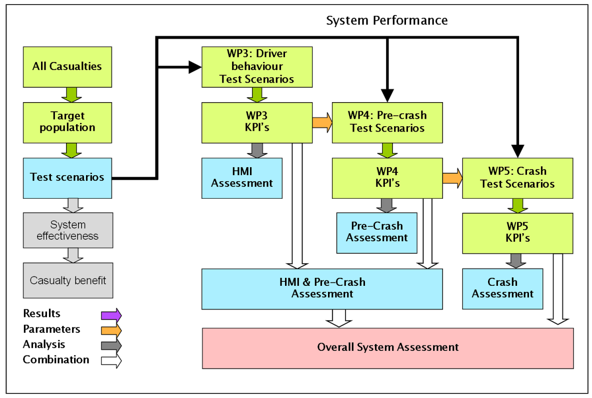


Figure 1. Structure of ASSESS project

The content of this paper focuses on the approach of WP3 "Driver Behavior Test Scenarios" as well as on its links to other work packages of the ASSESS project. The specific objective of WP3 is the development and evaluation of a test and assessment methodology to quantify and qualify the interaction of the driver with Integrated Vehicle Safety Systems in the context of the overall system assessment. On the basis of the accidentology [2], test scenarios for the HMI evaluation of IVSS are defined and implemented in test environments such as driving simulators and test tracks in order to perform experimental studies with volunteer drivers. The reaction of subjects to the HMI specification (e.g. acoustic forward collision warnings) is measured with the aid of "Key Performance Indicators" (KPIs). Those KPIs provide a basis for the HMI assessment as well as for the development of pre-crash test scenarios. In advance of the experimental studies, a so-called "story book" was defined as a general basis [3]. The story book describes the principles for setting up the experimental studies and thus should allow comparable studies for different and also for different kinds of test facilities.

METHODOLOGY

Story book as basic principle

The methodology describes the test setup and the test scenarios as well as the required output parameters and the data processing that is required to make an assessment of the system regarding human behavior. The following aspects were investigated and have been taken as a first approach towards assessment criteria:

- System performance - driver in the loop for full system performance
- Possible adverse effects on the task of driving due to a false system trigger

With respect to the assessment of the system performance, critical driving situations (known as TRUE maneuvers) must be implemented in the story book. To analyze the benefit of the HMI in such situations, the WP3 approach proposes comparing TRUE maneuvers with system performance (TRUEwith) to TRUE maneuvers without system performance (TRUEwithout). Based on the accidentology [4], “braking leading vehicle” and “cut in” maneuvers are suggested as TRUE maneuvers. For the assessment of a possible adverse effect due to false HMI activation (FALSE), the story book proposes to establish a relative comparison yardstick for the FALSE maneuver with a “reference event“, which is intended to represent a commonly occurring disturbance incident (REFERENCE) – such as “stone chipping” – during driving situations. Thus, the experimental design contains four maneuvers (TRUEwith, TRUEwithout, FALSE and REFERENCE) per test run and subject. To account for the expectation effects of the maneuvers, the sequence of the maneuvers is permuted within the experimental design. Table 1. shows the four permutations proposed by the story book.

Table 1.
Scenario permutations

sequence	maneuver 1	maneuver 2	maneuver 3	maneuver 4
A1	TRUEwith	FALSE	REFERENCE	TRUEwithout
A2	TRUEwith	REFERENCE	FALSE	TRUEwithout
B1	TRUEwithout	FALSE	REFERENCE	TRUEwith
B2	TRUEwithout	REFERENCE	FALSE	TRUEwith

A secondary task is implemented in the TRUE scenarios. This secondary task is intended to capture the attention of the driver in the event of the TRUE maneuver and to finally allow an evaluation of the effect of a warning or comparable system function in comparison with a TRUEwithout scenario, where no warning or function is triggered. The secondary task is intended to induce a visual time off road of more than one second. Therefore, an artificial mobile phone with a small display is implemented on the center console. The task of the subject is to read the number of an incoming phone call aloud. This secondary task is to be executed several times during normal driving and within the TRUE maneuvers.

To evaluate the quality of the driver reaction and thus the benefit of the system performance during the TRUE maneuvers, the “Brake Reaction Time” (BRT) and the “Time To Collision” (TTC) are selected as KPIs. For the assessment of possible side effects with respect to the FALSE and REFERENCE maneuvers, the analysis of the mental workload leads to the requested result. As a workload indicator, the statistical parameter “Steering Entropy” is used. The “Steering Entropy” analyzes the distribution of the difference between the real steering angle and a predicted steering angle calculated with the aim of obtaining a Taylor expansion. This was proposed by Nakayama et al. in 1999 [5] and effectively used by the INVENT Project [6]. With respect to the collection of subjective data, a set of standardized questionnaires – consisting of preliminary, interim and follow-up surveys – is developed [7]. The questionnaires cover data in terms of personal details of the subjects (e.g. age, gender, annual mileage), description and subjective assessment of each maneuver as well as an overall assessment of the experienced test run and system performance.

In order to ensure the statistical value of the experimental results, a homogeneous sample of 22 test subjects is defined for the scenario sets starting with TRUEwith (A1/A2) and the same sample size is defined for the scenario sets starting with TRUEwithout (B1/B2). In principle, the intention is to follow the described story book on all test facilities (simulator and track). The following text discusses the implementation of the experimental design on the one hand, but at the same time, concessions and compromises have to be considered due to facility limitations and, of particular importance, safety issues.

Experimental design of track test

In order to warranty sufficient safety and the repeatability of the test results, the IDIADA's dynamic platform A (Figure 2.) was selected to perform the tests. The main advantages of this track for tests are the fact that it covers a distance of 1.6 km in a straight line and an area of 2000 m², thus making the track long enough to conduct driver reaction tests safely.

Figure 2. IDIADA's dynamic platform A

The target vehicle used during the tests was IDIADA's propulsion vehicle carrying the ASSESSOR target. The ASSESSOR consisted of a full-size soft crash vehicle mounted on a rectangular frame (Figure 3.). The back of the propulsion vehicle system was covered with radar-absorbent material to make the vehicle invisible to radar sensors of the subject vehicle. The subject vehicle used for the experiment was equipped with a radar based IVSS, which warns the driver optically and acoustically at a TTC of approximately 2.6 sec.

Figure 3. ASSESSOR and propulsion system

The following measurement equipment (Figure 4.) was used during the experiment:

- High-precision differential GPS with vehicle-to-vehicle communication to measure the relative positions, speeds and "Time To Collision" between the vehicles.
- Brake pedal force sensor to detect the "Brake Reaktion Time"
- Microphone to detect the warning time
- Seatbelt sensor to detect pretension activation

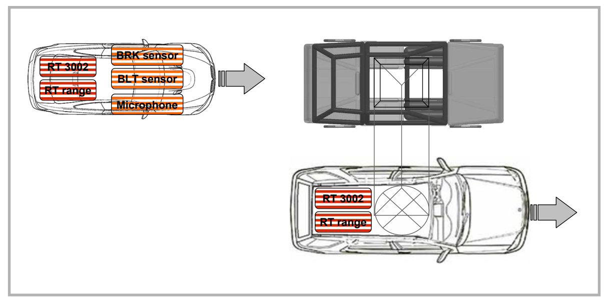


Figure 4. Measurement equipment

Two sequences from the story book (A1 and B2) were selected to perform driver reaction analysis. In contrast to the story book a total of just 16 subjects (22 are supposed) were selected for this test, out of which 10 achieved valid test runs. This limitation was due to the restricted availability of resources like the subject vehicle and to the complexity of implementing the complete story book in proving grounds. Subject selection was based on the following criteria:

- Age 25 - 50
- Annual mileage > 5,000 km/year
- Driving experience > 7 years

First of all, the driver was asked to drive at least one complete lap of IDIADA's general road to become familiar with the subject vehicle and the secondary task. When the driver was feeling comfortable enough, he was asked to enter the dynamic platform A. Once on the test track, the ASSESSOR and the propulsion system were briefly presented to the driver, and then the test sequence started. The maneuvers were performed as follows:

- TRUEwithout and TRUEwith: Both tests involved following the ASSESSOR, driving at 50 kph while maintaining a distance of 20 meters, and being distracted by the secondary task. After familiarization runs, the leading vehicle performed a 0.2 g deceleration, reducing its speed from 50 kph to 10 kph.

- REFERENCE The objective of this test was to measure the driver reaction to an unexpected noise, in that case “stone chipping”.

- FALSE: This test was used to measure the driver reaction in the event of a false warning by the pre-crash system. After a familiarization run, a corner reflector device was placed on the surface of the test zone to trigger a warning by the IVSS of the subject vehicle.

- After each test, the subject filled out the corresponding questionnaire.

Experimental design of simulator test

The experiments were conducted at the Toyota Driving Simulator located in the Toyota Motor Corporation Higashifuji Technical Center in Japan. The simulator uses an actual vehicle placed on a platform housed inside a dome with a diameter of 7.1 meters. A 360-degree view is projected on the inside wall of the dome, which is mounted on a 6-degrees-of-freedom motion base. The motion base is also able to move horizontally in a 35×20 meter range [8].

Figure 5. Toyota Driving Simulator

The driving route used in the simulator (Figure 6.) represented a virtual 2-lane rural highway surrounding a representation of the center of the existing Japanese city of Gotemba.

The standard Japanese driving rules are applicable.

- Maximum speed limit of 100 kph

- Drive on the left

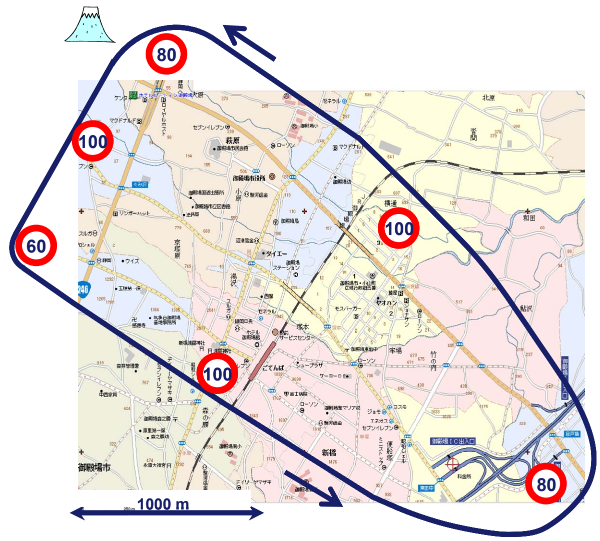


Figure 6. Overview of virtual test route

The critical event implemented for the TRUE scenario (Figure 7.) was “Leading Vehicle Decelerating”:

- The subject was instructed to follow a preceding vehicle at the normal driving speed (80-100 kph).

- The speed and distance of the leading vehicle were automatically controlled to adjust the headway time to approximately 2 seconds (headway time = relative distance/subject vehicle speed).

- The secondary task was triggered by the test operator (only on a straight section of track). This operation was repeated several times until the subject was considered to be accustomed to the secondary task.

- The deceleration of the leading vehicle was triggered by the test operator based on his judgment that the subject is distracted.

- The vehicle in front braked at a deceleration of 0.7 g until a complete stop.

- In the TRUEwith case, an artificial acoustic warning was issued around 3 seconds before a potential collision (in case of no driver reaction). In the TRUEwithout case, no warning was issued.

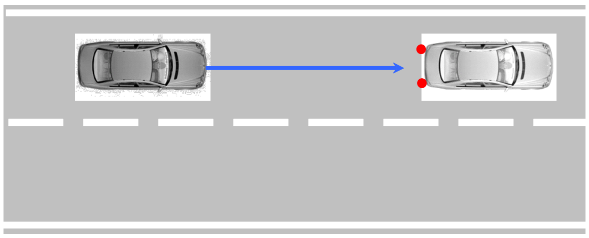


Figure 7. TRUE scenario

Figure 8. Secondary task display

FALSE and REFERENCE scenario (Figure 9. and 10.):

- The subject was instructed to overtake a truck or a bus traveling in the right-hand lane at a certain speed.

- The expected subject vehicle speed was equivalent to a velocity of approx. 100 kph and the bus/truck speed is 80 kph.

- 10 meters behind the bus/truck, a warning was issued in the FALSE scenario. An artificial "stone chipping" sound was played in the case of the REFERENCE scenario.

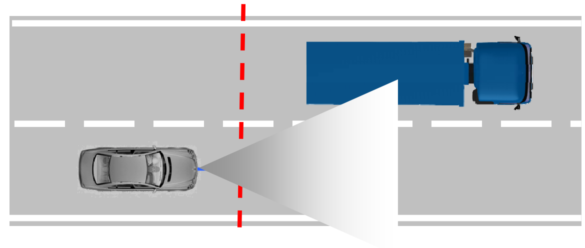


Figure 9. FALSE scenario

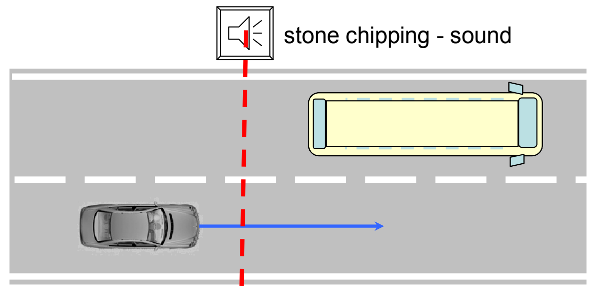


Figure 10. REFERENCE scenario

In total, 38 subjects without any previous experience with the Toyota driving simulator were selected for the experiments. The selection was made considering a balanced distribution in terms of age, gender and driving experience:

- 19 females and 19 males

- Age = [25, 71] y/o, average = 46 y/o

- Annual mileage = [120, 20000] = 9700 km

Some tests could not take place, were interrupted or incomplete due to inadequate setting of scenario or subject conditions.

Data obtained for TRUEwith vs. TRUEwithout analysis:

- 16 subjects started the experiments with a TRUEwith event (A1/A2 subjects)

- 18 subjects started the experiments with a TRUEwithout event (B1/B2 subjects)

- 15 subjects finished the experiments with a TRUEwithout event (A1/A2 subjects)

- 18 subjects finished the experiments with a TRUEwith event (B1/B2 subjects)

Data obtained for FALSE vs. REFERENCE analysis:

- 17 subjects experienced a FALSE event before a REFERENCE event (A1/B1 subjects)

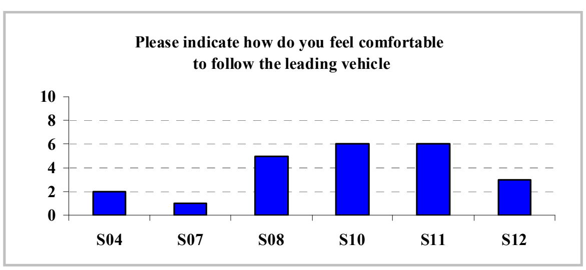
- 17 subjects experienced a REFERENCE event before a FALSE event (A2/B2 subjects)

RESULTS

This chapter describes the analysis of the gathered data. Within this paper the test track results are focused on the subjective data while the analysis of the driving simulator deals more with the objective data, particular with the KPIs. Thus the paper gives total overview of the evaluation of the complete data set as defined by the story book.

Results of track test

On the track, the intended experimental conditions are more difficult to control and to achieve compared to driving simulator conditions. Actually, driving at a speed of 50 kph while maintaining a distance of 20 meters from the vehicle in front is a difficult task to perform. The margins of variation are quite high, despite the previous learning phase. The longitudinal distance varies from 5 to 30 meters. Most of the drivers maintained a distance of between 15 and 25 meters at speeds varying from 40 to 53 kph. However, subjective evaluation shows that the task of following the vehicle in front is not perceived as difficult (Figure 11.).



very easy		easy		some		difficult		very difficult	
1	2	3	4	5	6	7	8	9	10

Figure 11. Subjective evaluation of the task of following the vehicle in front

Regarding the reliability of the collected data and the experimental conditions actually achieved, many subjects were rejected: Finally, only 2/10 valid drivers were analyzed in the TRUEwith condition and 7/10 valid drivers in the TRUEwithout condition (Table 2.). Considering the small number of valid drivers, it was not reasonable to compare the two conditions TRUEwith and TRUEwithout, nor was it possible to compare the two sequences (A1 vs. B2).

Table 2.
Summary of rejection of subjects

	TRUEwith	TRUEwithout
Valid drivers	n=2 (S04 and S08)	n= 7 (S04, S07, S09, S11, S12, S13, S16)
No data collected	n=2 (S10 and S15)	n=3 (S08, S10, S15)
No warning – driver brakes before the warning	n=3 (S09, S11, S13)	
Driver's braking and warning at the same time	n=3 (S07, S12, S16)	

The intended aim of the secondary task was to cause a visual distraction in order to create critical situations with regard to the decelerating vehicle in front. The visual requirement was not controllable, as the driver can choose the moment when he or she looks or doesn't look at the road. Observations show that some drivers carry out the secondary task quickly with one or two short glances, while others need more and longer glances. One methodological point to check was the effect of the secondary task on the driver's behavior after the familiarization phase. This effect was analyzed regarding the mental stress which was operationalized by the standard deviation of the "Steering Entropy" (SE - Std). Three sequences were used to evaluate the effect of the secondary task:

- A baseline sequence before the secondary task (Base_Std)

- A sequence during the secondary task, 1 sec. before the start and 5 sec. after the end (Event_Std)

- A sequence lasting 5 seconds immediately after the secondary task (Post_event_Std)

Regarding the collected data, 6 drivers were analyzed. The analyzed data covered two different laps by 4 drivers, and one lap each by the 2 other subjects. Considering the small number of subjects, it was only possible to perform qualitative and individual analyses (Figure 12.).

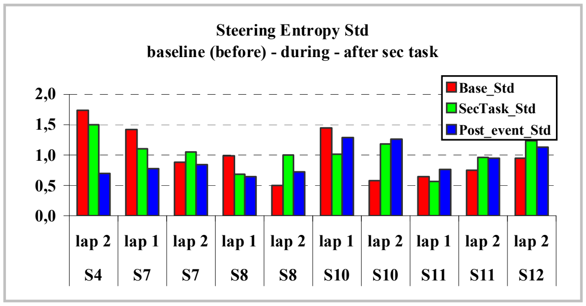
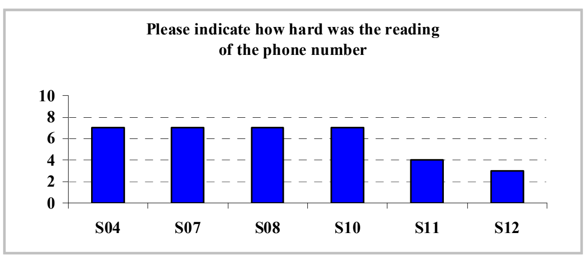


Figure 12. Effect of the secondary task on the "Steering Entropy"

The SE - Std increases with the secondary task for 2 drivers (S08 and S10) during lap 2. For the other drivers, the SE - Std decreases or is quite equal to thei individual baseline. It seems that the secondary task does not induce any additional mental stress. However, the questionnaires confirm the high requirement for S08 and S10, and show that 4 other drivers mention that the secondary task is difficult to achieve (Figure 13.).



very easy		easy		some		difficult		very difficult	
1	2	3	4	5	6	7	8	9	10

Figure 13. Subjective assessment of the secondary task

For the analysis of FALSE vs. REFERENCE maneuvers only the data of 6 drivers were reliable. In the FALSE situation, all drivers heard the tone and recognized it as a false warning (some drivers recalled the visual warning), some drivers had some expectations, because they saw an obstacle on the road (the corner reflector device). In the REFERENCE situation, all drivers heard the sound and did not recognize it as a "stone chipping" sound. Some drivers realized that the sound came from a laptop inside the vehicle. Figure 14. shows that the mental stress is higher with the false alarm compared with the "undefined sound" heard by the drivers.

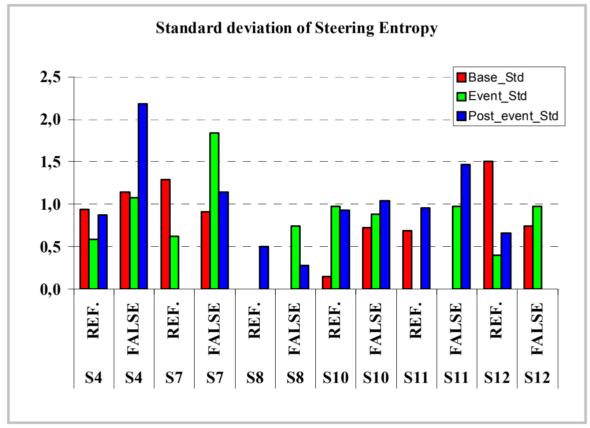
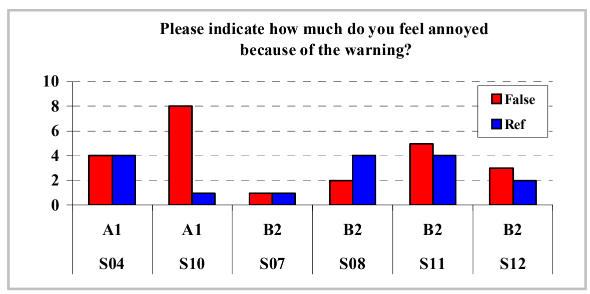


Figure 14. Comparison of mental stress in FALSE and REFERENCE conditions (SE - Std)

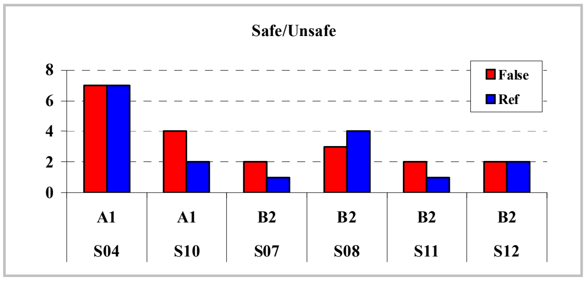
The subjective evaluation shows that the drivers were not annoyed by the false alarm because they expected it and were able to explain it, as they saw an object on the road that the IVSS might have detected by mistake, and there were no other vehicles around. A high level of annoyance was reported only once, and the driver involved (S10) reacted instinctively by decelerating (Figure 15.).



negligible		little		some		strong		very strong	
1	2	3	4	5	6	7	8	9	10

Figure 15. Subjective evaluation of annoyance

Only one driver felt unsafe when the false alarm occurred, because he was surprised by the false alarm and could not infer any reason (Figure 16.).



very safe		safe		some		unsafe		very unsafe	
1	2	3	4	5	6	7	8	9	10

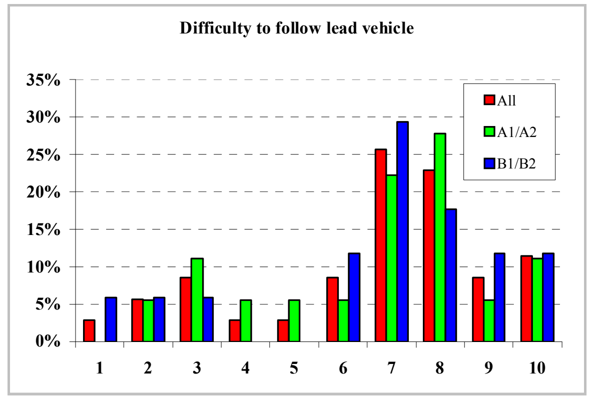
Figure 16. Subjective evaluation of feeling of safety

Results of simulator test

The results presented in this section focus on the evaluation of the proposed test design using a simulator as a tool to perform an analysis of the benefit of a pre-crash warning function. More particularly, the methodology is evaluated with regards to:

- Subject selection and validation
- Relevance of the secondary task
- Expectancy effects related to the 4th event
- Relevant KPIs to evaluate benefit of the warning function
- Finally, an attempt to specify the typical driver reaction has been made.

The advantage of driving simulator experiments compared to test track tests is that the initial conditions (speed, distance) are more controllable and should help to keep the test scenario critical. However, it was a challenge for most of the drivers to remain comfortable and drive in a natural way. Some variation in driving speed and headway time could be observed due to the difficulty that subjects had in performing the driving task as instructed (Figure 17.), resulting in different levels of imminence of a collision, represented by a higher ”Time To Collision” if no driver reaction had occurred (Figure 18.).



very easy		easy		some		difficult		very difficult	
1	2	3	4	5	6	7	8	9	10

Figure 17. Subjective assessment of the difficulty to follow lead vehicle in front

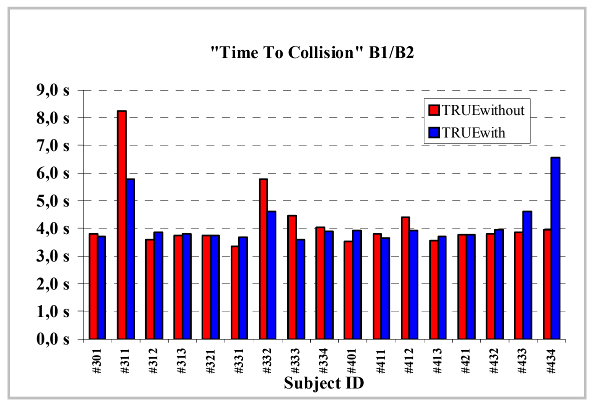


Figure 18. Remaining TTC when leading vehicle in front starts braking if no driver reaction has occurred

The remaining “Time To Collision” when the leading vehicle starts braking is not a boundary condition as such. However, the level of criticality of the event will depend on the combination of the imminence of the collision and of the duration of the visual distraction resulting from the secondary task. In other words, a longer duration before collision would require a longer visual distraction to ensure the event is critical enough.

As it is necessary to have a set of events which have been identified as critical enough to enable a relevant comparison between both conditions (with vs. without system), for the analysis of objective data, a preliminary filter has been applied excluding:

- Subjects who initiated a braking reaction before the start of the deceleration of the leading vehicle

- Subjects who aborted the secondary task before the leading vehicle started braking.

- Drivers who aborted the secondary task earlier than 4 seconds prior to an expected collision if no driver reaction had occurred.

As a remark, drivers who aborted the secondary task or applied the brakes after leading vehicle started braking but before a warning was issued (in the case of the TRUEwith event) were not necessarily excluded, to keep the same filtering conditions between the TRUEwith and TRUEwithout datasets. In addition, these drivers were slightly distracted and even though they could see the leading vehicle before the warning, they may not have immediately realized the criticality of the situation, and a warning function may be of help in that case to react faster or with stronger greater braking force. As a result, the data obtained are as follows:

- 15 subjects who started the experiments with a TRUEwith event (groups A1/A2) out of the initial sample of 20 subjects

- 17 subjects who started the experiments with a TRUEwithout event (groups B1/B2) out of the initial sample of 18 subjects

- 15 subjects who finished the experiments with a TRUEwithout event (groups A1/A2) out of the initial sample of 20 subjects

- 11 subjects who finished the experiments with a TRUEwith event (groups B1/B2) out of the initial sample of 18 subjects

The objective of the secondary task was to generate a visual distraction in order to achieve the situation where a collision is likely to occur. Aiming to control the visual distraction in a consistent and controllable way was a real challenge. It was observed that different attitudes were adopted by the subjects to perform the secondary task. One possible criterion to quantify the achieved level of visual distraction is the remaining duration before collision when the driver aborts the secondary task (end of last glance) (Figure 19.). Focusing on subjects who performed a TRUEwithout event at first (B1/B2 groups), an initial observation is that the secondary task resulted in a wide time range for ending the visual distraction. It can be observed that without the warning, around 65% of drivers aborted the visual distraction 2 to 3 seconds before the collision and around 29% between 1 to 2 seconds before the collision.

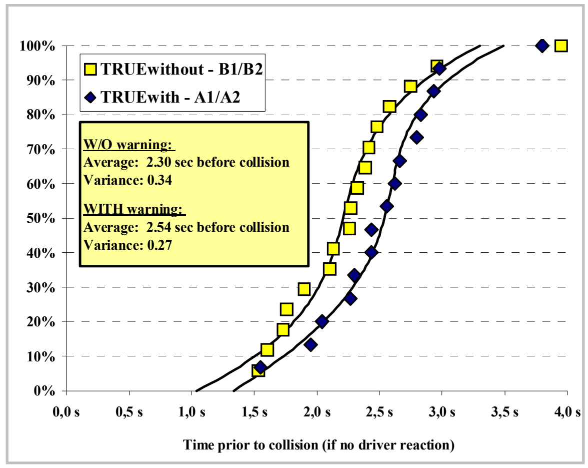


Figure 19. End of visual distraction in first events

All drivers aborted the visual distraction earlier than the last second before the collision. The duration of the visual distraction resulting from the secondary task and its robustness will be the main limitation to explore the benefit of a warning function. With a visual distraction which is aborted too early, it is likely that the situation would not be challenging enough to be able to observe a clear benefit from a warning function. In the experiments conducted here, by comparing TRUEwith and TRUEwithout subjects, some difference can be observed. However, from a statistical viewpoint, when performing an Anova analysis, this difference is not seen as significant, $F(1, 30) = 1.54$, $P < 0.2237$.

To investigate possible expectancy effects, TRUEwithout situations in 1st and 4th events were compared. During the first TRUE event, the subjects were not prepared to face a critical scenario. Drivers can be considered as “naïve drivers”.

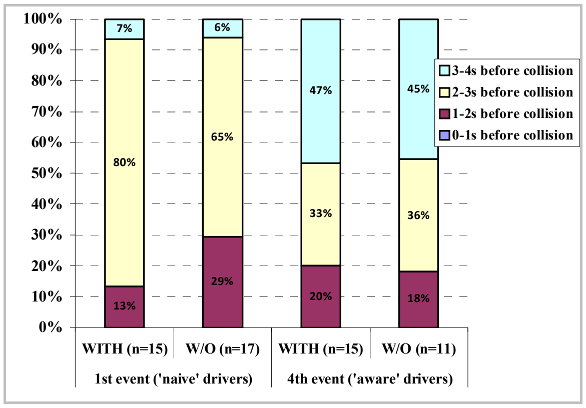


Figure 20. End of visual distraction – 1st vs. 4th events

In the fourth event, drivers have experienced a critical scenario a few minutes beforehand. They can be considered as "aware" drivers. It could be observed that they were prepared to face another critical event (Figure 20.):

- Indeed, a significant difference in the level of distraction can be observed between "naïve" and "aware" drivers. 45%-53% of "aware" drivers end the visual distraction earlier than 3 seconds before the estimated collision, while the figure was 6%-7% for normal drivers.

- As a result, a slight difference could be observed with the warning function in the case of "aware" drivers.

Due to the observed expectancy effects, the evaluation of the benefits of the warning is considered only for "naïve" drivers. Two KPIs were investigated related to brake timing:

- "Brake Reaction Time" from leading vehicle starts braking

- "Time To Collision" when driver applies the brakes

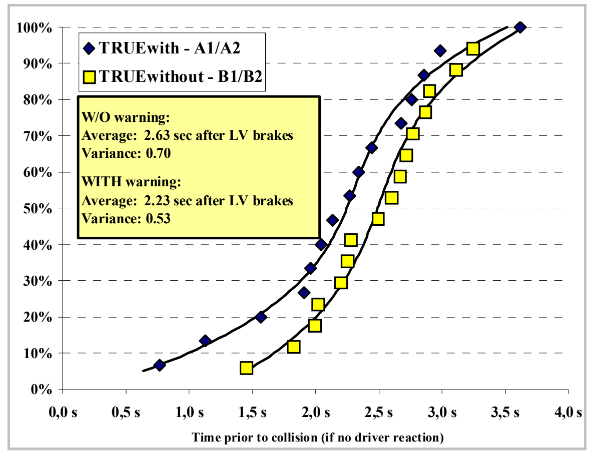


Figure 21. BRT from leading vehicle in front starts braking

The KPI "Brake Reaction Time" is relevant to highlight the difference in braking time of both conditions (TRUEwith vs. TRUEwithout). A benefit of the warning function can be observed here (Figure 21.), allowing earlier braking for subjects who experienced a warning. However, from a statistical viewpoint, when performing an Anova analysis, this difference is not seen as significant, $F(1, 30) = 2.03$, $P < 0.1641$. The main limitation of this indicator is that as such it is only applicable for the "leading vehicle braking" type of scenario. In the event of another type of scenario (e.g. "leading vehicle stopped" or "slower leading vehicle") another origin point will have to be redefined. Furthermore, this KPI remains valid as long as the initial conditions in the dataset remain in a reasonable range. Excessive variations of the initial conditions may make this KPI hard to use.

The well-known KPI "Time To Collision" (TTC) is defined by:

- TTC = relative distance/relative speed

However, in the particular case of the "leading vehicle braking" scenario, TTC is not linear with time and therefore will not be used, as the intention here is to understand the hypothetical time duration remaining before a collision would occur if the subject vehicle speed did not change.

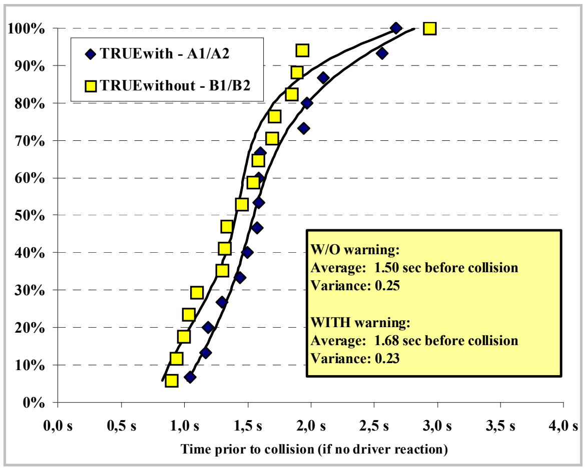


Figure 22. TTC at brake point

All drivers (with/without system) braked more than 1 second prior to the collision. With this KPI, a difference between both conditions can be observed (Figure 22.), showing earlier braking for subjects who experienced a warning. However, from a statistical viewpoint, when performing an Anova analysis, this difference is not seen as significant, $F(1, 30) = 1.09$, $P < 0.3051$. The advantage of this KPI is that it is independent of the test scenario. It can be applicable to any kind of pre-crash scenario (e.g. "leading vehicle stopped" or "slower leading vehicle").

Based on the obtained results, there was an attempt to define a "typical" and "generic" driver reaction model to be applied for further actual vehicle tests in FP7 ASSESS. Some parameters could be defined and summarized below.

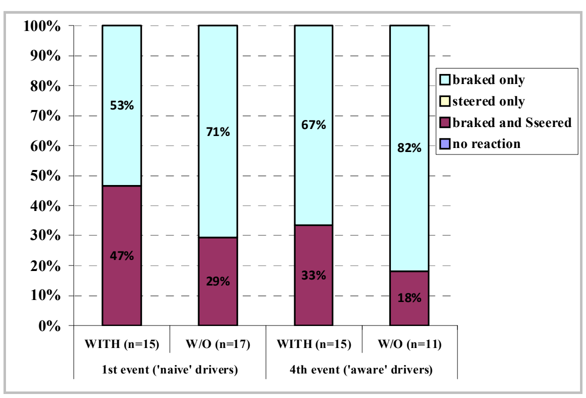


Figure 23. Driver's reaction to warning – type of avoidance maneuver

The type of avoidance maneuver was classified by whether the driver was only braking, making an attempt to avoid the vehicle in front by steering (confirmed visually from videos) or doing a combination of both braking and steering (Figure 23.). It was observed that in all cases, all drivers reacted by a single braking action or by a combination of braking and steering. No cases of "no reaction" were found. For those who reacted by a combination of braking and steering, it was observed that the brake was always applied before or at the same time than the steering action. However, it should be noted again that the performance of the secondary task plays a major role which can influence this result. When interpreted as a reaction to the warning function in TRUEwith cases, a model with respect to driver reaction time can be specified (Figure 24.):

- A fast reaction model would cover 25% of cases with a brake timing of 0.78 seconds after the warning is issued

- A low reaction model would cover the remaining 75% of cases with a brake timing of 1.81 seconds after the warning is issued

Considering the limitations mentioned in previous sections, it is important to note that this model is applicable for the given test scenario and the given secondary task. The result may differ in other situations.

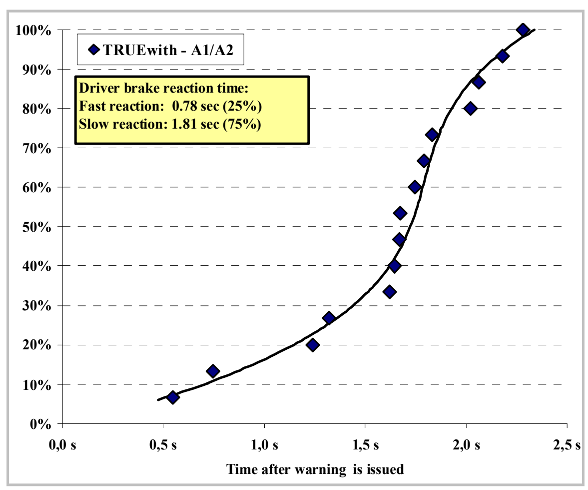


Figure 24. Brake reaction to warning

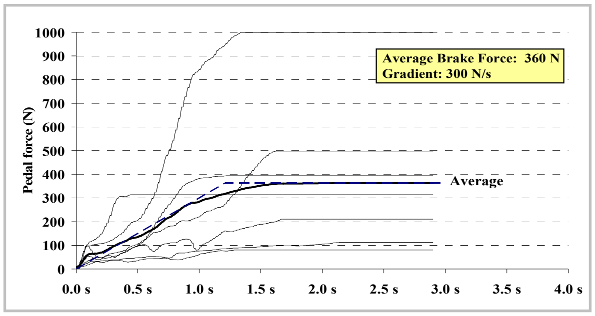


Figure 25. Braking profile as reaction to the warning (A1/A2 subjects who applied brakes only)

Focusing on the subjects who applied braking action exclusively (without any steering avoidance maneuver), the average braking profile has been estimated (Figure 25.):

- Brake force: 360 N
- Gradient: 300 N/sec

DISCUSSION

We have seen that to perform a relevant TRUEwith vs. TRUEwithout analysis, it is necessary to have a set of events which have been identified as critical enough to enable a relevant comparison between both conditions (with and without system). In that perspective, a test design in a driving simulator would be much easier to set up given the controllability of the initial conditions (speed and distance) compared to test track tests where a much higher rejection rate is expected. The test track is preferable considering testing with an actual car. However, a lot of limitations have to be taken into account (critical scenario, testing in a safe environment). The work done is promising but further work is necessary. The remaining question is "how critical should a TRUE event be?" An attempt has been made in the driving simulator experiments to define boundary conditions with respect to the criticality.

Apart from the scenario's initial conditions, the main parameter which will influence the criticality of the event is the "secondary task". Indeed, the visual distraction is expected to be dependent on the combination of the secondary task and of the scenario. A more demanding secondary task would lead to a higher proportion of distracted subjects, while a less demanding secondary task would lead to a smaller proportion. As a consequence, any observed benefit of a warning function will be highly dependent on the selected secondary task. The key question here is whether a given secondary task will induce a distraction which is representative of an "average" visual distraction in the real world.

The initial test design combined four maneuvers (TRUEwith, TRUEwithout, FALSE and REFERENCE) per test run and subject in different permutations. The intention was to optimize the number of subjects and to avoid any order or expectancy effects. Analysis of the results showed that for TRUE events, the level of expectancy is high in the 4th maneuver. After having experienced a critical scenario a few minutes beforehand, most of subjects were prepared to face another critical event, and a significant difference in driver reaction was observed. As a conclusion, such a test design combining more than one TRUE event is less appropriate.

Two KPIs ("Brake Reaction Time" and "Time To Collision") have been investigated regarding the evaluation of the IVSS's HMI benefit. Both are suitable to differentiate the effect of a warning function on the driver reaction by trend. However the differences were not significant for the conducted experiments. Some limitations regarding the application to different kind of maneuvers and regarding their interpretation have to be considered.

There was an attempt to define a "typical" and "generic" driver reaction model to be applied for further actual vehicle tests in FP7 ASSESS. It is important to note that the driver reaction model provided here is specific to one scenario ("leading vehicle braking" at 0.7 g) in combination with the secondary task used. Applicability to other test scenarios could not be verified and limitations considering the secondary task should be taken into account when further referring to this result.

Regarding the FALSE and REFERENCE scenarios, the qualitative analysis carried out for each subject indicates that subjective and objective indicators are complementary and relevant to evaluate the level of disturbance induced by the false alarm. But this result still needs to be confirmed with more subjects.

CONCLUSION

The story book for the assessment of driver behavior with respect to the benefit analysis of Integrated Vehicle Safety Systems, which was developed by WP3 within the ASSESS project, delivered the fundament for a purposeful experimental design. Its concept could be adapted to a test track and a driving simulator environment. A third experiment will be conducted at the Mercedes-Benz Driving Simulator in the same manner. In general, the transfer of the experimental design led to meaningful results. The effect of forward collision warning systems on driver behavior could be evaluated through the gathering and analysis of subjective and objective data. On the other hand also some limitations and open issues for further improvements were found. Measures will concern in particular the secondary task, avoidance of expectancy effects and the optimized adaption to the test track environment. To compile a draft protocol for the assessment of behavioral aspects as a final goal of WP3, the story book will be accordingly revised within WP3 and in agreement with the concerned WPs of the ASSESS project.

ACKNOWLEDGEMENT

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PERCEPTUAL RISK ESTIMATE (PRE): AN INDEX OF THE LONGITUDINAL RISK ESTIMATE

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ABSTRACT

Background: In order to help reduce rear-end collisions, a forward vehicle collision warning system has been developed and deployed. The effectiveness of the system largely depends on how early the warning can be given. However, we also need to consider that too early warning may cause a nuisance because the driver may not feel any avoidance maneuver is necessary at the timing. If the system can alert the driver by detecting the absence of braking at the normal timing based on his/her longitudinal risk estimate, the warning can be acceptable without nuisance. In order to achieve the goal, we aimed to develop an index of the driver's perceptual estimate of longitudinal risk. Method: First, we hypothesized that a driver judges when to brake based on two kinds of perception: kinematic perception to approach a lead vehicle and dynamic perception when the lead vehicle decelerates. Each perception was derived from previous studies of human perception. Then, an index of the longitudinal risk estimate reflecting these kinds of perception was proposed. The index is formulated as "perceptual relative velocity" divided by "perceptual distance." Both elements are corrected from their physical value so as to reflect their perceptual magnitude. The perceptual distance is the exponent of the distance between the subject vehicle and the lead vehicle. The perceptual relative velocity is the velocity difference of these two vehicles that is corrected by the subject vehicle's velocity and their relative acceleration. The hypothesis was tested on test track using two actual vehicles with the combination of various relative velocities and accelerations. Result: It was found that drivers' brake timings were well matched to the hypothesis; they braked when the proposed index reached a certain threshold. Thus, the index was confirmed to be able to measure driver's longitudinal risk estimate. We call the index Perceptual Risk Estimate (PRE). Since PRE can describe perceptual longitudinal risk, it is natural to consider that it also can predict the timing when a driver starts steering avoidance maneuver. The timing, i.e., the parameters of PRE, may be different from that of braking, though. We again tested with actual vehicles and found that PRE also matches to steering avoidance timing, and as we expected, the parameters were different from the ones for brakes. Finally, PRE was compared with other indices (TTC, THW, Risk Perception (RP), and KdB_c) and it was shown that the PRE is a comprehensive and enhanced model of those indices.

INTRODUCTION

Rear-end collisions are sometimes caused by human error such as distraction and inattention. In order to reduce those accidents, a forward vehicle collision warning system has been developed and deployed. The effectiveness of the system largely depends on how early the warning can be given; however, we also need to consider that a too early warning may cause a nuisance because the driver may not feel any avoidance maneuver is necessary at the timing. If the system can alert the driver by detecting the absence of braking at the normal timing based on his/her longitudinal risk feeling, the warning can be acceptable without nuisance. In order to achieve the goal, we aimed to develop an index of the driver's perceptual estimate of longitudinal risk.

First, we tested two major indices if they match to drivers' brake timing: 1. TTC (Time To Collision, i.e., relative distance divided by relative velocity) is the time to collision if the subject vehicle and the lead vehicle keep constant velocity. 2. KdB_c is an index for the approach and the proximity of the lead vehicle based on a driver's visual input on the retina [1].

As a result, a constant TTC did not match drivers' brake timing at low relative velocity; drivers' brake timing showed larger TTC. Also both the constant TTC and KdB_c estimated the risk lower than drivers' perception when the lead vehicle decelerated, thus they alert later than drivers' brake timing.

In this research, we hypothesized that a driver judges when to brake based on two kinds of perception: kinematic perception to approach a lead vehicle and dynamic perception when the lead vehicle decelerates.

KINEMATIC PERCEPTION

For the kinematic perception, it was hypothesized that a driver's brake timing was judged by Weber's Law. It states that the change in a stimulus that will be just noticeable is a constant ratio of the original stimulus. Applying the law to the situation of approaching a lead vehicle, we hypothesized the following relations:

(i) When the original relative distance is small, the subject vehicle's driver notices approaching a lead vehicle and brakes even if the relative distance becomes a little bit shorter.

(ii) On the other hand, when the original relative distance is large, the driver notices approaching the lead vehicle and brakes if the relative distance changes larger.

In these cases, the ratio of the changed distance to the original distance will be the same. This relationship can be formulated as follows:

$$\frac{\frac{\Delta D}{\Delta t}}{D} = \frac{Vr}{D} = const. \qquad (Eq.1)$$

Where,

D: Original relative distance [m]
ΔD: Distance changed in Δt [m]
Δt: Duration of time [s]
Vr: Relative velocity [m/s]

However, Eq. 1 is known as inverse TTC, and does not match the brake timing as mentioned earlier. It was hypothesized the reason of the discrepancy comes from perceptual errors in distance and relative velocity.

In the distance perception, the relation between actual distance (D_{real}) and perceived distance (D_{percep}) can be shown as Eq. 2 [2-3]. When the exponent n is not equal to 1, distance error becomes larger along with the actual distance.

$$D_{percep} = (D_{real})^n \qquad (Eq.2)$$

In the relative velocity perception, the lead vehicle's optic flow will be influenced by the subject vehicle velocity. It was hypothesized based on a previous study by Gray et al. [4] that the relative velocity is perceived higher when the subject vehicle velocity becomes higher.

$$Vr_{percep} = Vr_{real} + \alpha Vs_{real} \qquad (Eq.3)$$

Where,

Vr_{percep}: Perceived relative velocity [m/s]
Vr_{real}: Actual relative velocity [m/s]
Vs_{real}: Actual subject vehicle velocity [m/s]

Based on Eqs. 1-3, we hypothesized brake timing of kinematic perception as follows:

$$\frac{Vr + \alpha Vs}{D^n} = const. \qquad (Eq.4)$$

A driver is assumed to brake when the situation satisfies Eq. 4. In order to validate the hypothesis, we measured the brake timing of a driver in various combinations of subject vehicle velocity and relative velocity. An expert test driver was used for the experiment. He was asked to brake when he did not want to approach the lead vehicle anymore.

Figure 1 shows that the TTC and the relative distance when the test driver braked. Smaller distances and TTCs were found in the area of lower subject vehicle velocity (closer to the origin) and larger distances and TTCs in the area of higher velocity (away from the origin). From the figure, it was found that the driver did not brake at a constant TTC but the brake timing differs by the subject vehicle's velocity and the relative velocity.

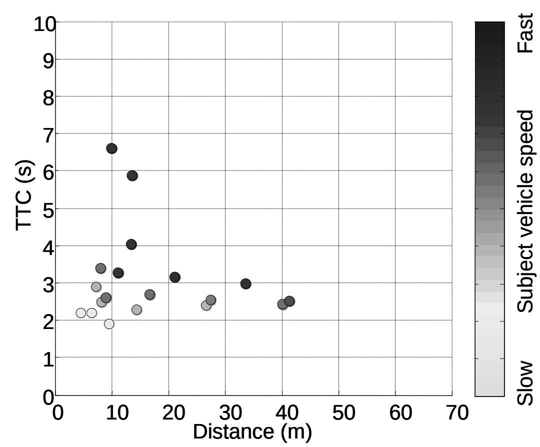

Figure 1. TTC - Distance graph of the brake timing

Figure 2 shows the brake timing in distance against the relative velocity. The brake timing dots were well matched to the line of Eq. 4 (bold dashed line for high velocity and bold dash-dotted line for low velocity). Here, the parameters of Eq. 4 (α, n, and the constant value of the right hand) were optimized to minimize the modeling error. The optimized parameter values were used for the following analyses.

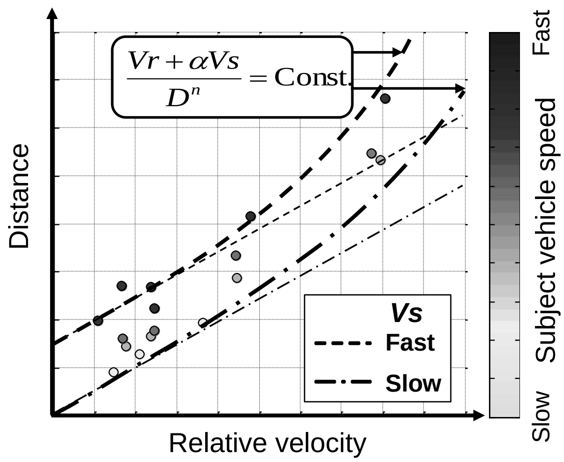

Figure 2. Distance - Relative velocity graph of the brake timing

The relation between the brake timing expressed in Eq. 4 and the relative distance is shown in Fig. 3. In the figure, the gray line shows the track during the test driving and the black dots show the brake timings. It was seen that brake timings were almost constant when they were expressed by the left-hand side of Eq. 4.

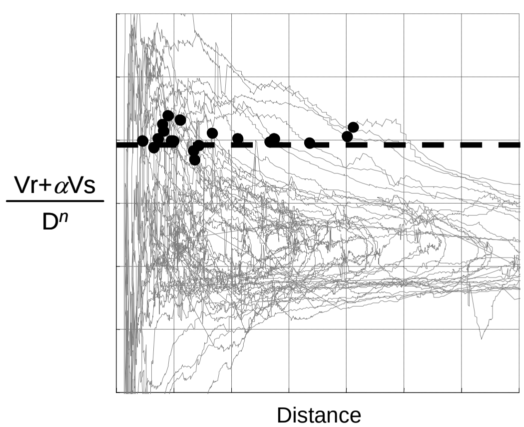

Figure 3. Brake timing corrected by the distance and subject vehicle's velocity

DYNAMIC PERCEPTION

In the previous section, we have analyzed the situation where both the subject vehicle and the lead vehicle traveled at constant velocities. When the lead vehicle decelerates, it can be assumed that the driver brakes earlier even if the subject vehicle's velocity and the relative velocity are the same.

Moreover, if there is a preceding car in front of the lead vehicle (two-car ahead of the subject vehicle) and the preceding car decelerates, the driver of the subject vehicle may press the brake earlier by foreseeing the lead vehicle's deceleration. We hypothesized from a previous study by Sasaki et al. [5] that such "foreseen" deceleration would affect the brake timing in addition to the lead vehicle's deceleration.

$$Vr_{Bon} = Vr_{percep} + RT\left(Ap_{real} + Af\right) \qquad Eq.5$$

Where,

Vr_{Bon}: Foreseen relative velocity when the driver pressed brake [m/s]
Vr_{percep}: Perceived relative velocity [m/s]
RT: Reaction time from releasing gas pedal to braking [s]
Ap_{real}: Deceleration of the lead vehicle [m/s^2]
Af: Foreseen deceleration of the lead vehicle [m/s^2]

We confirmed Eq. 5 by measuring the brake timing on a test track where drivers followed the lead vehicle that randomly and frequently decelerated and accelerated between 30 to 100 km/h.

Figure 4 shows the result. The horizontal axis shows the left-hand value of Eq. 5 and the vertical axis shows the foreseen relative velocity when the driver braked. Here, Vr_{Bon} was the relative velocity when the drivers braked, Vr_{percep} was the relative velocity when they released the gas pedal, and Ap_{real} was the deceleration of the lead vehicle at the timing. The outlined diamond plots show the brake timing if *Af*s are equal to zero, and the filled diamond plots show the brake timing where *Af*s were estimated to satisfy Eq. 5, thus the plots lie on the diagonal line by definition.

The average of the estimated *Af*s was rather small: 0.13 m/s^2 (SD = 0.22 m/s^2). This small value may be due to the experiment situation where there was no other car than the subject vehicle and the lead vehicle, and drivers knew the experiment setting (the lead vehicle frequently accelerated and decelerated). The effect of *Af* should be examined in the real traffic environment.

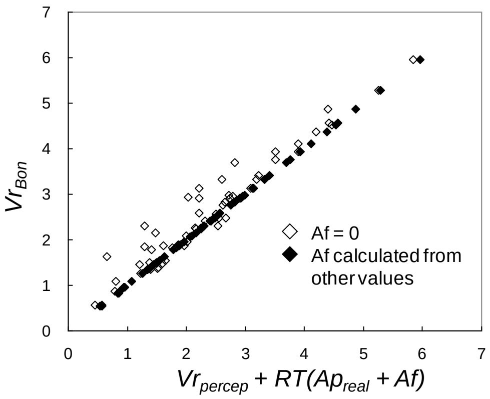

Figure 4. Test result to confirm Eq. 5

PERCEPTUAL RISK ESTIMATE

Based on Eqs. 1 to 5 in the previous sections, the following Eq. 6 can be derived to model the brake timing with both kinematic and dynamic perception:

$$\frac{Vr + \alpha Vs + RT\left(Ap + Af\right)}{D^n} = PRE \qquad Eq.6$$

We confirmed Eq. 6 on a test track with three drivers. It was found that the drivers' brake timings were well matched to the hypothesis; they braked when the ratio of the numerator and the denominator of Eq. 6 was at a certain value for various combinations of the subject vehicle's velocity, the relative velocity, and the lead vehicle deceleration (Figure 5). Thus, Eq. 6 was confirmed to be able to show drivers' brake timing.

We examine the meaning of Eq. 6. The numerator can be interpreted as "perceptual relative velocity" that includes foreseen lead vehicle movement. The denominator is interpreted as "perceptual distance," which is corrected from their physical value so as to reflect their perceptual magnitude. It can be thought that a driver brakes when the ratio of the perceptual relative velocity to the perceptual distance becomes a certain threshold. Therefore, the value of Eq. 6 can be thought of as the driver's longitudinal risk estimate. We call the value of Eq. 6 Perceptual Risk Estimate (PRE). It can also be thought that the inverse of Eq. 6 is perceptual TTC, where a driver brakes when the perceptual TTC reaches a certain value. The parameter values of Eq. 6 can be calculated by optimization of measured brake timings.

Since PRE can describe perceptual longitudinal risk, it is natural to consider that the index also can express the timing when a driver starts steering avoidance maneuver, although the timing, i.e., the parameters of PRE, may be different from those of braking. We again tested on the test track and found out that PRE can be used for predicting steering avoidance timing, and as we expected, the parameters were found different from the ones for brakes. The relationships among the parameters in Eq.6 between braking and steering avoidance are as follows:

$$\alpha_{brk} > \alpha_{steer}$$
$$RT_{brk} > RT_{steer}$$

Figure 6 shows an example of braking and steering avoidance timings in different subject vehicle's velocities.

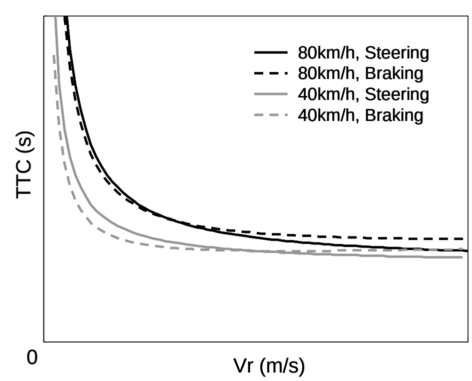

Figure 6. Relation between braking and steering avoidance timings of a driver at different subject vehicle's velocities.

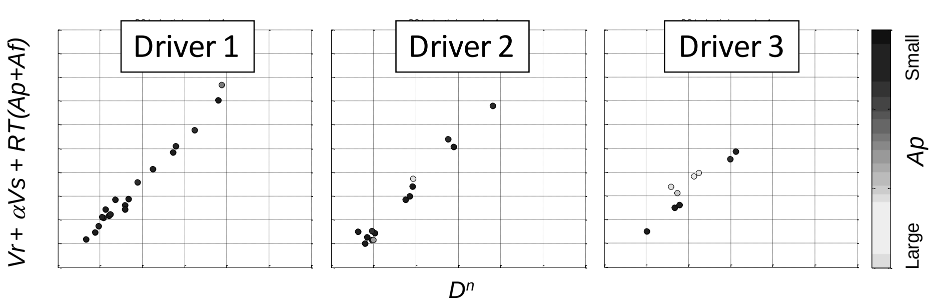

Fig. 5 Test result of three drivers' brake timing to confirm Eq. 6

DISCUSSION

There are some other indices of collision risk and brake timing proposed so far. We examined such indices as TTC, TTC with relative acceleration, THW, Risk Perception (RP) [6], and KdB_c, and clarified the relation of those indices towards PRE.

(1) TTC: The inverse TTC is formulated as Vr / D, which is the simplest form of PRE ($\alpha = 0$, $RT = 0$, $n = 1$). However, as mentioned in the introduction, the brake timing does not match a constant TTC in low relative velocity.

$$TTC = \frac{D}{Vr} = const. \rightarrow \frac{1}{TTC} = \frac{Vr}{D} = const. \qquad Eq.7$$

(2) TTC with relative acceleration: Considering relative acceleration, TTC can be shown as the upper formula of Eq. 8. The formula can be solved as the lower of Eq. 8, which can be interpreted as TTC adjusted by the relative acceleration. This is a form of PRE ($\alpha = 0$, $RT = \kappa$, $Ap + Af = Ar$, n = 1).

$$TTC = \frac{-Vr + \sqrt{Vr^2 + 2 \times D \times Ar}}{Ar} = const.$$
$$\rightarrow \frac{Vr + \kappa Ar}{D} = const. \qquad Eq.8$$

(3) THW (Time Headway): The inverse THW is formulated as Vs / D, which is a form of PRE ($\alpha = 1$, $n = 1$, $RT = 0$, no Vr). Because THW is constant if the subject vehicle's velocity is the same, THW does not match the brake timing in various relative velocities.

$$THW = \frac{D}{Vs} = const. \rightarrow \frac{1}{THW} = \frac{Vs}{D} = const. \qquad Eq.9$$

(4) RP (Risk Perception): Kondo et al. proposed Risk Perception that is the linear combination of TTC and THW. This index can be solved as a form of PRE ($\alpha = \lambda$, $n = 1$, $RT = 0$), i.e., TTC adjusted by the subject vehicle's velocity.

$$RF = \frac{a}{THW} + \frac{b}{TTC} = const. \rightarrow \frac{Vr + \lambda Vs}{D} = const. \qquad Eq.10$$

(5) KdB_c: KdB_c is shown as the right side of the first formula of Eq. 11. It seems complicated, however, it can be solved as a form of PRE ($\alpha = \mu$, $RT = 0$), which is interpreted as TTC adjusted by the subject vehicle velocity and powered distance.

$$KdB\_c(d) = 10 \times \log\left(\left|4 \times 10^7 \times \frac{Vr - dVp}{D^3}\right|\right) \mathrm{sgn}(-Vr + dVp)$$
$$= -22.66 \times \log_{10} D + 74.71$$
$$\rightarrow \frac{Vr + \mu Vs}{D^n} = const. \qquad Eq.11$$

From Eqs. 7 to 11, the exponent n and the constant values are different. The most important point is not the specific values of the parameter in each index but the common feature of the indices where longitudinal risk estimate can basically be expressed as the ratio of the relative velocity to the relative distance, adjusted by the subject vehicle's velocity, deceleration, and distance perception. Thus, we do not focus on showing concrete values of the parameters and the figure axes in this study.

Figure 7 shows the derived relation among the indices. As mentioned above, we found that the PRE is a comprehensive and enhanced model of those indices.

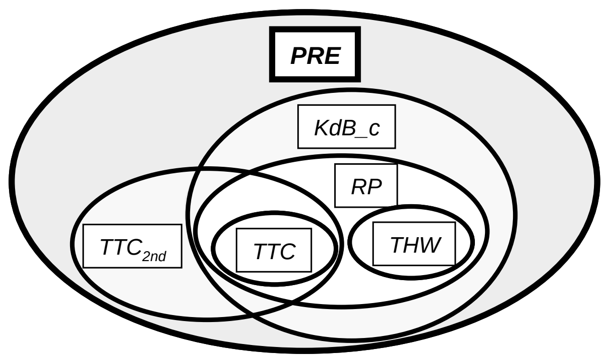

Figure 7. Relationship between PRE and other indices

CONCLUSION

In this research we developed an index of perceptual risk estimate (PRE) that estimated the brake timing: the drivers braked when the PRE reached a certain threshold. PRE also can predict the timing when a driver starts a steering avoidance maneuver, although the timing, i.e., the parameters of PRE, was different from those of braking. Finally, PRE was compared with other indices (TTC, THW, Risk Perception (RP), and KdB_c) and it was shown that the PRE is a comprehensive and enhanced model of those indices.

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

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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.

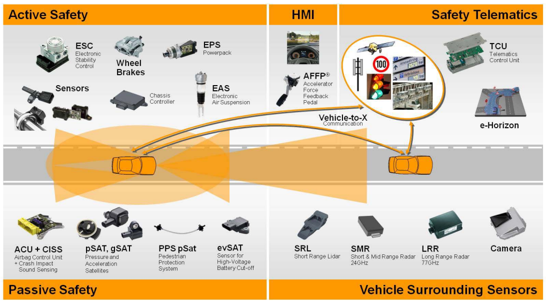

Figure 1. ContiGuard® - The Five Cornerstones & their Key Components

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.

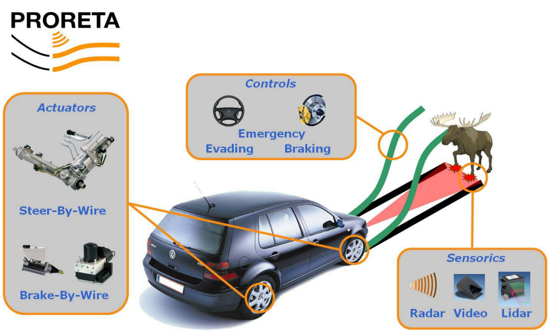

Figure 2. Overview PRORETA project

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.

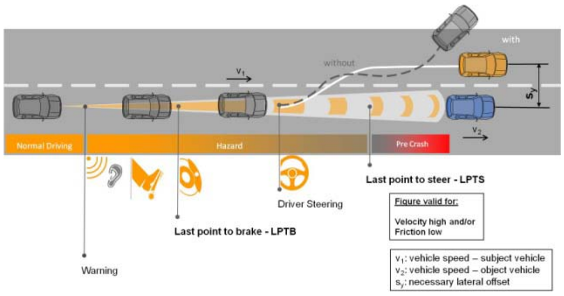

Figure 3. Collision avoidance by braking/ steering

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.

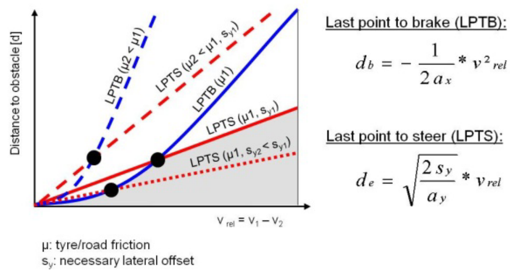

Figure 4. Necessary distances to avoid a collision by braking or steering

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.

<u>Effects of TTC:</u>

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.

<u>Effects of speed limit:</u>

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

<u>Methodology</u> 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.

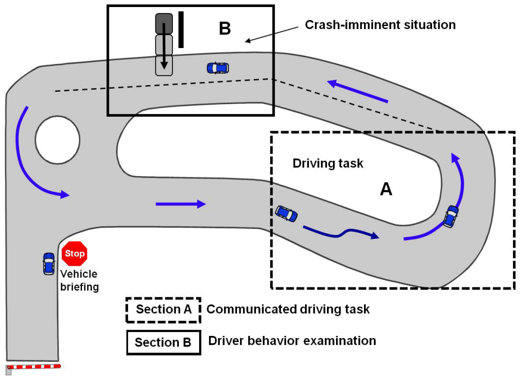

Figure 5. Map of the used test track

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.

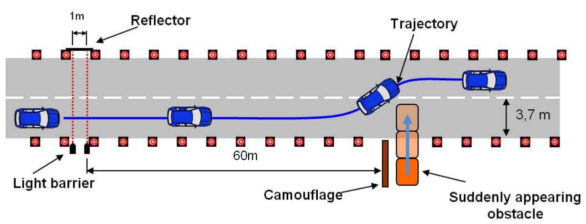

Figure 6. Two lane main road with incursion object from the right

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.

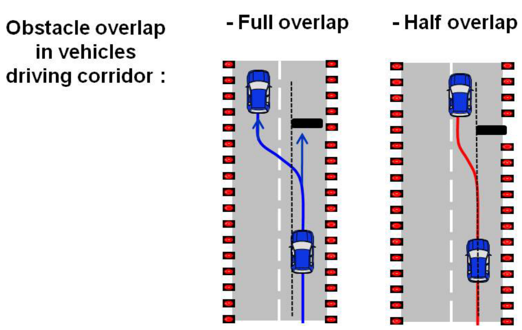

Figure 7. End position of obstacle after stop

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.

<u>Results</u> 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.

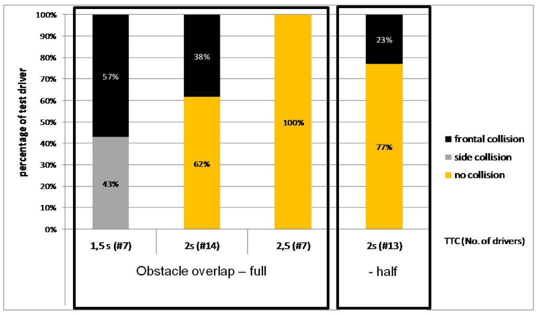

Fig. 8. Collision type evaluation

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.

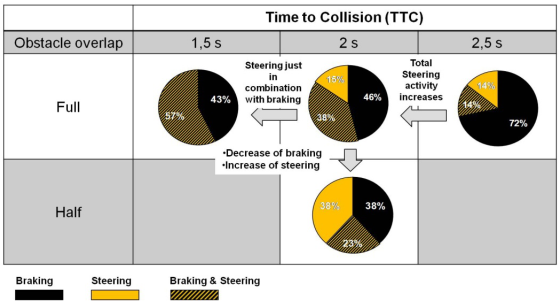

Fig. 9. Driver behavior evaluation

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.

Both examinations were consistent in the following results:

- 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).

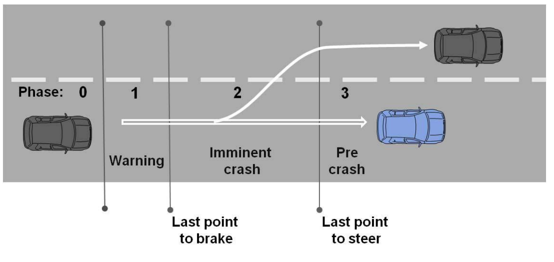

Fig. 10. Definition of the three fundamental hazard phases at high speed

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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THE DEVELOPMENT OF EQUIPMENT TO DETECT ALCOHOL IN THE HUMAN BODY

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Paper Number: 11-0441

ABSTRACT

This paper describes the development of equipment to detect alcohol in the human body. When drivers want to switch the engine on by the ignition-key, the equipment judges whether or not they have drunk alcohol. The theorem of the equipment to detect is based on the electrodermal activity. The comparison between the method and two kinds of equipment of breath alcohol detections on the market is performed. Their equipment has shown the higher level just after drinking alcohol, but they reveal lower levels when time has passed of drivers who were drunk. On the other hand, the method shows the same events of the values and questionnaires of volunteers.

INTRODUCTION

Many traffic accidents are a result of drinking and driving. In order to prevent accidents, much research has been performed such as interlock systems. The detector is applicable to measure breath alcohol concentration rapidly and easily. But they have some weak points and are troublesome for drivers to use. Furthermore, they are inaccurate to measure alcohol concentration. Because the breath with alcohol exhaled from alveolus is diluted throught the trachea. Therefore, some new detectors to measure accurately alcohol concentration are hoped to be developed.

BACKGROUND

There are many reports regarding traffic accidents caused by driving while intoxicated. In Japan, accidents by drivers who drink alcohol are decreasing. On the other hand, in the United States, there are much accident data reported by the government. There are many dangerous situations by drinking drivers even though accidents did not happen. It is said that when a serious accident occurs, there are 29 miner accidents waiting to happen by the Heinrich's Law. From economic cost for society is huge. It is hoped that new type of detectors are of an interlock system.

One of the authors has been studying the Electrodermal Activity (EDA) applied to detect driver's conditions such as drowsiness, fatigue and alcohol concentration included in basic researches [1]~[7]. There are two methods of electrodermal activity. One is the endosomatic recording and the other is exosomatic recording [8]. Here, the endosomatic recording is used.

Figure 1 and Figure 2 show the test results summarized comparison before drinking alcohol and after alcohol. Figure 1 shows the test results after drinking alcohol by the EDA, compared to ordinary conditions. Also it is verified to the usual digital detector of alcohol by respiration. Figure 2 reveals the test results performed under various conditions. As shown in the Figures, it is clear that differences between the condition after drinking alcohol and other conditions. Additionally, the fast Fourier's transform (FFT) carries out analyses of wave shapes for each condition. Each wave has characteristics corresponding each condition.

In order to detect alcohol concentration, breath alcohol concentration detectors are used in the actual market. Their measurements show a higher level just after drinking alcohol, but they reveal a lower level when time has passed though drivers were drunk. On the other hand, the method shows the same events of the values and questionnaires of volunteers.

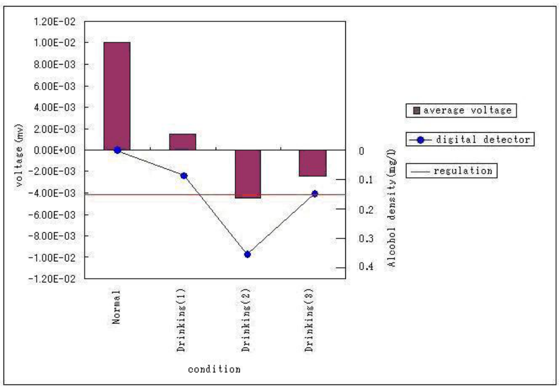

Figure 1 Test result after drinking alcohol by the Electrodermal Activity [7]

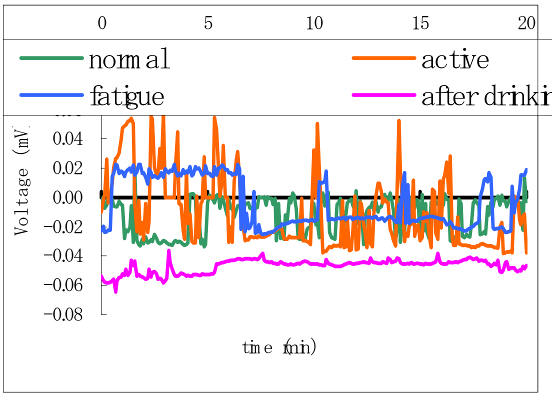

Figure 2 Test results performed under various conditions [2]

Figure 3 shows the relationship between the blood-alcohol content and the breath alcohol content [8]. The horizontal axis is the time (minute), the left vertical axis is the blood-alcohol content (mg/ml) and the right one is the breath-alcohol content (%).

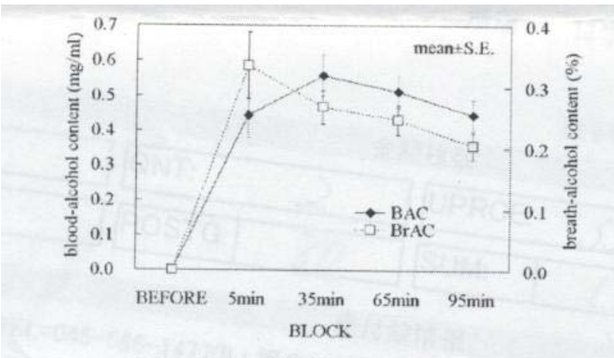

Figure 3 Relationship between the blood-alcohol content and the breath alcohol content [8]

As shown in the Figure 3, the higher level content just after drinking alcohol shows in the breath-alcohol but they reveal the lower level compared to the blood-alcohol content when time has passed.

Based on these tests, the sensor of detecting alcohol needs to develop reliable sensors as the interlock system.

METHLOGY

Human beings have many physiological characteristics such as brain waves, pulse rate, body temperature, and reveal facial expression, blink number and etc. Electrodermal Activity (EDA) is one of the physiological characteristics. And it is selected among them as the equipment to inspect drowsiness or fatigue. Researches by using it have been studying by many researchers. There are two methods of electrodermal activity. One is an endosomatic recording and the other is an exosomatic recording [9]. In this study the endosomatic recording is used.

1) Equipment

Figure 4 shows the system of the electrodermal activity. One sensor places on the left hand, and the other inserted on the ignition key sets on the ignition key and pinched with right fingers. The sensor of the electrode is made of the Ag-AgCl. They are connected to the USB with eight channels by harnesses and the USB connected to the PC.

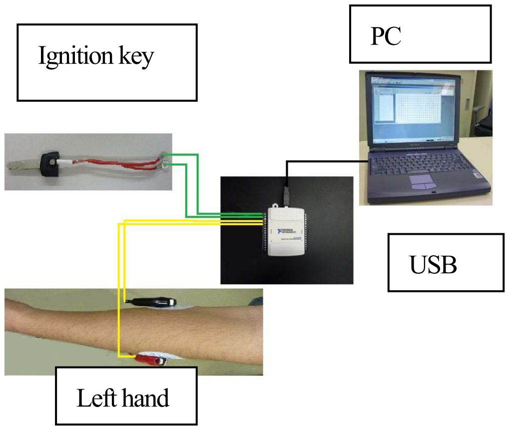

Figure 4 System of measurement of the EDA

Recently, the detector is applicable to measure the breath alcohol concentration rapidly and easily. In this study, two types of the breath alcohol detector are available for testing. The type A (CA2000) has the piece in the mouth and the type B (SOCIACX) is to breathe upon the piece.

2) Experimental Conditions

/ Measurement of a certain volunteer by using the EDA in a day and a week

/ After drinking alcohol, measurement of many volunteers by using the EDA, and the comparison between the EDA and the breath alcohol equipment

/Carrying out subjective questionnaires of intoxicated feelings to voluntaries

/Analysis of data

The contents of volunteers are shown in the Table 1.

Table 1 Contents of volunteers

	Age	Number
Male	20 to 34	10
Female	22 to 24	4

EXPERIMENTAL RESULTS

1) Basic measurement

As described above, tests were performed owing to take various basic parameters such as kinds of electrodes, the distances of each electrode, both hands set with electrodes and etc.

In this study, the fluctuation of EDA of a certain volunteer in a day and a week is measured. The Figure 5 shows the results of the fluctuation of the EDA in a day. The Figure 6 shows the results of fluctuation of it in a week. As shown in these figures, the EDA's values of common life are steady states. The horizontal and vertical axes show the time (hour) and the level of the EDA (mV).

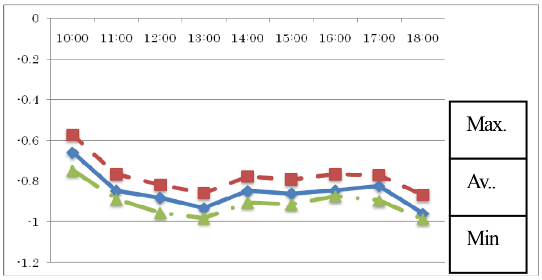

Figure 5 Fluctuation of EDA of a certain volunteer in a day (Maximum, minimum and average of waves)

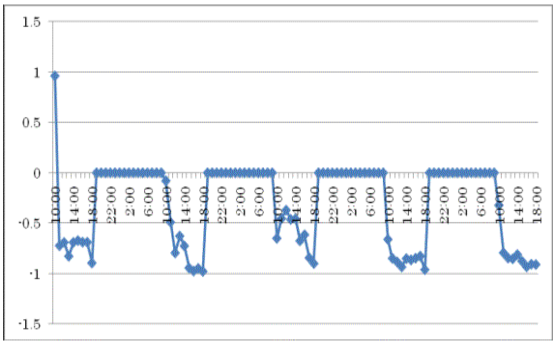

Figure 6 Fluctuation of EDA of a certain volunteer in a week (Average of waves)

2) EDA after drinking alcohol

Results of the EDA after drinking shows the Figure 7 compared with two breath alcohol concentration equipment. Just after drinking alcohol, the values of the EDA have the tendency of decrease from non-alcohol condition and slightly recovery when time has passed. On the other hand, the values of the breath alcohol concentration increase just after drinking and as time's passing though taking more drinking, the values decrease by using both breath alcohol equipment. The horizontal axis shows the number of the beer (350cc with 5 % alcohol per one bottle) and passing time (minute). The left vertical axis shows the alcohol concentration (mg/ml) and the right vertical axis does the absolute values of the EDA (mV).

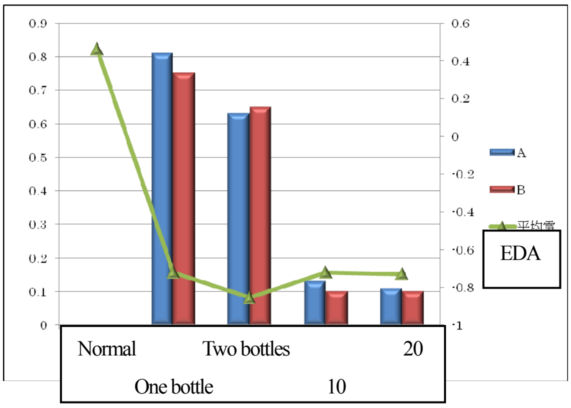

Figure 7 Results of the EDA and both breath alcohol equipment after drinking alcohol

The comparison between the data from inter-net with the breath alcohol concentration and two measurements of this time performs. Conditions such as drinking alcohol are as same as inter-net data. Figure 8 shows the results of comparisons of them. As shown in the Figure, two breath alcohol concentration equipment of this time reveal higher level just after drinking alcohol and show lower level as time passes. On the contrary, the data of the inter-net the level decrease gradually. The vertical axis indicates that the upper poison is the high concentration.

The value of the EDA indicates a constant level as the alcohol would remain in the body.

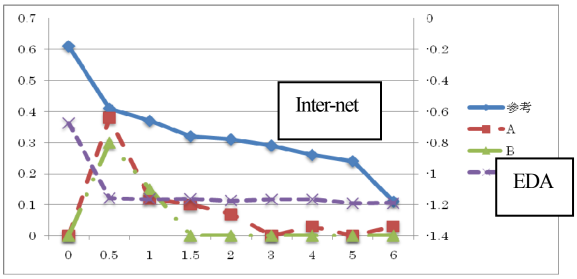

Figure 8 Comparison between the data from inter-net with the breath alcohol concentration

These measurements of the alcohol concentration show the deferent values among the equipment of the breath alcohol.

3) The relationship between the experimental data and the results of volunteer's statements

The comparison between data of EDA and questionnaires to volunteers performs according to contents shown in the Table 2, in which are subjective questionnaires of intoxicated feelings to voluntaries. Contents consist of three parts such as condition, content and score. The content is divided two parts. One is physical questionnaire and the other is feeling. The volunteers answer to questions. Also, the score makes up five levels.

Table 2 Questionnaire to volunteer

Condition	Content /Physical questionnaire /Feeling questionnaire	Score
Serious drunk	/Having nausea /Occurring to do nothing	5
Strong drunk	/Feeling dizzy in standing /Feeling disgust	4
Recognition of drunk	/High temperature /Drunk slightly	3
Slight drunk	/Becoming skin red /Feeling refreshing	2
Normal		1

The Figure 9 shows the relationship between experimental data and the results of volunteer's statements. The right vertical axis added in the Figure shows the score.

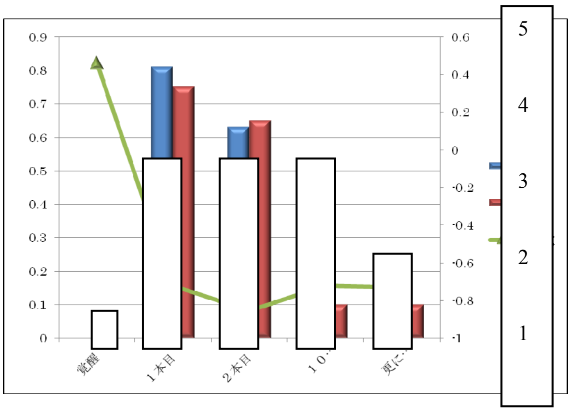

Figure 9 the relationship between experimental data and the results of volunteer's statements

Though the values taken by two alcohol equipment are lower levels as the time passes, the statements of the volunteer reveal the high score after drinking alcohol.

4) Data analysis

Many experimental tests are performed to volunteers as shown in the Table 1. Data show the various patterns according to the individualities in these tests. So data are needs to analyses and evaluate.

First, the First Fourier Transfer Analysis (FFT) and the minimum square method of EDA are studies. Here, the minimum square method is used.

Next, as the data reveals the difference of the individuality, the amplitude, length, and frequency of waves of EDA are evaluated.

(1) Absolute value of wave

The evaluation of data is made by the absolute value of waves as shown in the Figure 7. Also, The evaluation of data is made by the absolute value of waves as shown in the Figure 10.

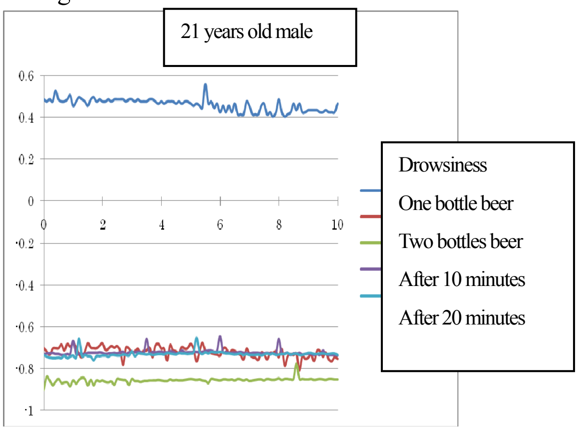

Figure 10 Evaluation of data is calculated by the absolute value of waves

Both measurement results show different values at the same conditions due to difference of individuals.

(2) Amplitude value of wave

The evaluation of data made by the amplitude value is shown in the Figure 11.

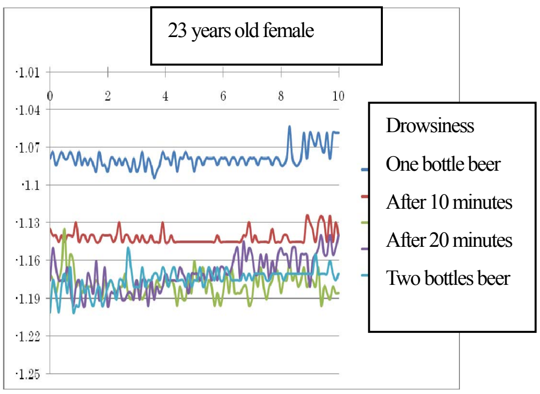

Figure 11 Evaluation of data is calculated by the amplitude value of wave

(3) The least squares method

There are many filters to analyses data. In this case, the least squares method is applicable to use. And the evaluations of data are calculated by the absolute or amplitude of waves as shown in the Figure 12.

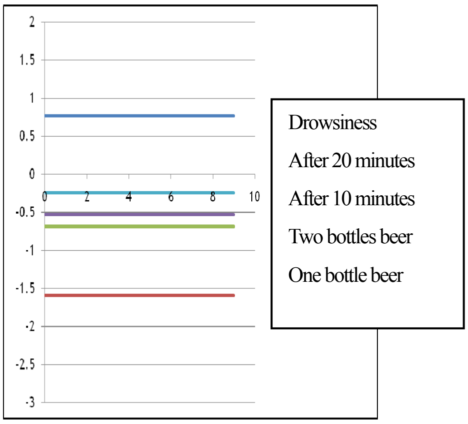

Figure 12 Evaluation of data is calculated by the amplitude value of wave after analyzing filter

CONSIDERATIONS AND CONCLUSIONS

Some results of our research are summarized as follows:

1) The values of the Electrodermal Activity (EDA) of human beings in daily life are consistent.
2) The values of the EDA measured on the both hands and on the ignition-key show the same.
3) Measurements of alcohol concentrations by using the breath testing equipment how a high level just after drinking alcohol, but show a lower level when the time has passed.
4) Measurements of alcohol concentrations by using the EDA show a constant level when time has passed.
5) Both measurements show different values at the same conditions due to difference of individuals.
6) According to the questionnaires of volunteers, the recordings of the breath alcohol become lower though they experienced drunken conditions. On the other hand, recordings by the EDA show the same drunken situations as the feelings of volunteers. The reasons are that the breath with alcohol exhaled from alveolus is being diluted though the trachea. These dilutions do not show the accurate values.
7) Though the recordings of the alcohol concentrations by the EDA depend on the difference of individuals, they can be solved by the computational post-treatments such as the Fast Fourier's transform (FFT).

It is possible to develop the detector of lock inter system by using the EDA. If the system can be developed, many drivers could be prevented from causing serious accidents.

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USING VEHICLE-BASED SENSORS OF DRIVER BEHAVIOR TO DETECT ALCOHOL IMPAIRMENT

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ABSTRACT

Despite persistent efforts at the local, state, and federal levels, alcohol-impaired crashes still contribute to approximately 30% of all traffic fatalities. Although enforcement and educational approaches have helped to reduce alcohol-impaired fatalities, other approaches will be required to further reduce alcohol-related fatalities. This paper describes an approach that detects alcohol impairment in real time using vehicle-based sensors to detect alcohol-related changes in drivers' behavior.

Data were collected on the National Advanced Driving Simulator from 108 volunteer drivers. Three age groups (21-34, 38-51, and 55-68 years of age) drove through representative situations on three types of roadways (urban, freeway, and rural) at three levels of blood alcohol content (0.00%, 0.05%, and 0.10% BAC).

Driver control input, vehicle state, driving context and driver state data, individually and in combination, reveal signatures of alcohol impairment. Algorithms built on these signatures detect drivers with BAC levels that are over the legal limit with an accuracy of approximately 80%, similar to the Standardized Field Sobriety Test (SFST) used by law enforcement. Each of the three algorithms combined information across time to predict impairment. The time required to detect impairment ranged from eight minutes, for complex algorithms (i.e., support vector machines and decision trees

applied to relatively demanding driving situations), to twenty-five minutes for simple algorithms (i.e., logistic regression). Timely impairment detection depends critically on the driving context: variables specific to the particular driving situation result in much more timely impairment detection than generic variables.

INTRODUCTION

Despite persistent efforts at the local, state, and federal levels, alcohol-impaired driving crashes still contribute to approximately 30% of all traffic fatalities. The proportion of fatally injured drivers with blood alcohol concentrations (BAC) greater than or equal to 0.08% has remained at 31-32% for the past ten years [1]. Although enforcement and educational approaches have helped to reduce alcohol-impaired fatalities, other approaches merit investigation. One such approach concerns countermeasures that capitalize on the increasingly sophisticated sensor and computational platform that is available on many production vehicles. Such vehicle-based countermeasures have the potential to address alcohol-impaired driving and save thousands of lives each year.

Vehicle-based countermeasures use sensors that describe drivers' control inputs (e.g., steering wheel and brake pedal movement), vehicle state (e.g., accelerometer and lane position), driving context (e.g., speed zone information and proximity of surrounding vehicles), and driver state (e.g., eye movements and posture). Data from these sensors can be transformed, combined, and processed with a variety of algorithms to develop a detailed description of the driver's response to the roadway. These sensors and algorithms hold promise for identifying a range of driver impairments, including distraction, drowsiness, and even age-related cognitive decline. Alcohol represents a particularly important impairment that might be detected by vehicle-based sensors and algorithms.

This paper describes the development and evaluation of algorithms to detect the behavioral signature of alcohol. Such an algorithm is a central element of any vehicle-based countermeasure for alcohol-related crashes. Algorithm development depends on collecting data from impaired and unimpaired drivers. This research used data collected from three age groups of drivers (21-34, 38-51, and 55-68 years of age) driving through representative situations on three types of roadways (urban, freeway, and rural) at three levels of alcohol concentration (0.00%, 0.05%, and 0.10% BAC). The high fidelity of the National Advanced Driving Simulator (NADS) makes these data unique. Drivers' control inputs, vehicle state, driving context, and driver state were captured in representative driving situations, with precise control and in great detail. This report describes how, individually and in combination, these data reveal signatures of alcohol impairment, and how well algorithms built on these signatures detect drivers with BAC levels that are over the legal limit of 0.08%.

The overall objectives were to:

- Identify signatures of impairment and develop algorithms to detect alcohol-related impairment
- Compare robustness of metrics and algorithms

METHOD

Participants

Data were collected from 108 volunteer drivers from three age groups (21-34, 38-51, and 55-68 years of age) driving through representative situations on three types of roadways (urban, freeway, and rural) at three levels of blood alcohol content (0.00%, 0.05%, and 0.10% BAC). Table 1 summarizes participant characteristics.

To be eligible, participants were required to:
- Possess a valid US driver's license
- Have been licensed driver for two or more years
- Drive at least 10,000 miles per year
- Have no restrictions on driver's license except for vision
- To not have been taking illegal drugs or drugs that interacted with alcohol
- Not require the use of any special equipment to drive.
- Have been a moderate to heavy drinker, but not a chronic alcohol abuser.

Table 1. Participant Characteristics

	Age 21-34		Age 38-51		Age 55-68	
Variable	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Number completed	18	18	18	18	18	18
Mean age (years)	26.6	26.8	43.2	44.7	59.6	61.1
Mean height (inches)	70.7	65.5	70.6	65.4	70.1	64.8
Mean weight (pounds)	199.8	159.6	220.6	175.3	211.9	172.9
Mean body mass index	27.9	26.1	31.1	28.6	30.2	29.0
Heavy Drinkers	89%	61%	78%	50%	67%	61%

Procedure

An initial telephone interview was conducted to determine eligibility for the study. Applicants were screened in terms of health history, current health status, and use of alcohol and other drugs. The Quantity-Frequency-Variability (QFV) scale [2] was used to determine whether applicants were moderate drinkers or heavy drinkers and the Audit survey [3, 4] was used to exclude chronic alcohol abusers. Pregnancy, disease, or evidence of substance abuse resulted in exclusion from the study. Participants taking prescription medications that interact with alcohol were also excluded from the study.

Each participant participated in four sessions, the last three separated by one week. Order of target BAC levels and scenario event sequence were counterbalanced. The time of day of each of the three sessions was the same for a given participant.

On study Visit 1 (screening), each participant informed consent was obtained. They then provided a urine sample for the drug screen and, for females, the pregnancy screen. During a five-minute period following these activities, the participant sat alone in the room where subsequent measurements of blood pressure, heart rate, height, and weight were made.

Cardiovascular measures were taken and compared to acceptable ranges (systolic blood pressure = 120 ± 30 mmHg, diastolic blood pressure = 80 ± 20 mmHg, heart rate = 70 ± 20) to assess eligibility for the study. If participants met study criteria, they were then administered a breath alcohol test and verbally administered the QFV and the Audit Survey to further confirm eligibility. Participants who were not moderate or heavy drinkers on the QFV were excluded. Additionally, participants who were classified with potentially dangerous drinking patterns on the Audit Survey were excluded.

If participants met study criteria, they completed demographic surveys. These surveys included questions related to crashes, moving violations, driver behavior, drinking, and driving history. Participants viewed an orientation and training presentation that provided an overview of the simulator cab and the secondary task they were asked to complete while driving.

The task consisted of the participant turning on the CD player and sequentially advancing the CD player to two tracks provided in an auditory cue and then turning off the CD player.

Participants then completed the practice drive and completed surveys after their drive about how they felt and about the realism of the simulator. The practice drive included making a left hand turn, driving on two- and four-lane roads, and changing CDs.

During Visits 2, 3, and 4 all participants completed a urine drug screen and, for females, a pregnancy screen to confirm eligibility for the study. Participants' blood pressure and heart rate were obtained to verify study eligibility. If participants met study criteria, they then received a breath alcohol test, the QFV, and the Audit Survey to further confirm eligibility. If eligible to continue, the time and duration of last sleep, and time and contents of last meal were recorded. Age, gender, height, weight, and drinking practice were used to calculate the alcohol dose.

Participants were served three equal-sized drinks at 10-minute intervals and were instructed to pace each drink evenly over the 10-minute period. NADS staff monitored the participants periodically throughout the drinking period to ensure an even pace of drinking.

On the days when participants were dosed to achieve 0.10% and 0.05% BAC, the amount of alcohol consumed was calculated to produce a peak BAC of 0.115% or a peak BAC of 0.065%. On the 0.00% peak BAC day, the drink consisted of one part water and 1.5 parts orange juice. Each of the glasses had its rim swabbed with vodka and 10 ml of vodka was floated to produce an initial taste and odor of alcohol.

Sixteen minutes after the end of the third drink, BAC measurements were taken at two- to five-minute intervals until the target BAC (± 0.005%) was reached. Peak BAC was expected 30 minutes after the end of the third drink. Table 2 summarizes the BAC levels.

Table 2. Summary of BAC levels for the two experimental conditions.

Test Time	**0.05% BAC (*N* = 108)**			**0.10% BAC (*N* = 108)**		
	M	***SD***	**Median**	***M***	***SD***	**Median**
Pre-drive	0.053	0.005	0.054	0.098	0.009	0.102
Post-drive	0.042	0.006	0.043	0.088	0.009	0.090
Mean	0.047	0.005	0.048	0.093	0.008	0.095

When the target BAC was reached, the participants drove in the NADS. All data were collected as the BAC declined to minimize extraneous variation associated with the effect of rising and falling BAC levels and to represent the most likely situation under which alcohol-impaired driving occurs. As soon as the simulator returned to the dock and the participant exited the simulator (within 5 minutes of completing the drive), a BAC measurement was obtained, followed by an SFST. The individuals conducting the SFST were trained according to NHTSA's guidelines. The Stanford Sleepiness scale was also administered before and after each drive.

Participants were not informed of their measured BACs until their participation in the study was completed. On all experimental days, the participants were transported home after their BAC dropped below 0.03%. At the end of Visit 4, participants were debriefed and paid $250. Pro-rated compensation was provided for participants who did not complete the study.

Apparatus

The National Advanced Driving Simulator (NADS), shown in Figure 1, made it possible to collect representative driving behavior data from intoxicated drivers in a safe and controlled manner. This is the highest fidelity simulator in the United States and allowed for precise characterization of driver response. Drivers' control inputs, vehicle state, driving context, and driver state were captured in representative driving situations (see Figure 2).

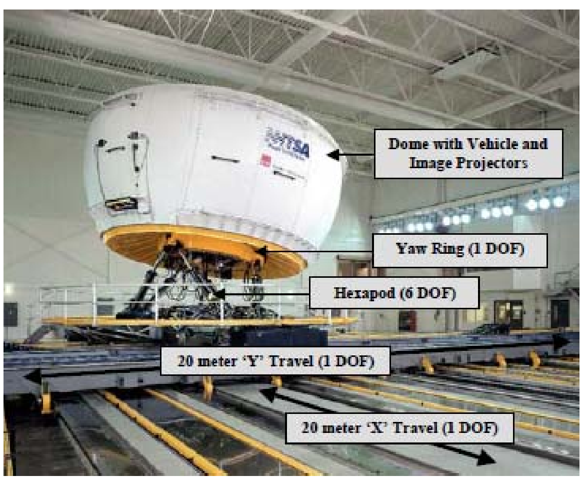

Figure 1. The NADS-1 high-fidelity driving simulator

Figure 2. An urban driving scene from the NADS-1 simulator.

Simulator Scenario

Each drive was composed of three nighttime driving segments. The drives started with an urban segment composed of a two-lane roadway through a city with posted speed limits of 25 to 45 mph with signal-controlled and uncontrolled intersections. (see Figure 3 and Figure 4) An interstate segment followed that consisted of a four-lane divided expressway with a posted speed limit of 70 mph. Following a period in which drivers followed the vehicle ahead, they encountered infrequent lane changes associated with the need to pass several slower-moving trucks (see Figure 5). The drives concluded with a rural segment composed of a two-lane undivided road with curves (see Figure 6 and Figure 7). A portion of the rural segment was gravel. These three segments mimicked a drive home from an urban bar to a rural home via an interstate. Events in each of the three segments combined to provide a representative trip home in which drivers encountered situations that might be encountered in a real drive.

Figure 3. Approach to curve in urban drive

Figure 4. Straight roadway segment in urban drive

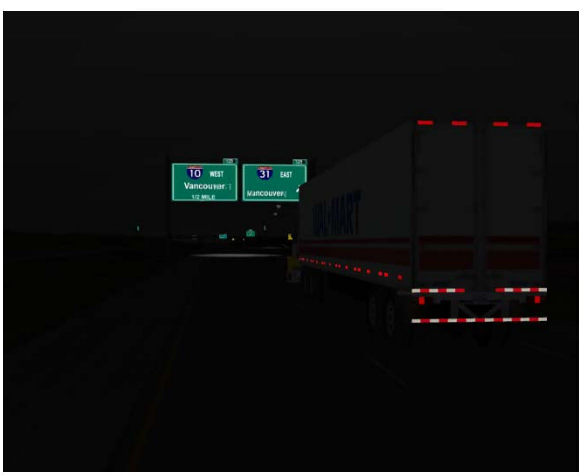

Figure 5. Passing truck on Interstate.

Figure 6. Approach to rural curve

Figure 7. Rural vertical curve.

RESULTS

Sensitivity of Scenarios to Alcohol

Analysis of common driving metrics demonstrates the sensitivity of the drive to alcohol impairment. As expected, lane position variation was particularly sensitive (see Figure 8) and speed variation (see Figure 9) was less so. Increasing BAC levels affected driving performance in an orderly manner—higher BAC levels led to a linear decrease in performance. Alcohol levels did not interact with age, gender, and roadway situation, which might have otherwise undermined the association of driving metrics and alcohol impairment.

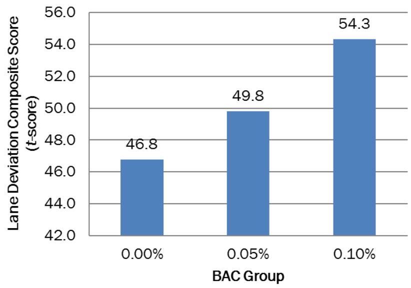

Figure 8. Lane deviation scores by BAC group

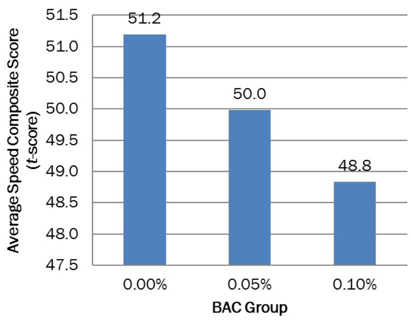

Figure 9. Average speed scores by BAC group.

Detecting Alcohol Impairment

The primary objectives for algorithm development and evaluation include:

- Develop algorithms to detect alcohol-related impairment based on behavioral signatures that vehicle-based sensors can measure
- Compare sensitivity, robustness, and timeliness of metrics and algorithms.

These objectives are addressed by describing the performance of a logistic regression algorithm that builds directly on an analysis of simple measures of driving performance—lane position variability, mean speed, and speed variability. To go beyond a linear combination of these three simple indicators of driver impairment, a decision tree algorithm was fit to individual events and to the urban, freeway, and rural segments to identify behavioral signatures of alcohol impairment. A support vector machine (SVM) was also developed for these road segments. These signatures provide a detailed description of alcohol impairment that supports more accurate detection than the three-variable logistic regression.

The objective of the following analyses was to determine whether it is possible to distinguish between drivers with BACs above 0.08% and those below 0.08%. To that end, a new variable was created (BAC Status) by dichotomizing the pre- and post-drive BACs as either both being less than 0.08% or both being at or above 0.08%. The dichotomization produced 313 valid cases. Eleven cases were eliminated because the pre- and post-drive BACs were not on the same side of the 0.08% cutoff. The median BAC for the low BAC status condition (BAC $<$ 0.08%) was 0.037%. The median BAC for the high BAC status condition (BAC $\geq$ 0.08%) was 0.097%. The median differences between the conditions were 0.06%.

Three general algorithms were developed. The first was based on logistic regression and was fit using a standard least squares regression approach using the entire dataset. The two other approaches to algorithm development used support vector machines (SVMs) and decision trees, which can often outperform linear combinations of the features [5].

Originally developed by Vapnik [6], SVMs have several advantages over approaches that make assumptions of linearity and normality. The SVM approach identifies a hyperplane that separates instances with different BAC levels [7]. SVMs are particularly well-suited to extract information from noisy data [8] and avoid overfitting by minimizing the upper bound of the generalization error [9]. The C4.5 decision tree approach, developed by Quinlan, classifies data by creating a tree that divides the data using the gini index, which weights feature influence in a linear fashion [10, 11]. Adaptive boosting (AdaBoost) sequentially fits a series of classification algorithms, with greater emphasis on previously misclassified instances. It then combines the output of the classification algorithms by adjusting the importance of each classifier based on its error rate [12]. This approach is particularly valuable where a single decision tree or SVM cannot capture the complexity of the underlying relationships. Adaptive boosting was applied to both the Decision Tree and SVM, but not the logistic regression. Detailed discussion of the algorithms can be found in the NHTSA report [13].

Three criteria are used throughout to assess algorithm sensitivity: accuracy, positive predictive performance (PPP), and area under curve (AUC). Accuracy measures the percent of cases that were correctly classified, and PPP measures the degree to which those drivers that were judged to have high BAC levels actually had high BAC levels.

Performance measures such as correct detection or overall accuracy fail to provide a complete description of algorithm performance because they do not account for the baseline frequency of impairment nor differences in the decision criterion. An algorithm can correctly identify all instances of impairment simply by setting a very low decision criterion, but such an algorithm would misclassify all cases where there was no impairment. The signal detection parameter, d', avoids these problems, but its underlying assumptions include symmetry of signal and noise distributions, which are often violated. AUC is a nonparametric version of d', and represents the area under the receiver operator curve, which provides a robust performance measure that does not depend on the assumptions underlying d'. Perfect classification performance is indicated by an AUC of 1.0, and chance performance is indicated by 0.50. AUC is an unbiased measure of algorithm performance, but accuracy and PPP are more easily interpreted, so all three are used in describing the algorithms.

Three different algorithms (logistic regression, support vector machines, and decision trees) were developed to predict whether the driver was above the legal limit, using average speed, minimum speed, variability in speed, lane position and variability in lane position. The algorithms achieved an accuracy of approximately 80%, comparable to that of the SFST used by law enforcement. Each of the three algorithms combined information across time to predict impairment.

Classification accuracy was consistent with previous studies—classification accuracy exceeded 82% for all three algorithms, with the decision tree being most accurate (84.7), followed by SVM (82.3) and logistic regression (82.0). Not surprisingly, the performance discriminating between BAC levels above and below 0.08 was somewhat worse than between the more extreme range defined by the experimental conditions of 0.00% and 0.10% BAC. Table 3 shows the accuracy ranges from approximately 80.5 to 82.5%. Given that even with the SFST, the current “gold-standard” for identifying alcohol impairment, there was overlap between the BAC levels, as shown in Figure 10, the failure of the algorithms to perfectly discriminate between BACs is not surprising.

Table 3. Performance of three algorithms classifying drivers with BAC above and below 0.08% using the SFST, with confidence intervals in the parentheses.

	Accuracy	AUC	PPP
Decision tree	81.8 (5.9)	.76 (0.087)	78.4 (15.5)
SVM	80.5 (6.9)	.81 (0.072)	75.6 (17.9)
Logistic regression	82.5 (5.5)	.80 (0.062)	75.9 (13.6)

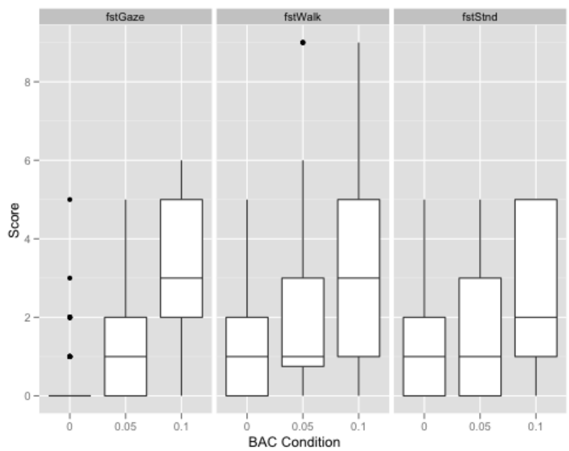

Figure 10. SFST scores show considerable overlap across BAC conditions.

The time required to detect impairment varied depending on the algorithm used. For example, when a simple algorithm (i.e., logistic regression) was used, it could take twenty-five minutes to detect impairment. However, when more complex algorithms were used (i.e., support vector machines and decision trees) for relatively demanding driving situations, impairment could be detected in as little as eight minutes. The time required to detect impairment depends on the driving context: impairment is detected more quickly when variables specific to the particular driving situation are considered (e.g. lane keeping on a rural road), rather than generic variables (e.g., number of lane departures). Timely impairment detection depends critically on the driving context: variables specific to the particular driving situation result in much more timely impairment detection than generic variables.

To illustrate this effect, the area under the curve for the decision tree algorithm are plotted in Figure 11 and show a general trend toward increasing sensitivity with longer events, but also indicate that longer events provide an increasing benefit. This figure also shows the substantial differences between events, with Urban Drive (102) and Urban Curves (106) being more sensitive than their duration would suggest, contrasting with Interstate Curves (205), which is less sensitive. As noted previously, highly precise impairment detection can occur in eight minutes if the driver encounters situations similar to Urban Curves (106) followed by Dark Rural (304). These results show that timely impairment detection depends on the types of events encountered by the driver, as well as the duration of information accumulation.

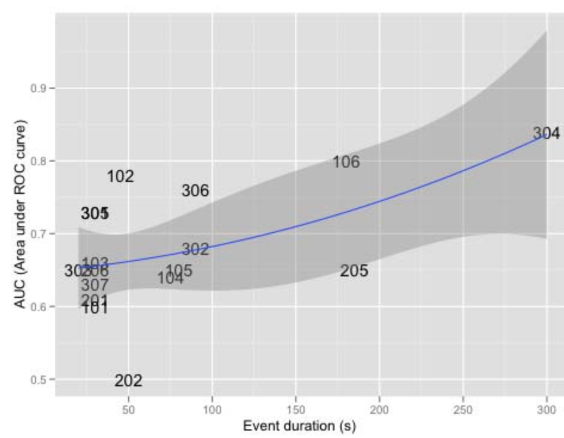

Figure 11. The sensitivity of each event as a function of its duration

Just as algorithms that consider differences in the driving context perform better, so do algorithms that consider differences between drivers. Algorithms tailored to the individual perform much better than generic algorithms that do not reflect differences between drivers. For example, an individualized algorithm might focus on a change from an individual's ability to accurately maintain lane position or speed rather than reaching a generic threshold of impaired lane keeping or speed. Although generic algorithms provide sufficient sensitivity to be useful, even very limited individualization greatly improves performance.

CONCLUSIONS

This study demonstrated that a vehicle-based system using measures of driver behavior can differentiate between drivers with BAC levels above and below 0.08% with sensitivity similar to the SFST. Because the indicators of alcohol impairment become much stronger at higher levels, the sensitivity would likely increase substantially if the algorithm was used to identify those with BAC levels over 0.15%. These outcomes strongly support the potential of vehicle-based systems to detect impaired driving which could ultimately help to prevent and mitigate alcohol-related crashes.

On the basis of this research, standard deviation of lane position and average speed were shown to be reliable measures of impairment that can be feasibly captured over a number of driving situations, and appear robust enough to be useful in future vehicle-based countermeasures. Minimum speed, as well as standard deviation of lane position and speed are useful indicators that might have particular utility in alcohol warning monitors designed to provide feedback to drivers.

A second general finding is that the driving context strongly influences impairment-detection performance. Contrary to many previous simulator studies of alcohol-impaired driving, this study used a representative series of 19 events over three types of roadway situations. These events revealed that impairment detection depends on the type of event. Because driving is a satisficing rather than optimizing activity, drivers can take many paths through low-demand situations that are all satisfactory. This variety of satisfactory responses masks impairment. The variety of events also requires a greater variety of measures to capture the relevant behavior in each event. All of these findings imply that detecting alcohol-related impairment, and impairment detection more generally, depends on the driving situation. Algorithm development needs to consider roadway situations as much as it needs to consider the drivers' perceptual, motor, and decision-making response to the impairment.

These results support the long-term research objective of using algorithms that detect impairment to provide drivers with feedback that will discourage or prevent drinking and driving. Ultimately the distraction-detection algorithms developed in this study could support a range of vehicle-based interventions to prevent alcohol-related crashes. The promising results associated with alcohol-related impairment detection also suggest other types of impairment detection might also hold promise, most notably distraction and drowsiness.

ACKNOWLEDGEMENTS

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DRIVER ALCOHOL DETECTION SYSTEM FOR SAFETY (DADSS) – PHASE I PROTOTYPE TESTING AND FINDINGS

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ABSTRACT

The Driver Alcohol Detection System for Safety Program is a research partnership between the National Highway Traffic Safety Administration and the Automotive Coalition for Traffic Safety. The cooperative agreement seeks to assess the current state of detection technologies that are capable of measuring blood alcohol concentration, and to support the development and testing of prototypes and subsequent hardware that could be installed in vehicles. Three Phase I proof-of-principle prototype sensors now have been developed. Two of the sensors are designed to remotely measure alcohol concentration in drivers' breath from the ambient air in the vehicle cabin, and the third is designed to measure alcohol in the drivers' finger tissue through placement of a finger on the sensor. To validate the performance of the prototypes, unique standard calibration devices have been developed for both the breath- and touch-based systems that exceed current alcohol-testing specifications. A testing program was undertaken to provide an understanding of whether the devices ultimately can meet the performance specifications needed for non-invasive alcohol testing. Bench testing determined the prototypes' accuracy, precision, and speed of measurement and established what additional development will be needed in Phase II. Limited human subject testing permitted an understanding of the in vivo relationship among the various measures of blood alcohol as provided by blood, breath, and the prototype devices. This paper provides the results of prototype testing and outlines further development needed.

INTRODUCTION

The Driver Alcohol Detection System for Safety (DADSS) Program is a research partnership between the National Highway Traffic Safety Administration (NHTSA) and the Automotive Coalition for Traffic Safety (ACTS) to explore the feasibility, the potential benefits of, and the public policy challenges associated with a more widespread use of non-invasive technology to prevent alcohol-impaired driving. The five-year program is a cost-sharing program between the parties, and funding for ACTS currently is provided by motor vehicle manufacturers (BMW, Chrysler, Ford, General Motors, Honda, Hyundai/Kia, Jaguar Land Rover, Mazda, Mercedes Benz, Mitsubishi, Nissan, Porsche, Toyota, Volkswagen, and Volvo). To be acceptable for use among all drivers, many of whom do not drink and drive, in-vehicle alcohol detection technologies must be seamless with the driving task; they must be non-intrusive, reliable, durable, and require little or no maintenance. The cooperative agreement seeks to assess the current state of detection technologies that are capable of measuring blood alcohol concentration (BAC) or Breath Alcohol Concentration (BrAC), and to support the development and testing of prototypes and subsequent hardware that could be installed in vehicles. The goal, at the end of the five-year program, is the practical demonstration in a research vehicle of alcohol detection subsystems suitable for subsequent installation in a vehicle.

DADSS devices have the potential to significantly reduce alcohol-impaired driving and the crash deaths and injuries that ensue. The technical challenges are substantial, however the possible benefits to society are compelling, with the potential to prevent up to 8,000 motor vehicle deaths every year if all drivers with BACs at or above the legal limit (0.08 g/dL) were unable to drive (IIHS, 2011).

The purpose of this paper is to provide a summary of research to date, including the technology review process, details about technologies chosen for Phase I development and the prototypes developed, as well as the development of bench testing devices, and the results of bench and human subject testing. The paper will conclude with a discussion of further development that is needed to meet DADSS specifications and next steps.

THE DADSS PROGRAM

A two-phased R&D program

The DADSS research and development effort is following a two-stage process. The Phase I effort, now complete, focused on the development of working proof-of-principle (PoP) prototypes. Phase II is the major development effort that will lead to a research vehicle to demonstrate the technologies.

The specific objective for Phase I was to develop PoP prototypes intended to represent devices capable of rapidly and accurately measuring the driver's BAC non-intrusively. The prototypes, which were required to address just the accuracy, precision, and speed of measurement specifications, did not attempt to simulate the visual appearance, choice of materials or intended manufacturing process. The overall aim was to validate the potential design approach, as well as point to areas where further development and testing may be necessary. The Phase I development comprised a 12-month period of performance and involved three companies.

The Phase II development stage will result in the practical demonstration of an alcohol detection subsystem suitable for subsequent installation in a vehicle. The program is envisaged to span approximately two years. Phase II awards will be made only to those bidders that have achieved successful Phase I progress with regard to the merits of the technological approach adopted. It is anticipated that funding for Phase II development will be awarded during the first half of 2011 following which technology companies will work towards the development of a research vehicle to demonstrate the DADSS technologies by the second half of 2013.

DADSS Program Details

The first tasks to be undertaken in Phase I included a comprehensive review of emerging and existing state-of-the-art technologies for alcohol detection and the development of performance specifications. A Request For Information (RFI) was published as a means by which the DADSS program was first communicated to potential vendors. The goal of the RFI was to establish the level of interest among technology developers in taking part in the research, the kinds of technologies available, and their states of development relevant to in-vehicle application. Based on an evaluation of the 17 responses received, a Request for Proposals (RFP) was sent to eight businesses with prior experience in alcohol detection or related technologies, and three contracts were awarded for the development of Phase I PoP prototypes.

Two technology approaches were chosen for Phase I development; Tissue Spectrometry Systems (touch-based) and Distant/or Offset Spectrometry Systems (breath-based). For a full discussion of the decision process by which these approaches were identified see Ferguson et al., 2010. Two companies, Autoliv and Alcohol Countermeasure Systems (ACS) were chosen to develop prototypes that used the breath-based approach, and TruTouch Technologies was chosen to develop a prototype that used the touch-based approach.

PoP Prototypes and Principles of Operation

Tissue spectrometry systems – Also known as near-infrared (NIR) spectrometry, this is a noninvasive approach that utilizes the near infrared region of the electromagnetic spectrum (from about 0.7 μm to 2.5 μm) to measure substances of interest in bodily tissue. The measurement begins by illuminating the user's skin with NIR light which propagates into the tissue (the skin has to be in contact with the device). The beam of light can penetrate tissue at depths of up to 5 mm to reach the dermal layer where alcohol that is dissolved in water resides. A portion of the light is diffusely reflected back to the skin's surface and collected by an optical touch pad. The light contains information on the unique chemical information and tissue structure of the user. This light is analyzed to determine the alcohol concentration and, when applicable, verify the identity of the user. Because of the complex nature of tissue composition, the challenge is to measure the concentration of alcohol (sensitivity) while ignoring all the other interfering analytes or signals (selectivity).

Although the entire NIR spectrum spans the wavelengths from 0.7-2.5 µm, TruTouch has determined that the 1.25-2.5 µm portion provides the highest sensitivity and selectivity for alcohol measurement. The 0.7-1.25 µm portion of the NIR is limited by the presence of skin pigments such as melanin that can create large differences among people, particularly of different ethnicities. In contrast, the longer wavelength portion of the NIR, from 1.25-2.5 µm, is virtually unaffected by skin pigmentation (Anderson et al., 1981). One other advantage of using this part of the spectrum is that the alcohol signal in the 1.25-2.5 µm region is hundreds of times stronger than the signal in the 0.7-1.25 µm part of the NIR.

The TruTouch prototype system is based on a proprietary Fourier transform spectrometer coupled with a compact, fiber optic touchpad with which the user interfaces. To conduct a test, the user makes contact with the intermediate phalanges of their index finger onto the fiber optic touchpad (Figure 1). The prototype automatically detects the presence of the finger and initiates an alcohol test. Once the spectral data have been collected, automated quality control metrics ensure that the test sample is a valid human finger and that all test parameters are within acceptable limits. An alcohol test result then is calculated and displayed on-screen.

The prototype system is a stand-alone test unit with the sensor, data processing unit, and operating software fully contained inside the unit. For operation in Phase I benchmark testing, a PC-based application is run on an external computer and communicates with the prototype via a wired Ethernet connection. This setup allows for flexible configuration and data logging requirements for this phase of testing. All data collection, quality control screening, and measurement calculations are performed within the prototype itself.

Figure 1. TruTouch prototype with user's index finger during measurement

Distant/Offset Spectrometry systems – Distant spectrometry systems use an approach similar to tissue spectrometry, in that they utilize the mid infrared (MIR) region of the electromagnetic spectrum (2.5-25 µm); however no skin contact is required. The two approaches under development aim to remotely analyze alcohol in breath within the vehicle cabin without the driver having to specifically provide a deep-lung breath sample. The working principle of the sensor is to use measurements of expired carbon dioxide (CO_2) as an indication of the degree of dilution of the alcohol in expired air. Normal concentration of CO_2 in ambient air is close to zero. Furthermore, CO_2 concentration in alveolar air is both known and predictable, and remarkably constant. Thus, by simultaneously measuring CO_2 and alcohol, the degree of dilution can be compensated for using a mathematical algorithm. According to Hök (2006), the ratio between the measured concentrations of CO_2 and alcohol, together with the known value of CO_2 in alveolar air, can provide the alveolar air alcohol concentration. The sensor technologies under development use MIR spectroscopy for both alcohol and CO_2. The MIR-based sensors can be stable over the full product lifetime, eliminating the need for recurrent calibrations.

For in-vehicle use the system could employ multiple sensors placed strategically around the cabin of the vehicle close to the driver. The challenge is to determine the number and placement of sensors needed to measure alcohol quickly and accurately given the dynamics of the cabin air, and to ensure that there is no potential bias introduced as a result of passengers who may have been drinking.

The Autoliv prototype is shown in Figure 2. This prototype uses a patented optical device in which multiple reflections of the IR beam within a closed space enables the calculation of alcohol concentration with high resolution. The expired breath from the driver is drawn into the optical module through the breathing cup. Once in the chamber, IR light is emitted from a light source and reflected by mirrors to increase the overall length of the IR optical path, thus increasing the prototype's resolution. Detectors in the module then measure the ethanol and CO_2 concentrations. For the purposes of human subject testing, the current device requires drivers to blow towards the sensor, which is positioned at a distance of 5 inches.

Figure 2. Autoliv prototype

Autoliv provided two prototypes at the completion of Phase I. The first prototype (Version 1) used an injection molded optical module with integrated mirrors. Upon initial testing, it was determined that the radii and location of the mirrors did not conform to the required specifications, which significantly reduced the accuracy and precision of the unit. This issue was addressed by providing a second prototype (Version 2) with add-on glass mirrors. However, during bench testing a small gas leakage was discovered in the optical module of the Version 2 prototype. This leakage, due to the add-on glass mirrors, did not have an impact on ethanol measurements since it only affected a very small part of the optical path. But for the CO_2 measurement which has a short optical path, the effect was significant.

The ACS prototype also relies on MIR detection methodology to detect alcohol in the cabin air using a Daylight Solutions Swept Sensor™ that enables identification and analysis of ethanol.

The sensor unit contains a broadly tunable external cavity quantum cascade laser (ECqcL™), capable of scanning a particular wavelength band of the MIR spectrum in less than 100 ms. It also contains optical detection components and electronics to convert the returned optical signal into an electronic signal that can be further processed by the unit. This system includes an extraction pump that allows gas samples to be pulled through the sample cell. The control electronics are contained underneath the sensor unit. Spectroscopic data are transmitted to a PC for further processing and analysis. For the prototype shown in Figure 3, a chiller was used to keep the Swept Sensor™ at a constant temperature.

Figure 3. ACS prototype with DLS Swept Sensor™ technology and required chiller to maintain constant temperature

The Swept Sensor™ was designed to measure ethanol and CO_2 simultaneously in ambient air. The sensor's laser continuously "sweeps" across the wavelength band. Upon initial evaluation of the Swept Sensor™ by ACS, they discovered a very weak CO_2 absorption in the spectral range where ethanol absorption was identified, and the Swept Sensor™ prototype CO_2 sensitivity did not measure below 5000 parts per million (ppm). Because of the amount of dilution of the expired breath as it mixes with the ambient air in the vehicle cabin, CO_2 detection in the range of 400-500 ppm is required. Therefore the sensor was unable to measure CO_2 at the necessary dilution. ACS modified the unit to incorporate a SenseAir CO_2 detector; a state-of-the art sensor which is able to measure CO_2 concentrations at the required ppm level. This modification was intended to allow the simultaneous detection of ethanol and CO_2 in the diluted human breath, however, the modification did not achieve the desired results.

Performance Specifications

Based on input from the ACTS Blue Ribbon Panel, a group of experts formed to help advise the DADSS program, ACTS has developed performance specifications that are designed to focus the current and future development of relevant emerging and existing alcohol detection technologies. In addition to requirements for a high level of accuracy and precision and very fast time to measurement, the influences of environment, issues related to user acceptance, long-term reliability, and system maintenance requirements will be assessed. The performance specifications with definitions, measurement requirements, and acceptable performance levels are provided in the DADSS Subsystem Performance Specification Document (http://dev.dadss.org/sites/default/files/dadss001-draft_100908.pdf). The accuracy, precision, and speed of measurement requirements adopted by the DADSS Program are much more stringent than currently available commercial alcohol measurement technologies are capable of achieving.

Accuracy and Precision – Accuracy is defined as the degree of closeness of a measured or calculated quantity to its actual (true) value (also referred to as the Systematic Error – SE). Precision is the degree of mutual agreement among a series of individual measurements or values (also referred to as the Standard Deviation – SD). To limit the number of misclassification errors, accuracy and precision must be very high, otherwise drivers may be incorrectly classified as being over the threshold (false positives), or below the legal limit (false negatives). To assure that drivers with BACs at or above the legal limit will not be able to drive, while at the same time allowing those below the limit to drive unhindered, SE and SD requirements at a BAC of 0.08 g/dL will need to achieve levels of 0.0003%. See Table 1 for the accuracy (SE) and precision (SD) requirements at other BACs.

Table 1. DADSS Performance Specifications (% BAC or % BrAC)

Ethanol concentration	SE	SD
0.020	0.0010	0.0010
0.040	0.0010	0.0010
0.060	0.0007	0.0007
0.080	0.0003	0.0003
0.120	0.0010	0.0010

Speed of measurement – Sober drivers should not be inconvenienced each time they drive their vehicle by having to wait for the system to function. Current breath-based alcohol measurement devices can take 30 seconds or longer to provide an estimate of BrAC. However, the DADSS device should take no longer to provide a measurement than the current industry standard time taken to activate the motive power of the vehicle. Thus, the subsystem should be capable of providing a BAC reading and communicating the result within 325 milliseconds. It should be capable of providing a second reading, if necessary, within 400 milliseconds.

STANDARD CALIBRATION DEVICE (SCD) DEVELOPMENT

Standard Calibration Devices (SCD) were developed to assess and document the accuracy and precision of the Phase I prototypes. Two different SCDs were developed for prototype testing; one breath-based and one touch-based. There are two aspects that were addressed. First, samples of simulated "breath" and "tissue" were developed to provide a calibrated (known) and consistent ethanol concentration in vapor and/or liquid to the PoP prototype. These samples also had to provide reasonable facsimiles of human breath and tissue. As noted above, the DADSS Performance Specifications for accuracy (SE) and precision (SD) are significantly more stringent than current evidential calibration instruments, thus the sample sources of breath and tissue had to exceed the DADSS specifications by an order of magnitude. The second requirement necessitated the development of delivery methods so that the targeted samples could be effectively delivered to the prototypes.

An SCD qualification process was developed to document that the breath and tissue sample performance meet the requisite performance specifications. Initially, components of the breath and tissue SCD were measured with a Gas Chromatograph (GC) using a Flame Ionization Detector (FID) to verify that the critical SEs and SDs were achieved. To establish SCD repeatability, the GC testing was repeated for each increment of the specification's target physiological test range of 0.02 % BAC through 0.12 % BAC.

Tissue Spectrometry SCD

An SCD sample that simulates human tissue must produce a consistent ethanol response from the sensor at all concentrations of BAC, mimic the average optical scattering properties of human tissue over the target NIR wavelength range, and maintain the test material at normal human skin temperature (34 ºC). Figure 4 compares NIR reflectance of human versus simulated tissue and demonstrates the high level of concordance at the relevant wavenumbers.

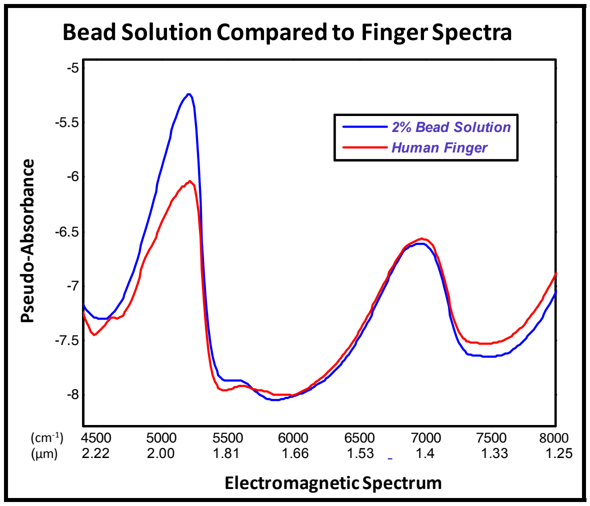

Figure 4. Comparison of NIR reflectance of simulated tissue solution with human tissue

The system also must support varying concentrations of ethanol over the target BAC test range of 0.02% through 0.12 % BAC.

Tissue calibration mixtures – Working with TruTouch Technologies, an SCD system was developed that comprised standardized aqueous test samples representative of human tissue and an electromechanical fluidic system for introducing the samples to the sensor. The standardized aqueous test samples are gravimetrically prepared solutions that use mono-dispersive polystyrene microspheres as an optical scattering agent. Quantities of ethanol in the solutions are certified by GC analysis to meet the required concentration levels after the beads are added. The simulated tissue solutions were stored in individual 15 mL vials. In addition to water and alcohol the "tissue" samples contain normal components of human blood such as urea, salt, and creatinine, as well as albumin that simulates blood density, microspheres that simulate the reflectance and scattering properties of collagen, and Triton that prevents the beads from clumping.

Electromechanical Fluidic System – The fluidic delivery system module was designed to easily attach to the TruTouch prototype sensor. The system module creates a liquid seal interface to support direct coupling between the optical sensor and the SCD test sample. The system also includes an agitation mechanism to prevent settling of the microspheres without introducing bubbles into the sample at the optical surface. The sealed system prevents evaporation loss, allows for sample removal, cleaning, and drying between sample measurements to prevent cross-contamination, and provides a reasonable degree of automation to avoid operator error. The prototype fluidics system is illustrated in Figure 5.

Figure 5. Liquid coupling interface and prototype delivery system

TruTouch provided SCD samples to S.E.D. Medical Laboratories, a third-party laboratory, for independent analysis of the ethanol concentration in the SCD simulated tissue solutions. Based on these analyses, the tissue SCD does not currently meet the DADDS Performance Specifications. It is not known whether this inability to meet the specifications is due to the properties of the tissue samples themselves or to S.E.D's equipment capabilities. However, ACTS intends to verify the results in-house. Further development also will be undertaken to improve accuracy and precision of the tissue SCD and the usability of the delivery system.

Distant Spectrometry SCD

The first step in the development of highly accurate breath samples was the production of standardized calibration dry gases. Then the next step was to develop the DADSS dry gas mixture with the potential to exceed the DADSS Performance Specifications.

Two ethanol gas mixtures in 110 L pressurized bottles were developed in cooperation with ILMO Products Company:

1. Ethanol/Nitrogen (N_2)
2. Ethanol/N_2/5 % CO_2/16 % oxygen (O_2)

Each mixture was gravimetrically prepared at concentrations of 0.02, 0.04, 0.06, 0.08, 0.12 % BrAC. The mixtures were certified at ±0.5 ppm (±0.0002 % BrAC) by the vendor, exceeding the 0.0003 % BAC SE and SD when tested at 0.08 % BAC. In-house GC testing confirmed that the gas mixtures provided the levels of accuracy and precision for ethanol and other gases to the DADSS specifications over the complete range of gas concentrations. Additional testing verified acceptable shelf-life stability of the gas bottles.

Having validated that the dry gas mixtures complied with DADSS specifications, the next step was to humidify the gases to simulate human breath. Tests were conducted using a spirometer on a healthy male subject to measure the average flow rate and time of an exhaled breath. The ACTS team then developed a Wet Gas Breath Alcohol Simulator (WGBAS), shown in Figure 6, to add the necessary humidity.

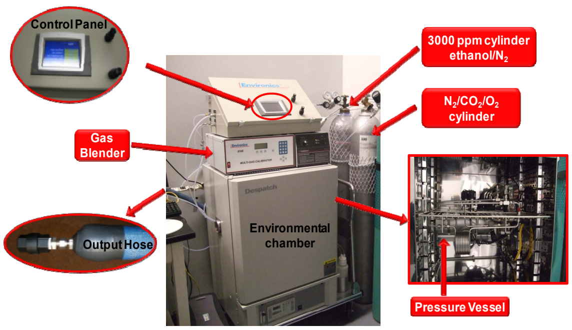

Figure 6. WGBAS Configuration

The WGBAS uses two dry gas sources: the first a mixture of $N_2/CO_2/O_2$, and the second a 3000 ppm cylinder of ethanol, balanced with nitrogen. Mass flow controllers (MFC) generate the range of humidified ethanol from 0.02 % BAC to 0.12 % BAC. The gas in the premixed cylinder of $N_2/CO_2/O_2$ enters the gas mixing module, flowing through humidifier metering valves located in an enclosure on top of the heated chamber. The proportional control of these valves allows the humidity to be adjusted. The ethanol/ N_2 mixture flows out of the second MFC and into the bypass line that flows around the humidifier. The humidified $N_2/CO_2/O_2$ mixture and the ethanol mixture meet before entering the hygrometer, which reports the dew point, humidity and gas temperature values, allowing for any necessary adjustments to obtain the required output of the humidifier. The humidified gas mixture then passes into the evacuated pressure vessel where it accumulates to a preset pressure, as monitored by an absolute pressure transmitter. When the preset pressure is met, the pressurized gas is expelled into the evacuated output tubing. As the gas leaves the system it is cooled to 34°C, the dew point temperature of the mixture, at a rate of approximately 1 liter in 2-3 seconds, thus simulating a humidified gas flow of breath. Figure 7 shows the WGBAS principle of operation described above.

The SCD dry gas, when passed directly through the WGBAS, was capable not only of meeting but also exceeding the DADSS SEs and SDs. In the second set of verification tests, humidity was added to the mixed gases with an output dew point of 34 °C. The addition of humidity resulted in much larger SE values than the DADSS specifications and the SD values were influenced by differences in the ethanol concentration, with only the lowest ethanol concentration being able to meet and exceed the specifications.

The WGBAS was not used in the Phase I evaluation process due to its current early development status. The system will undergo additional enhancements in Phase II to improve accuracy and precision through the introduction of a closed-loop feedback system to control the amount of ethanol concentration mixed into the gas stream. Therefore, the system is planned to be used for prototypes evaluation in Phase II.

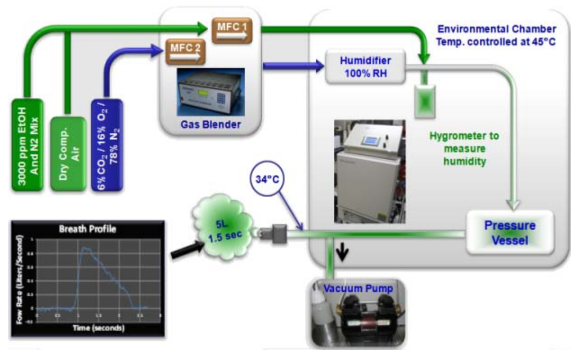

Figure 7. WGBAS principal of operation

PROTOTYPE TESTING

Bench Test Protocols

To undertake the prototype verification, equipment and materials were organized in a dedicated laboratory wherein both bench and human subject tests were conducted. Human subject testing of the prototypes required a BioSafety Level-1 Laboratory for safe handling of human blood.

The prototypes were tested in a standardized manner using bench tests. SCDs were used to provide accurate and consistent samples to the prototypes. The bench tests of each system were divided into test matrices to characterize the performance of the prototypes under different conditions. One matrix tested the sensor in an ideal or best-case scenario for comparison with the DADSS specifications. Another matrix tested the sensors as used in the human subject tests. SE was calculated using:

$$SE = |\bar{x} - \text{SCD ethanol concentration}|$$

Where $\bar{x}$ is the data averaged using:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

and SD was calculated using:

$$SD = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Tissue Spectrometry System Test Protocols – The tissue spectrometry prototype was tested using the developed calibration mixture and the electromechanical fluidic system. Matrix I tested the sensor's accuracy and precision as a function of different sampling times and BACs (0.02, 0.04, 0.06, 0.08, 0.12%). This matrix provided the longest continuous sample exposure time and was used to characterize the sensor's performance and capabilities to meet the DADSS specifications. The solutions were tested for 60 seconds, 30 seconds, 15 seconds, and 5 seconds respectively.

In Matrix II, sampling times were changed to determine whether the prototype can distinguish between one long continuous reading versus multiple shorter readings combined into a longer reading. Solutions at BACs of 0.02, 0.04, 0.06, 0.08, 0.12% were tested at 60 seconds divided into two 30 seconds intervals (30x2), 60 seconds divided into four 15 second intervals (15x4), or 30 seconds divided into two 15 second intervals (15x2). Note that all human subject tests provided a 60 second sample divided into four 15 second intervals for participant comfort.

Distant Spectrometry Systems Test Protocols – The distant spectrometry prototypes were tested using the developed dry gas mixtures. The first four seconds of the dry gas release allowed the system to stabilize. The prototype software stored the next five seconds of data while the dry gas steadily released from the cylinder. This was done to ensure that the prototype was exposed to a steady gas sample. One second after the prototype data collection was completed the dry gas flow was stopped. The prototype was passively purged with ambient air for 30 seconds between each test.

Matrix I tested the prototype's accuracy and precision to various alcohol concentrations when the SCD dry gas, which contained a mixture of ethanol, 5 % CO_2, 16 % O_2, and N_2, was directly connected to the prototypes. This test matrix provided the best-case scenario for the sensors due to the lack of dilution and was used to characterize the sensor's performance and capabilities to meet the DADSS Performance Specifications.

Matrix II tested the prototypes' accuracy and precision to alcohol concentrations when the SCD dry gas mixture was released at a distance of five inches from the sensor thus diluting the CO_2 concentration to 0.9 % . This configuration simulated dilution of the human breath in an automobile cabin environment. Note that the protocol used for human subject testing required the breath sample be delivered into a collection cup at a distance of about five inches from the subject's mouth.

A series of device validation experiments using human subjects were conducted in collaboration with the Behavioral Psychopharmacology Research Laboratory (BPRL), McLean Hospital, Harvard Medical School. BrAC was measured using a highly-accurate evidential breath device (the Nanopuls Evidenzer Mobil 240). Venous blood samples were drawn to provide measurements of BAC, and both the Autoliv and TruTouch prototypes were used to provide estimates of BrAC and tissue alcohol concentration (TAC). The aim of the study was to assess the prototypes' ability to provide accurate measurements of blood alcohol concentrations over a wide range of blood alcohol concentrations, both during the absorption and elimination stages, in an extended period of time (7 hours). Human volunteers were dosed with alcohol to produce blood alcohol concentrations in the range of 0.10 to 0.12 % BAC.

Attempts to use the ACS prototype for human subject testing yielded inconsistent data. Furthermore, the device required a significant effort to incorporate it into the testing program due to the complexity of the system and its operating software. Use of this device not only produced inconsistent results but also was time-consuming to use with the subjects, thereby jeopardizing the sequence and frequency of testing of the other devices. Therefore, the ACS prototype was eliminated from human subject tests.

All protocols, recruitment procedures, informed consent documents and experimental details of the study were approved by the McLean Hospital

Institutional Review Board. Sixteen individuals participated in the test series. The alcohol dose and drinking regimen were adjusted during the first four participants to optimize the drinking protocol and alcohol dose. In addition, fine adjustments to the sampling procedure were made in order to achieve the target blood levels and sustained peak of intoxication. Adjustments also were made to the drinking regimen so that there were times during the absorption phase when mouth alcohol had dissipated and breath samples could be collected.

RESULTS

TruTouch Technologies Bench Tests Results

One concern was whether the SCD simulated tissue solution would degrade over time. TruTouch had reported that the lifespan of the solution was 20 minutes. The first tests with the TruTouch prototype and the fluidic system (Figure 8) characterized the simulated tissue solution degradation over time. Several vials were run with sequential 60 second sample times for 25 minutes to verify the reported lifespan. It was found that samples began to degrade after ten minutes. As a result it was decided to conduct tests for the full 20 minutes for quality control and future studies of vial-to-vial variability, however only the first ten minutes of collected data were used for all subsequent analysis.

Results of Matrix I testing at 0.08 %BAC are shown in Figure 9. An inverse relationship was observed between sampling time and estimated accuracy and precision (SEs and SDs, respectively). This indicates the sensor's signal-to-noise ratio (SNR) influenced the prototype's accuracy and precision since higher signal strength (longer sampling time) resulted in lower noise (lower SE and SD) and vice versa. The similarity between the findings at 60 seconds and 30 seconds sample times indicates that the minimum sample exposure time to achieve the sensor's maximum capabilities was between 30 and 60 seconds; longer sampling exposure times would not produce significant performance improvements.

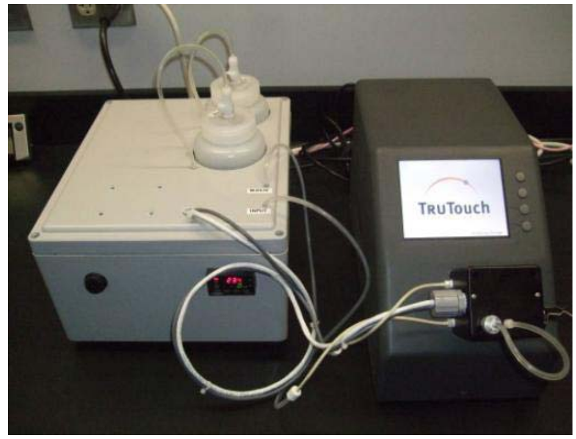

Figure 8. TruTouch bench test configuration

With respect to accuracy (SE), the sensor was able to exceed the DADSS specification at 60 seconds and 30 seconds, and was close to the specification at 15 seconds. However, with respect to precision (SD) the prototype failed to meet the DADSS specifications at all of the sampling time/BAC combinations, being higher by an order of magnitude.

Figure 10 provides the results of Matrix II testing. It should be noted that fewer tests were conducted for each sampling time/BAC combination than in Matrix I with correspondingly lower confidence in the results. Comparing the precision estimates (SD) derived from the 60 second Matrix I results and the 30x2 and 15x4 Matrix II results indicated comparable results can be obtained from each testing method. Accuracy estimates (SE) derived using the shorter intervals that were combined (30x2, 15x4, and 15x2) generally resulted in higher precision estimates than the longer continuous interval (60 and 30 seconds). The dissimilar SE among the different testing sequences may indicate a system recalibration or algorithm adjustment should be considered (combining numerous short readings into a longer reading). Another possibility is that the discrepancies could be attributed to SCD limitations, such as vial-to-vial variability. Additional testing would be required to provide insight into the nature of the inconsistencies.

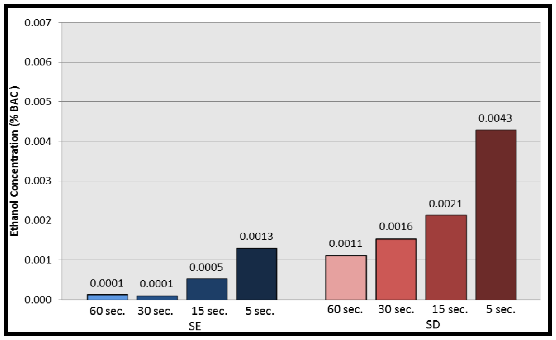

Figure 9. TruTouch bench test Matrix I SE and SD results at 0.08 % BAC

Figure 11. Autoliv bench test Matrix I configuration

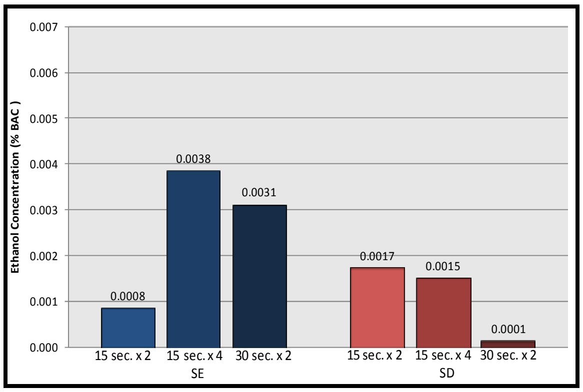

Figure 10. TruTouch bench test Matrix II SD and SE results at 0.08 % BAC

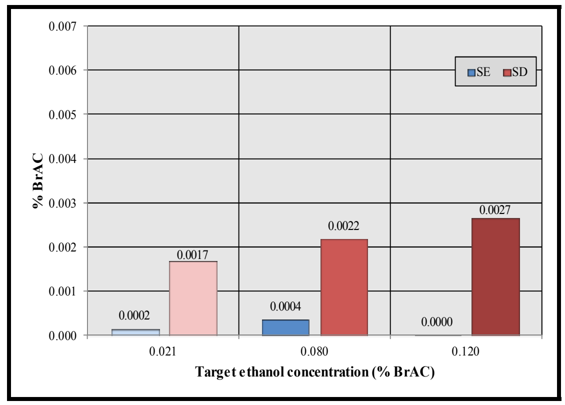

Figure 12. Autoliv bench test Matrix I results using direct connection of dry gas

Autoliv Development AB Bench Tests Results

Figure 11 provides an image of the assembly of the Autoliv PoP prototype and SCD dry gas cylinder for Matrix I bench tests. Figure 12 illustrates the results when dry gas is connected directly to the prototype. At a 5 seconds gas exposure time, the Autoliv prototype was able to closely approximate and even exceed the DADSS accuracy specifications (SE) at BACs of 0.02. 0.08, and 0.12%. These results indicate the prototype may have been accurately calibrated or tuned. The precision estimates (SD) all exceeded the DADSS specifications and exhibited a slight upward trend as a function of BAC. This may be the result of the sensor's sensitivity to the internal CO_2 leak.

Figure 13 provides an image of the assembly of the Autoliv prototype, SCD dry gas cylinder, and dilution chamber for Matrix II bench tests. Figure 14 shows the results when the dry gas is diluted before entering the prototype. The dilution distance was 5 inches and according to the reading from the CO_2 sensor, the concentrations were diluted from 5.0 % to 0.9 %. As with Matrix I tests, the lower SE values indicate the prototype may have been adjusted to produce accurate results. However, the SD was an order of magnitude greater when the SCD dry gas was diluted instead of directly connected. This finding demonstrated the sensor's sensitivity to SNR because the diluted gas produced a much smaller signal (lower ethanol concentration as a result of the dilution). Amplification of noise in the smaller signal results in increased variability in the prototype's output.

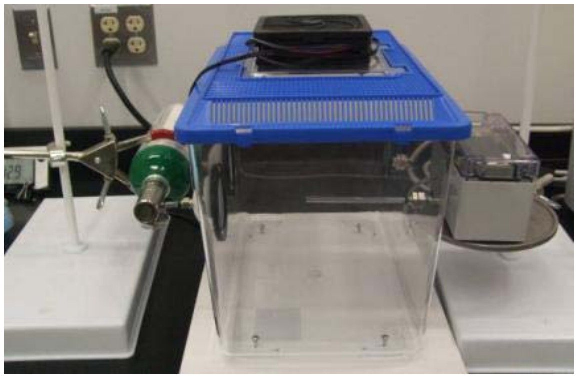

Figure 13. Matrix II diluted dry gas bench test configuration

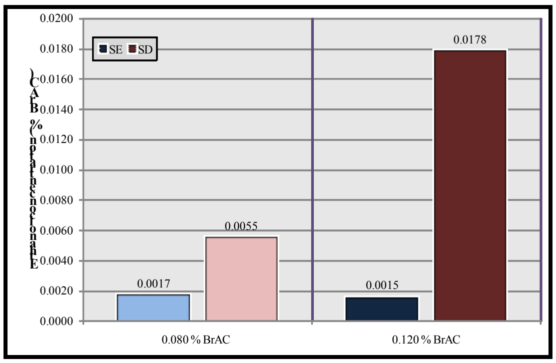

Figure 14. Autoliv bench test Matrix II results using diluted dry gas samples

Alcohol Countermeasure Systems Bench Test Results

The initial bench tests of the ACS prototype (using direct connection of SCD dry gases) were performed to evaluate the system's operations. Due to software limitations of the prototype software, the dry gas valve and data collection processes could not be automatically controlled. To complete a test, the dry gas SCD had to be controlled separately which meant that the prototype was not exposed to a constant SCD gas flow. ACS developed their software to automatically detect the increase in CO_2, thus triggering the ethanol reading once a defined CO_2 threshold was reached. Although this method is more representative of the system application in a vehicle, the DLS Swept Sensor's™ capabilities cannot be tested independently from the SenseAir CO_2 sensor. Additionally, the ACS system's sensor, hardware, and software were extremely cumbersome to work with, which made the ACS prototype far more difficult and time consuming to operate than the other prototypes.

Figure 15 shows Matrix I bench test results after ten tests. The results of the SCD dry gas connected directly to the ACS prototype yielded ambiguous results for both accuracy and precision. It should be noted that the scale of the graph is different than the other results graphs presented due to the higher values recorded.

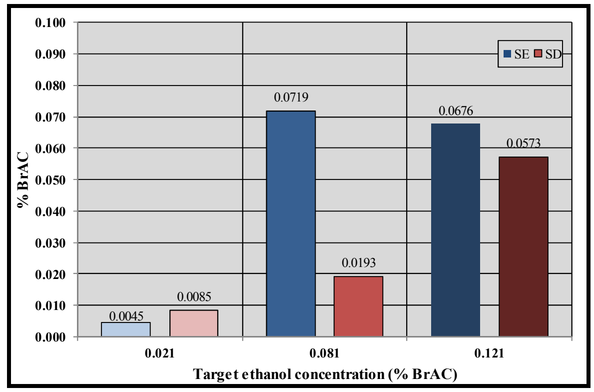

Figure 15. ACS bench test Matrix I results

The Matrix II bench tests, in which the dry gas mixtures at various BACs were diluted before introduction to the sensor, also yielded highly erratic accuracy and precision estimates for ethanol concentration.

Human Subject Tests

A couple of examples of the time course results of repeated whole blood, tissue, and breath samples for sixteen participants are shown in Figure 16 and Figure 17. Missing data points for whole blood measurements were due to technical problems with the sampling devices or with blood clots in the catheter. No breath samples were collected during the lunch period (about 3.5 to 4.5 hours from the start of the study). There were some variations in peak alcohol levels from about 0.105 % to 0.171 % BAC indicating some individual variability in absorption and metabolism despite a standardized dosing regimen. The absorption phase was characterized by a steady rise in alcohol levels, peaking around 2 hours, as measured by whole blood analysis and all three devices. Peak levels were observed for variable lengths of time across participants with some displaying a "plateau" in alcohol levels while others showed more of a sharp peak that then settled into a plateau.

Elimination of alcohol was characteristically a linear function. Sampling continued until breath alcohol levels were at or below 0.02 % or 7 hours after the start of the session and the participants passed a Field Sobriety Test.

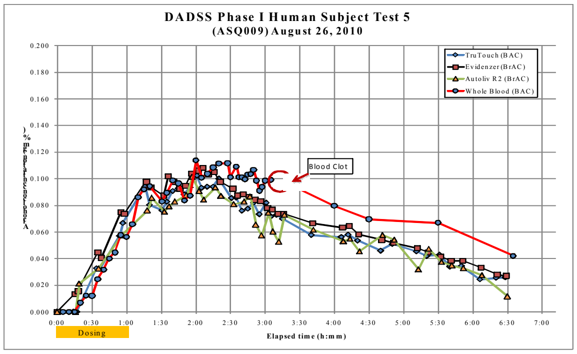

Figure 16. Human subject test 5 results

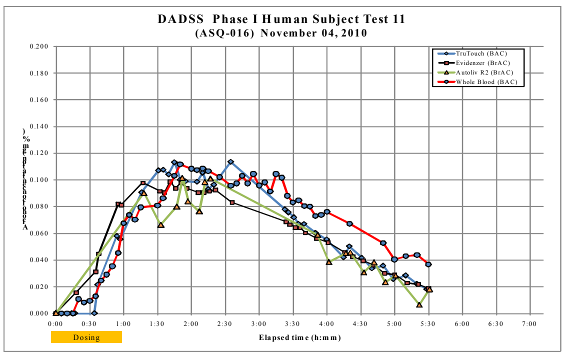

Figure 17. Human subject test 11 results

Across the participants studied to date, the estimates of blood alcohol concentrations obtained from the Autoliv breath device were the most variable and correlated less with the evidential breath results and results from the "gold standard" analysis of venous blood alcohol. The increased variability of the Autoliv prototype may be a function of the CO_2 leak and high directional dependence of the sample source (i.e., the angle at which subjects blow into the collection cup). The results obtained from the TruTouch device more closely tracked both the Evidenzer and blood alcohol levels over a wider range of alcohol concentrations and over the entire session.

A comparison of alcohol concentrations derived from whole blood analysis and breath from the Evidenzer breath analyzer revealed that whole blood values were lower than breath samples during the early absorption phase of alcohol (zero to two hours) and higher than breath samples during the elimination phase (two to three hours) after acute alcohol administration. This relationship is a well-known profile of alcohol kinetics that is observed when comparing the absorption and elimination/ metabolism phases of acute alcohol administration. These differences are less apparent after multiple drinks have been consumed.

GAP ANALYSIS

A detailed gap analysis was required from each of the technology developers to address the specifications with which their prototype did not conform. They were then required to identify any limitations that would prevent a technology from providing the necessary performance, including the ability of the technology to be deployed in a vehicle as an item of standard equipment. In addition they were required to identify the level of effort needed to meet the DADSS specifications.

Both TruTouch and Autoliv indicated that the performance limitations are not due to fundamental limits of the technology and can be addressed in the Phase II development effort. They also provided details of the necessary modifications to meet the DADSS specifications to be implemented in Phase II. ACS on the other hand indicated that in their assessment, the performance limitations were the result of the technology implementation used, and will not be pursuing this approach further.

CONCLUSIONS

In the last two years significant progress has been made to identify DADSS technologies that have the potential to be used on a more widespread basis in passenger vehicles. Two specific approaches have been chosen for further investigation; tissue spectrometry, or touch based, and distant/offset spectrometry, or breath based sensors (Ferguson et al., 2010). Three Phase I proof-of-principle prototype DADSS sensors now have been developed. Two of the sensors are designed to remotely measure alcohol concentration in drivers' breath from the ambient air in the vehicle cabin, and the third is designed to measure alcohol in the drivers' finger tissue through placement of a finger on the sensor.

Phase I development now has been completed. The aim of Phase I was to validate potential design approaches, as well as point to areas where further development and testing are necessary. Three prototype devices have been delivered and have undergone testing. Based on the results of testing, one touch-based approach and one breath-based approach are judged to have the potential with future development to measure BAC quickly, and with high levels of accuracy and precision. These approaches should commence Phase II development during the first half of 2011. Significant additional research and development is needed, but the technology companies have identified potential technological modifications to the devices that will enable them to meet the DADSS specifications at the end of the Phase II development.

Progress also has been made to develop calibration devices for both breath-and touch-based bench testing that will be able to measure whether the DADSS devices can meet the stringent criteria for accuracy and precision. Unique standard calibration devices have been developed for both the breath- and touch-based systems that go well beyond current alcohol-testing specifications. Further development will be required during Phase II to optimize the usability of the standard calibration devices as well as to improve accuracy and precision of the breath and tissue simulated samples.

In summary, the DADSS Program so far has accomplished the goals set at the onset of the program. Prototype testing has indicated that there are potential technologies that ultimately could function non-invasively in a vehicle environment to measure a driver's BAC. Furthermore, the DADSS Program is on track to develop research vehicles to demonstrate the technologies by the second half of 2013.

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THINKING ABOUT DISTRACTION – A CONCEPTUAL FRAMEWORK FOR ASSESSING DRIVER-VEHICLE ON-ROAD PERFORMANCE IN RELATION TO SECONDARY TASK ACTIVITY

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ABSTRACT

Recently, the relationship between driver distraction and road safety has come strongly into focus, based on findings presented from Naturalistic Driving Studies and Field Operational Tests.

Reviews of current literature on the subject show that the available conceptual frameworks for describing the relationship between secondary task involvement and driver performance are predominantly linear and mono-dimensional, i.e. they propose a single, direct and linear correlation between secondary task engagement and reduction in driver performance. However, as research into other areas of human performance show, descriptions of a linear and/or mono-dimensional character rarely are sufficient to predict the differences between mono- and multitasking in human operators.

Transferred to automotive safety, this means that to evaluate the effects of new in-vehicle systems on driver performance, a more sophisticated framework is needed. In particular, any warning/intervention capabilities of the vehicle, the current performance capacity of the driver, and primary task demand variation all need to be added and accounted for in order to accurately assess the extent to which secondary task involvement may degrade primary task performance.

In this paper, a conceptual framework which takes these additional dimensions into account is outlined. The framework describes how driver performance capacity, the availability of active safety systems in the vehicle and the current demands from the traffic environment should be jointly considered in relation to the effects on driver performance of secondary task engagement. Based on this, general areas where improvements can be made in order to mitigate negative consequences of non-driving tasks are presented.

INTRODUCTION

Driver distraction is widely recognized as a significant road safety issue[1][2]. Numerous studies point to distraction as an important underlying reason for why drivers get involved in crashes. For example, the U.S. Department of Transportation's analysis of several crash databases suggests that approximately 18-22% of crashes are associated with what they define as distracting activities [3].

These statistics seem clear enough, but when it comes to preventing distraction related crashes, it gets more complicated. First, there is the issue of defining what distraction is. In the NTHSA study [3], distraction is defined in a wide and inclusive sense, focusing on what they identify as sources of distraction. These include phoning, eating, reading, personal hygiene, reaching for objects in the vehicle, etc, i.e. any non-driving related activity the driver was involved in when the crash occurred.

However, if one looks at the general prevalence of such non-driving related activities, Stutts et al [4] found that of the total driving time, drivers spent approximately 15.3 % engaged in conversation with passengers and 14.5 % doing some other activity. Sayer et al [5] found that drivers engage in some secondary tasks 34 % of total driving time, with conversation with another passenger as the most frequent (15 %), followed by grooming (6.5%), use of a hand-held cellular phone (5.3%), and eating or drinking (1.9%). Finally, Klauer, et al. [6] found that drivers engaged in secondary tasks 23.5 % of the time that they were driving.

Taken together with the NHTSA study on crashes involving distraction, these numbers suggest an interesting picture. At face value, the simplest interpretation would be that non-driving related activities should be viewed as a form of exposure, rather than as reasons for why crashes occur. Put differently, the numbers in [3] on drivers doing non-driving related tasks when crashing are exactly what one would expect, given the prevalence of secondary task engagement in ordinary driving identified by the naturalistic driving studies. In fact, if non-driving related activities take up ~25-30 % of the total driving time and crash databases show such activities to be associated with only 18-22 % of all crashes, there is either a real underreporting problem, or non-driving related tasks may actually have a protective effect (the relative risk of a crash is higher for drivers not doing secondary tasks).

It follows that not all non-driving related tasks can automatically be classified as distractions, in the sense that performing them increases the risk of being involved in a crash. While underreporting certainly is an issue in this area, the numbers suggest the effects of non-driving related tasks cannot be conceptualized as a direct, linear correlation between secondary task engagement and reduction in driver performance. Instead, to understand how non-driving related tasks may compromise driver performance, a more nuanced description of the underlying mechanisms is required.

One way to approach this challenge is to start with the analysis of the data from the 100 car naturalistic driving study performed by Guo & Hankey [7]. When looking at the effect of non-driving related tasks, they differentiated between three levels of secondary task complexity, based on definitions of manual-visual complexity in Dingus et al [8], as shown in Table 1. In this classification, simple secondary tasks require, at most, one button press or eye glance away from the forward roadway. A moderate secondary task require one to two button presses and/or eye glances away from the forward roadway, while complex secondary tasks require more than two button presses and/or eye glances away from the forward roadway.

Given this definition, Guo & Hankey [7] found that only complex tasks (e.g. dialing a handheld device) increased crash risk. Simple and moderately complex secondary tasks (e.g. eating, drinking, talking to a passenger) on the other hand actually showed a protective effect, i.e. the risk of being involved in a crash or near crash decreased when drivers performed these activities. Engaging in simple and moderately complex secondary tasks thus seems to be better than doing nothing at all, while engaging in complex tasks get people into trouble.

The most straightforward interpretation of these results is that doing something else while driving actually improves how well you drive ,at least in terms of avoiding near crashes and crashes, up to a certain level of task complexity, where the capacity to drive safely instead becomes compromised by concurrent activity involvement. To understand how and why this can be the case, two further explanatory dimensions that characterize human behavior and performance need to be introduced, namely *arousal* and *adaptivity*. The concept of arousal, here understood as the level of activation/excitation in the driver, can be used to explain why simple and moderately complex tasks improve driving performance, while conceptualizing driving as a continuous adaptive process helps explain why complex tasks lead to increased crash and near crash risk.

Table 1: Assignment of secondary tasks to three levels of manual-visual complexity

	Simple	Moderate	Complex
1	Adjusting Radio	Talking / Listening to handheld device	Dialing a handheld device
2	Adjusting other devices integral to the vehicle	Handheld device other	Locating / reaching / answering a handheld device
3	Talking to passenger in adjacent seat	Inserting /retrieving CD	Operating a personal digital assistant (PDA)
4	Talking/Singing: no passenger present	Inserting / retrieving cassette	Viewing a PDA
5	Drinking	Reaching for object (not handheld device)	Reading
6	Smoking	Combing or fixing hair	Animal / object in vehicle
7	Lost in thought	Other personal hygiene	Reaching for a moving object
8	Other simple tasks	Eating	Insect in vehicle
9		Looking at external object	Applying makeup

AROUSAL

In many disciplines, from toxicology, enzymology and biomedicine to experimental psychology, one of the most fundamental mechanisms describing how well an organism performs is what generally can be referred to as hormesis, or the dose-response concept [9]. In experimental psychology, the phenomenon goes under the name of the Yerkes-Dodson law (most famously described by Broadhurst [10]). The Yerkes-Dodson law is a dose-response description of the relationship of stress to performance under varying degrees of task complexity/difficulty.

The original Yerkes-Dodson law essentially stated that a high level of motivation can enhance learning on an easy task and impair learning on a difficult task. Put differently, performance on simple tasks is continuously improved when arousal increases (linear relationship), while for more complex and difficult tasks, the initial improvement reaches a peak at some level of arousal, and then decreases as arousal continues to decrease (curvilinear relationship). also, the more difficult the task, the earlier (or more to the left) comes peak performance, i.e. the level of arousal for optimal performance decreases with increased task complexity.

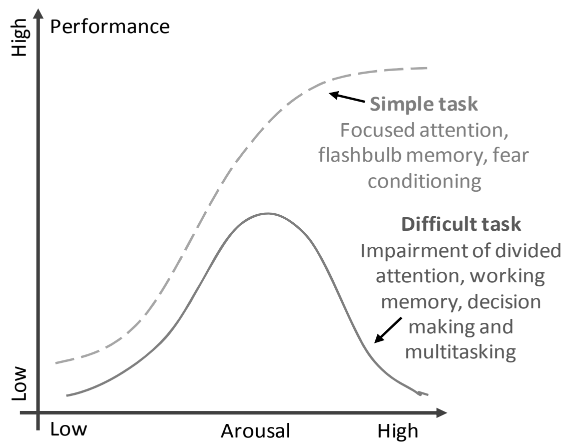

Figure 1: Illustration of original Yerkes-Dodson law, adapted from [12].

This law has been validated for motor complexity, i.e. if the task requires fine motor skill, the optimal level of arousal is low, while if the task only requires gross motor skill, the optimal level of arousal is high [11]. It also seems to cover cognition in an interesting way, i.e. if the successful completion of a task requires involvement of the Pre-Frontal Cortex (PFC), then performance on that task is likely to suffer under conditions of high arousal [12]. For example, high states of anxiety have little or no effect on performance in simple, single-digit, mental calculations, which place minimal demands on PFC based working memory capacity. On the other hand people who perform more complex mental math, such as double-digit calculations which require more working memory and thus increased PFC involvement, are more susceptible to impairment by anxiety [13]. Notably, even the single-digit calculations were susceptible to impairment by anxiety if a PFC-dependent component, such as decision-making, was included in the calculations [13].

AROUSAL - IMPLICATIONS FOR DRIVING

The Yerkes-Dodson law offers a partial explanation of the results in [7]. Driving, in the sense of maneuvering at normal speeds, is fairly reminiscent of walking. In terms of how Guo & Hankey classified task complexity, driving a vehicle would be considered a simple task, like for example drinking from a bottle, i.e. it is an overlearned, highly automated task that does not require a dedicated PFC component or motor control effort.

It follows that performance in terms of vehicle maneuvering alone can be expected to follow the level of arousal in the linear rather than the curvilinear fashion depicted above in Fig 1**,** i.e. the more aroused or engaged the driver is, the better the vehicle control will be. It also follows that the task of just maneuvering the vehicle will not lead to increased arousal, in the sense that it that would lead to general driving performance improvement in terms of avoiding crashes and near crashes. To make that happen, some other condition which stresses, or arouses, the biological system (the driver) is necessary.

According to the findings of Guo & Hankey, secondary tasks appear to be able to take on this stressor role. When simple and moderately complex secondary tasks are added to the driving task, arousal increases in a way which results in overall better driving performance. However, when the added tasks go beyond a certain level of complexity, driving performance starts to decrease and eventually goes below the level of performance that can be expected for just driving under low arousal.

The Yerkes-Dodson law can also be applied to other stressors than non-driving related tasks, such as when there is a difficult traffic situation to negotiate or when the driver is trying to win a race. Here the difficulty of negotiation the external situation drives an increased arousal in the driver, which in turn leads to improved driving performance up to the point where the driver reaches his/her performance limits (i.e. even if you want to win the race and stay absolutely focused, you may loose to a more skilled driver). This roughly corresponds to the peak performance metaphor in sports, i.e. the coach wants the players to be sufficiently aroused to perform at their best, but not overly aroused because then they start making mistakes.

The Yerkes-Dodson law also explains situations where stress or arousal is self induced, e.g. when a really tired driver starts talking to himself to avoid falling asleep. In fact, one way of explaining why truck drivers show less risk of crash or near crash involvement when using CB radio [7] could be on exactly these lines; when tired or drowsy the driver calls up a friend and starts up a conversation in order to increase his own alertness.

However, while the Yerkes-Dodson law can be used to explain why simple and moderately complex tasks improve driving performance, it does not account for why complex tasks lead to increased crash risk. The reason for this is that engaging in secondary, non-driving related tasks while driving is largely a self paced activity. In other words, the driver chooses when, where and for how long s/he should do it, as well as how to time-share between that and the driving task.

Given that drivers generally do not want to crash, it follows that there must exist a mechanism by which complex tasks, but not simple or moderately complex tasks, compromise the driver's capacity to judge when, and to what extent s/he should engage in that task. To understand what this mechanism might look like, it is first necessary to put forward a general understanding of driving and the driver's role in it.

ADAPTIVITY

One way of viewing driving is as a control task which involves continuous adaptation in the face of a changing environment, in a way which promotes goal fulfillment [14]. Control can be generally defined as the ability to direct and manage the development of events [15] , or more specifically the maintenance of one or more goal states in face of disturbances [14].

In engineering control theory, a goal state is often called the reference, or target, value. To describe how drivers set these target values, Näätänen & Summala [16] proposed the zero-risk theory. The theory says that driver behavior can be understood as a balancing act between excitatory "forces" that represent a motivation for the driver to actively seek and exploit opportunities for action present in the environment (such as looking for a gap to overtake in), and inhibitory forces, originally proposed as based on experiences of subjective risk, and driven by a desire to avoid such risk completely.

Vaa [17] recently developed this idea further by incorporating Damasio's concept of *somatic markers* [18], i.e. emotional signals that attach positive or negative values to possible action choices, based on the outcome of making similar choices in the past. Vaa states that adaptive driver behavior largely is governed by such somatic markers, i.e. the driver experiences unpleasant feelings in response to threatening situations and acts accordingly. Building on this, Summala [19] proposed a modified zero–risk model where the driver strives to maintain a state of zero discomfort rather than zero subjective risk.

The way drivers select reference values for the control tasks can thus be viewed as a balance act between a desire for goal fulfillment and discomfort avoidance. The result is adaptive driver behavior, where drivers respond to changes in driving demand (current and predicted) by selecting reference values that will result in goal fulfillment without generating feelings of discomfort.

In more general terms, drivers principally seek goal states which they believe are within a safety zone [19]. Also, to maintain the state of zero discomfort, drivers generally prefer goal states with a certain minimum distance, or safety margin, to the safety zone boundary. This can be conceptualized as a comfort zone, i.e. a region of reference values for which no discomfort is felt or predicted by the driver, and which the driver therefore prefers to stay within. If the comfort zone boundary is exceeded, a feeling of discomfort will be experienced, resulting in adaptive behavior in terms of corrective actions [19][20].

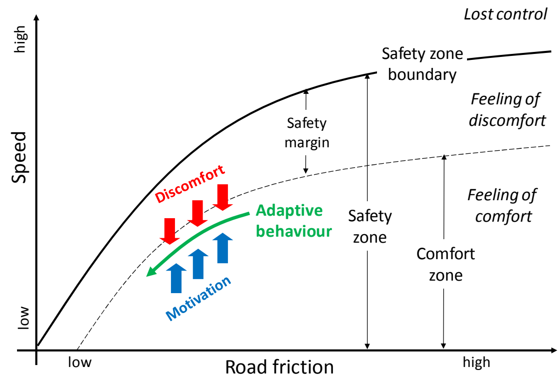

Figure 2: Illustration of driver adapting speed to comfort zone boundary in face of changing friction conditions (adapted from [19]).

In this example, the driver successfully perceives the change in safety zone boundary which occurs when friction is reduced due to for example a sudden snowfall. Since the current speed feels uncomfortable in relation to this change in conditions, the driver adapts by slowing down to a speed well below the safety zone boundary for the new friction conditions, and manages to do so without exiting the comfort zone. The driver thus avoids feelings of discomfort as well as loss of control.

Successful adaptation and, hence, maintenance of control, depends on several factors. One is an accurate estimation of the safety zone boundary. This includes accurate perception of variables which specify the physical limits for action, such as road geometry, presence of other road users, friction, etc., but also relies on general information (e.g. from a traffic information service) and previously acquired world knowledge (e.g. roads may become extra slippery in shaded areas after night frost).

Another key factor that governs successful adaptation is expectancy. In general, drivers adapt their goal states not only based on what the current situation looks like, but also on how they expect it to unfold. In particular, expectancy determines drivers' anticipatory visual search and attention allocation strategies [21][22][23]. Expectancy is supported both by perception of the current driving situation (position of other vehicles, etc) as well as by previous knowledge and experience of traffic environment properties and road user behavior.

A third factor is the way in which drivers update their estimate of the safety zone boundary. In engineering, control is discussed in terms of optimization, with the aim of minimizing any deviation from intended goal states. However, human control seems to follow another principle. The reason is that maintaining control requires effort, and people are generally unwilling to invest more than the perceived necessary effort to reach a satisfactory level of control performance. Since optimal performance usually requires more effort than doing something ”good enough”, people tend to trade off performance against effort in order to preserve energy [24]. This type of control can be called satisficing control, and represents a form of energy conservation. Satisficing can be regarded as the normal mode of operation in everyday driving [25][26][19], as well as in human decision making in general [27][28].

One implication for driving is that drivers will reassess where they are in relation to the safety zone boundary in a satisficing rather than an optimizing way. For example, when driving on a wide motorway in sparse traffic there is little motivation to stay exactly in the middle of the lane. The driver may therefore tolerate some lane drift rather than attempt to keep the vehicle precisely at lane centre. In this condition, tracking and adjusting to the lane markers can be an intermittent rather than continuous activity, something which frees up time and resources for doing something else, should the driver be motivated to do so.

ADAPTIVITY - IMPLICATIONS FOR SAFE DRIVING

A key element in the relationship between driving and non-driving related tasks is time-sharing, i.e. how the drivers partition their time between the two tasks. If driving is conceptualized as a continuous adaptive process where drivers strive to stay within the comfort zone, then driving while doing something else can be characterised as a process where the driver continuously shifts between doing the other task and reassessing the safety zone boundary. Based on this view, one way of understanding how complex tasks may compromise safety is that they at times are able to disturb the reassessment of the safety zone boundary, either by prolonging the time between assessments so much that what goes on outside the vehicle changes significantly more than the driver expects, or by compromising the actual boundary assessment.

The ability of complex tasks to disturb reassessment of the safety zone boundary probably is due to a combination of emotional, cognitive and visual-motor components. Of these, the visual-motor component is perhaps the most obvious and immediately comprehensible (in fact, it actually corresponds to the definition of task complexity above [8]). If the driver has to look somewhere else than on the road to continue with a task, e.g. to read from a display or to coordinate hand/finger movements to press buttons on a handheld device, the time it takes to complete that visual-motor task will be a key determinant for the time between safety zone boundary re-assessments, i.e. looking back on the road and re-evaluating the driving situation.

Emotional components are also relatively easy to picture. In Näätänen & Summala’s original model [16], they are offered in terms of what they call *extra motives.* In relation to the comfort zone for driving described above, they predict that the feelings of discomfort induced by driving outside the “normal” comfort zone sometimes can be suppressed or outweighed by feelings related to *extra motives*. These motives typically come in the form of strong emotions, such as anger directed at a slow lead vehicle when short on time, a deep desire to impress co-travellers or the sensual pleasure of travelling at high speed [16].

However, extra motives can also be expected for non-driving related tasks. For example, when communicating with other people, sending time critical messages (“I’m running late, so you need to pick up the kids from school!”) might provide such an extra motive. When extra motives drive the performance of non-driving related tasks, these may become prioritized at the cost of the normal reassessment of the safety zone boundary, thus either delaying the assessment and/or reducing its accuracy.

In terms of cognitive components, Diamond et al suggest that in general, tasks that require the involvement of the pre-frontal cortex (PFC), should all exhibit the curvilinear rather than the linear component of the Yerkes-Dodson law [12]. In other words, one way of operationalizing the distinction between “simple” and “complex” tasks is to determine to what extent they involve a PFC mediated component. This is not directly applicable to Guo & Hankey's results [7], as the separation of tasks they use is based on manual-visual complexity rather than PFC involvement. For example, talking to a passenger is listed as a simple task, though that would (hopefully) be a clear sign of PFC involvement.

However, another way of conceptualizing the effect of cognitive load is as potentially contributing to quality degradation in the comfort zone boundary reassessment. Support for this idea comes from several recent studies which have found that drivers who do cognitive tasks respond slower to cued events. For example, drivers without cognitive loading respond faster to a braking lead vehicle if the braking is cued by an event further down the road, such as a pedestrian crossing the road, than when there is no apparent reason for the braking. Drivers doing a working memory task on the other hand respond as if the lead vehicle was braking for no apparent reason in both situations [30] [31].

Thus, while looking away from the forward roadway at the same time as something unexpected happens may be the key mechanism underlying critical events [32][24], one must not forget that an underlying reason for looking away in the first place may be a sub-standard assessment of the safety zone boundary (i.e. whether it is a good time to look away), due to cognitive load.

A NEW FRAMEWORK FOR UNDERSTANDING DISTRACTION AND ITS IMPLICATIONS FOR VEHICLE DESIGN

One assumption underlying the current debate on distraction is that distraction causes crashes. As the above discussion on the extent to which drivers engage in non-driving related activities shows, this represents an overly simplistic representation of the challenges of driving and how drivers cope with them. To understand how non-driving related tasks effect the risk of crash involvement, further performance shaping dimensions are necessary to include. First and foremost, the non-linear coupling between arousal and task complexity needs to be accounted for, i.e. one must integrate the realization that driving performance inherently depends on both the level of arousal as well as on the level of total task complexity.

One way such a new framework can be conceptualized is illustrated in Figure 3. Here the area of sufficiently high driving performance is conceptualized as a performance comfort zone, wedged between the states of insufficient driver arousal and too high total task complexity (i.e. the demand of driving and non-driving tasks combined).

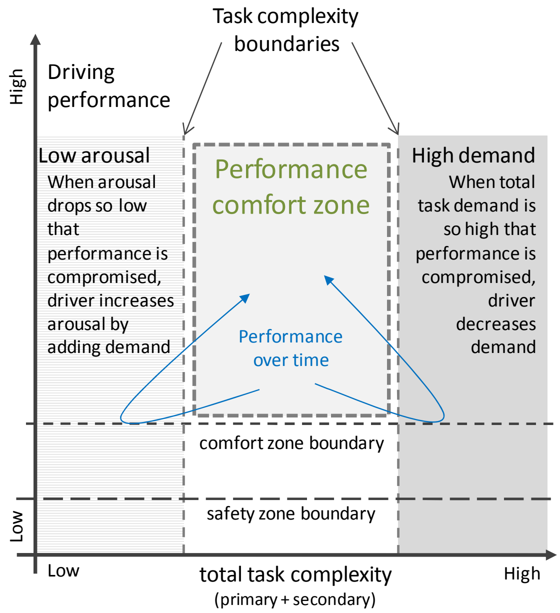

Figure 3: Driver adaptively staying in the performance comfort zone by adding demand when arousal is low and removing demand when complexity is high.

In terms of the discussion on arousal and adaptivity above, drivers in this framework are viewed as actors which proactively keep themselves in this performance comfort zone by adjusting total task complexity when approaching the performance comfort zone boundaries. When they feel their driving performance become too low (e.g. the driver is tired), and the driving task itself is too simple to maintain a sufficient level of arousal to keep performance up (.e.g. sparse traffic, monotonous road), they add one or more non-driving related tasks to increase total task complexity (like talking over CB-radio), thereby increasing their arousal which in turn pushes the level of driving performance up. Reversely, in driving situations where total task demand becomes so high that they are pushed close to, or outside, the comfort zone boundary, they adjust by reducing total task complexity, for example by slowing down (reduced primary task complexity) and/or suspending the non-driving related task.

This way of conceptualizing the relationship between driving and non-driving tasks has several implications for future vehicle design. First, in terms of maintaining a sufficient level of arousal to keep driving performance within the comfort zone (and thus within the safety zone boundary), one implication is that the vehicle could be used to actively engage the driver in a situation where the driver's arousal level drops so low that primary task performance is compromised and the driver fails to self-adjust. Accomplishing this presents two technical challenges; how to detect low arousal and how to create an interaction with the driver that increases driver vigilance.

In terms of detecting low levels of arousal, several systems are already being deployed in the vehicle fleets. For example, Volvo Cars has developed Driver Alert Control, which essentially tracks lane keeping performance to a degradation level predictive of drivers about to fall asleep [33]. While the current suggestion from the system to the driver should s/he exceed a certain level of impairment is to take a break, more sophisticated methods of interaction once this level of impairment is detected could be suggested, to cover also those drivers who for some reason are either unable or unwilling to break their journey.

Second, given the framework above, the negative effects which complex tasks occasionally have can be conceptualized as a delay or a quality degradation in the driver's reassessment of the comfort zone boundary, leading to involuntary boundary crossings and late adjustments. This description is in line with findings on typical accident mechanisms from the 100 car study [32] [34], and it points to two key parameters when it comes to designing new in-vehicle tasks that would be defined as complex according to Dingus et al

[8]. These are time sharing and what can be called immersion resilience.

Time sharing refers to how the driver divides his/her attention between the primary and secondary task. In principle, any non-driving related task should be possible to perform without compromising the possibility of a frequent reassessment of the safety zone boundary, i.e. each cycle of interaction with the non-driving task needs to be kept shorter than a certain length of time. For example, the 100 car study showed that the risk of risk of crash and near crash involvement was significantly higher for drivers who looked away from the forward roadway for more than 2 seconds within a 6 second time frame prior to the event [34], compared to looking away less than 2 seconds. This means that if each step of a non-driving task can be accomplished within say 1.5 seconds, the effect on crash risk of performing that task would probably be the same as when talking to a passenger, i.e. incident/crash risk remains neutral or decreases.

Immersion resilience refers to the need to avoid a situation where the secondary task in practice becomes the primary task, i.e. the non-driving task takes performance priority over driving. In the field of computer game design, the literature is rich with examples of how to enhance a player's level of immersion in a game (e.g. a simple search in the Science Direct-database on the keywords "game immersion" yields 2837 hits). However, in terms of in-vehicle task design, all findings on how to make the players "forget" the immediate surroundings and drag them into the game can essentially be viewed as an errata list, i.e. design features one need to implement differently in order to let the driver at all times prioritize the primary task. Accomplishing this is of course less straightforward than keeping interaction cycles short. However, one direct implication for evaluation is that when measuring interaction cycle length during multitask performance, one should not discard outliers in the data before verifying they their timing is uncorrelated to the steps of the task. Otherwise one might miss that or those steps which need redesign, in an otherwise sound interaction process.

Third, there will be situations where the driving task itself is so complex that engaging in any further tasks will be detrimental to driving performance. As this presents a form of upper boundary for task complexity, it follows that if a high quality assessment of the demands of the driving task can be made, one could in principle let drivers perform any non-driving related task which does not add to total task complexity in such a way that the boundary is crossed. Choosing when and where to let drivers perform non-driving related tasks based on primary task demand is often referred to as workload management. Initial steps have already been taken in this domain. For example, Volvo Cars have developed the Intelligent Driver Information System (IDIS), which delays information from the car's onboard systems or re-routes incoming calls to voice mail when on entrance ramps to freeways, etc. However, more can probably be done in this area, given the decreasing cost of sensors and computing power.

Fourth, most tasks listed in the NHTSA crash analysis and the NDS studies as distractions (e.g. eating, drinking, smoking, checking one's hair in the rearview mirror, engaging in conversations with passengers, reaching for items on adjacent seat, etc) are difficult influence through vehicle design. Moreover, inasmuch as some non-driving task engagement is driven by extra motives, it is difficult to conceive of a remedy based on vehicle design. One must therefore continue to expect that situations where driver performance is degraded due to non-driving related task engagement will continue to occur, even if the design of all in-vehicle system interactions should be perfected.

To mitigate the possible negative outcomes of these situations, a different strategy is required. Fortunately, one such strategy is already in place in form of the advanced driver assistance systems currently being developed by vehicle manufacturers, such as Forward Collision Warning and Lane Departure Warning. Basically, one way of describing what these systems do is to say that they mitigate effects of distraction. In other words, they are thought to be the most effective in situations where the driver unwittingly compromises his/her preferred safety margin, i.e. when the reassessment of the safety zone boundary is late or inadequate, and where the system can alert the driver to this problem.

While many of these systems are already being deployed, given the framework description above it follows that they most likely can be further refined by an onboard assessment of the driver's task state. If one knows when the driver is engaging in a non-driving related tasks (e.g. through head-/eye tracking, or similar), the driver assistance systems could be proactively tuned to this task state by for example temporarily increasing their sensitivity and/or giving the warning slightly earlier, should the need arise. In this way, it is possible to compensate for possible driver response delays due to the time needed for reassessment once the driver gets back in the loop .

CONCLUSIONS

In this paper, a conceptual framework which uses the dimensions of arousal and adaptation and task complexity to characterize the relationship between performance on driving and non-driving related tasks, is outlined. An analysis of recent studies on the prevalence of non-driving related activities in naturalistic driving studies and crash databases suggests that distraction cannot be understood as a linear relationship between secondary task involvement and crash risk. Instead, primary task demand, secondary task complexity, the level of arousal in the driver and any warning/intervention capabilities of the vehicle all need to be integrated and accounted for in order to accurately assess the extent to which secondary task involvement may degrade primary task performance. Based on this framework, several implications for the future design and availability of in-vehicle tasks are outlined, along with a discussion of which complementary steps may be necessary to fully mitigate the negative consequences of doing non-driving related tasks.

While the proposed framework may be overly complex for some situations (e.g., taking active safety systems into account will not be relevant for non-equipped vehicles), it is nonetheless believed that discussions and actions related to driver distraction will benefit from a more integrated, multidimensional framework for analyzing and understanding the difficulties distraction poses.

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INFLUENCE OF THE MINIMUM SWERVING DISTANCE ON THE DEVELOPMENT OF POWERED TWO WHEELER ACTIVE BRAKING

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ABSTRACT

Among driver assistance systems recently applied to PTWs (ABS, CBS, etc.), the autonomous braking without input from the rider, named *Active Braking (AB),* is one of the most promising safety functions. The potential benefits of the AB are encouraging, although the improper activation of the AB is dangerous for the rider. Therefore the triggering must occur only when the vehicle is in stability conditions and the obstacle is no longer avoidable neither by braking nor by swerving.
In the present paper the last-second swerving maneuver is analyzed to identify the minimum swerving distance (L_{sw}) the rider requires to avoid the collision against an obstacle by turning, as an input for the triggering logic of the AB system. A physical model to define the minimum swerving distance is proposed. To validate the model, an experimental campaign was carried out using a scooter equipped with a prototype AB system and involving 12 test riders. The tests showed the good prediction capability of the L_{sw} algorithm for different riding styles and different scenarios with fixed obstacles.

INTRODUCTION

In the last ten years (2000-2009) the number of road fatalities in Europe significantly decreased. In the same period the number of the fatalities in moped accident generally decreased, although the number of motorcycle and scooter fatalities increased in 8 European countries[1]. The motorized two wheelers require countermeasures and especially motorcycles and scooters.
In the automotive field among the state of the art in terms of non-collaborative safety technology is the AEB (Autonomous Emergency Braking) which started to equip some of the high end passenger cars. A similar system was proved to be applicable to PTWs and the potential benefits were shown [1]. This autonomous braking system for PTWs was named active braking (AB).
The AEB for passenger cars is triggered when the parameter time to collision (TTC) is lower than 1 s [2, 3], i.e. when the collision is substantially unavoidable. Similarly, the AB was designed to deploy when the collision is physically inevitable thus skipping the risk for a dangerous triggering when the rider's maneuvering can still avoid the crash.
The research on the AB system for PTW focused on the car-following configuration along a straight path. This restriction reduces the applicability of the AB although the basic configuration represents a fundamental step for the system development.
The triggering algorithm compares the obstacle distance with the minimum distance needed to avoid the crash either by purely braking or purely swerving. The potential shorter avoidance distance obtained by a combination of braking and swerving will be theoretically investigated.
The present paper focuses on the validation of the model computing the minimum swerving distance. The model was tested with an experimental campaign involving 12 riders who performed last second avoidance maneuvers of a fixed obstacle at different speed and with different obstacle width.

MINIMUM SWERVING DISTANCE

The swerving maneuver was described by several models assuming time-based algorithms [2] and distance-based algorithms [4, 5, 6].
The model proposed in this paper is distance-based and it is used to compute the L_{sw} distance representing the theoretical limit beyond which the obstacle is no more avoidable by an evasive maneuver. Comparing L_{sw} with the distance between the host vehicle and the leading vehicle it is possible to evaluate the possibility to perform the swerving emergency maneuver and avoid the collision. The collision becomes unavoidable if the distance from the obstacle x_{obj} is lower than the braking distance and there is no trajectory available to elude the collision with the obstacle by an evasive maneuver.
The L_{sw} algorithm provides a simplified kinematics of the maneuver based on a steady turn: the detailed dynamics is replaced by a geometric model. The

1 International Traffic Safety Data & Analysis Group "IRTAD Road Safety 2010 – Annual Report".

L_{sw} model is computed under the following hypotheses:

- the PTW performs a steady turn;
- the velocity of the PTW and the velocity of the leading vehicle are constant;
- the radius of the trajectory is the minimum radius (R_{min}) the PTW can achieve according to the maximum feasible roll angle.
- The model assumes constant R = R_{min} along the whole evasive maneuver.

With these hypotheses the real maneuver should take a longer space than the theoretical maneuver. The real maneuver is composed of two parts:

- the initial transient where the rider applies the countersteering action to enter the turn. The trajectory radius in this part of the maneuver (R_{it}) is higher than the radius of the L_{sw} trajectory, $R_{it} > R_{min}$;
- the unsteady curve after entering the turn. The unsteady effects while maneuvering give the possibility to perform the second part of the evasive curve with a radius R_{uc} lower than the R_{min}, $R_{uc} < R_{min}$.

The L_{sw} model assumes that the aforementioned aspects of a real curve compensate each other and the initial transient effects are higher than the unsteady effects. Accordingly the L_{sw} model represents a theoretical limit: the rider cannot avoid a collision with an obstacle by performing the swerving maneuver at a distance lower than the L_{sw} distance.

The curve description using the swerve model takes into account the maximum roll angle (φ_{max}) the PTW can achieve. This parameter is a function of the adherence between the tire and the road. The model considers the maximum value of the side acceleration $a_{y,max}$ constant along the trajectory. Hence the radius of the path is computed according to Equations (1) and (2),

$$R_{min} = \frac{V_{PTW}^2}{a_{y,max}} \qquad (1)$$

$$a_{y,max} = g \cdot \tan(\varphi_{max}) \qquad (2)$$

where g is the acceleration of gravity and V_{PTW} the PTW velocity. The PTW and the leading vehicle velocities and the obstacle width are the other variables for the L_{sw} model. The L_{sw} curve is computed by the Equation (3),

$$L_{sw} = \sqrt{2 \cdot R_{min} \cdot (\mathrm{b}+\mathrm{e}) + b^2 - e^2} - \mathrm{k} \cdot V_{PTW} \cdot V_{obj} \cdot \arccos\left(\frac{\mathrm{R_{min}} - \mathrm{e}}{\mathrm{R_{min}} + \mathrm{b}}\right) \qquad (3)$$

$$\mathrm{k} = \frac{1}{g \cdot \tan(\varphi_{max})} \qquad (4)$$

where b is half the width of the host vehicle, e is the side length of the obstacle according to the driving path (Figure 1). The first part of the Equation (3) describes the swerving distance considering

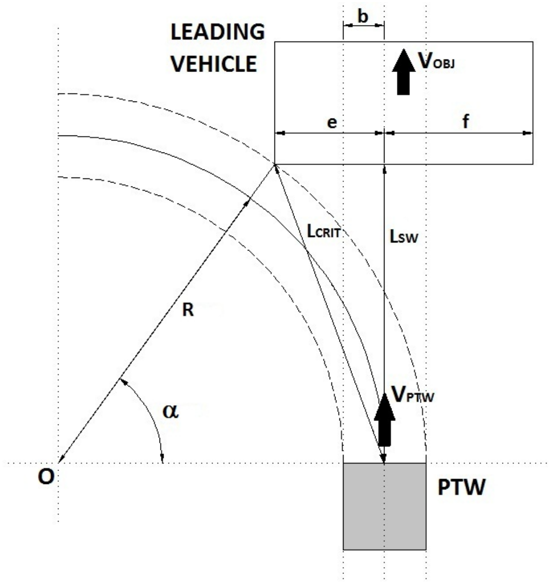

Figure 1. Last-second swerving maneuver.

a static obstacle in front of the host vehicle. The second part takes into account a moving obstacle with velocity V_{obj}. When the vehicle is not aligned with the leading vehicle, a model similar to [7] (Figure 1) can be adopted. It considers the side edge of the obstacle in order to compute whether the evasive maneuver is allowed instead of the L_{sw} distance: the escape trajectory is not available if the leading vehicle has a side edge closer than the distance L_{crit}.

The L_{crit} distance is given by the Equation (5).

$$L_{crit} = \sqrt{{L_{sw}}^2 + e^2} \qquad (5)$$

In the present paper the L_{sw} model was adopted.

Comparison with the Kamm's circle

The L_{sw} model is a modified version of the distance-based algorithm using the *Kamm's circle theory* [8] adopted by Kampchen [4] and Schmidt [5]. The Kamm's circle theory considers all the possible trajectories the host vehicle can perform to avoid the collision. It computes the evasive trajectories assuming the maximum side forces that rise in the tire-road interaction. A simplification to the algorithm is to consider the forces between the road surface and the PTW tire as isotropic, hence the ellipse of the adherence coefficient is a circle. The overall acceleration a that a PTW can generate is a combination of the longitudinal acceleration a_x and the side acceleration a_y. The combination of those two components is a function of the angle γ:

$$\begin{cases} a_x = a \cdot \cos(\gamma) \\ a_y = a \cdot \sin(\gamma) \end{cases} \qquad (6)$$

The possible evasive maneuvers are functions of the acceleration a, the angle γ and the initial PTW

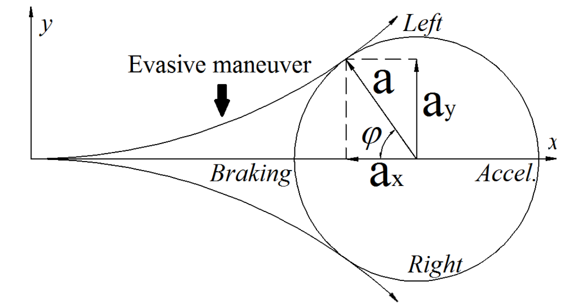

Figure 2. Evasive maneuver computed by the Kamm's circle.

velocity V_{PTW} and they are tangent to a circular region with radius $a_{y,max}$ (Figure 2).
According to the Kamm's circle theory the minimum swerving distance ($L_{sw,K}$) is computed as in Equation (7):

$$L_{sw,K} = \sqrt{\frac{2\cdot e}{\mu\cdot g\cdot\sin(\gamma)}}\cdot\left(V_{PTW}-V_{obj}\right) + e\cdot\frac{\cos(\gamma)-\frac{d_{obj}}{\mu\cdot g}}{\sin(\gamma)}; \quad (7)$$

$$\gamma: \frac{(V_{PTW}-V_{obj})\cdot\cos(\gamma)}{\sqrt{2\cdot\mu\cdot g\cdot e}} + \frac{1-\frac{d_{obj}}{\mu\cdot g}\cdot\cos(\gamma)}{\sqrt{\sin(\gamma)}} = 0; \quad (8)$$

where μ is the adherence coefficient and d_{obj} is the deceleration of the leading vehicle. The authors implemented the MAGIC FORMULA by Pacejka [9] for motorcycle tires to compute the adherence coefficient in detail. Hence the main parameters affecting μ without considering the inertial features of the PTW are the sideslip angle and the roll angle. The sideslip angle was set to 1°. To show the differences between the L_{sw} model and the Kamm's circle model the minimum swerving distances are computed in the following conditions:

a. same maximum roll angle;
b. same adherence coefficient.

Case a.

Taking into account different roll angles the models give different minimum swerving distances. As Figures 3a, 3b and 3c show at low values of the roll angle the L_{sw} distance is higher than the distance of the Kamm's model, whereas at high roll angles the situation is inverted.
When comparing the minimum swerving distance using the same maximum roll angle, the two models produce different results. When the roll angle is higher than 30° the L_{sw} distance is lower than the Kamm's swerving distance, therefore the L_{sw} is precautionary. When the roll angle is lower than 30° the Kamm's swerving distance is lower than the L_{sw} distance. Nevertheless those distances are greater than the distances computed with higher roll angles.

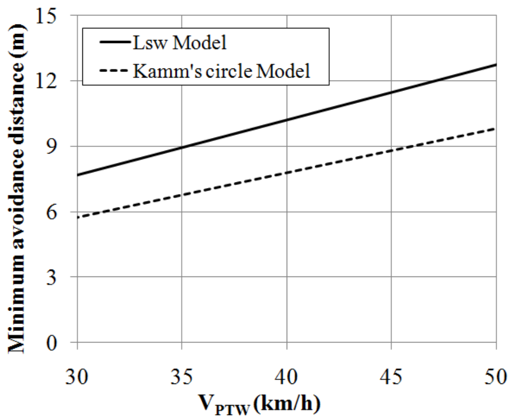

Figure 3a. Comparison between the L_{sw} curve and the Kamm's circle curve considering a roll angle φ_{max} = 15°.

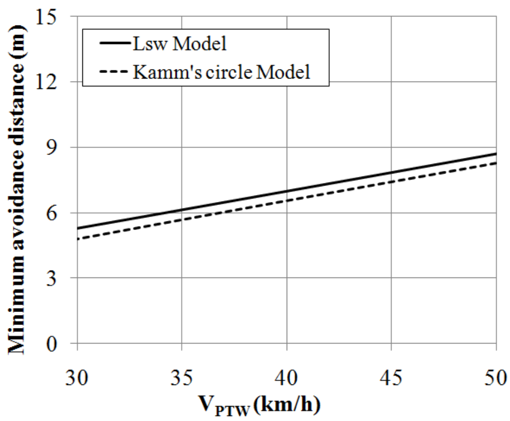

Figure 3b. Comparison between the L_{sw} curve and the Kamm's circle curve considering a roll angle φ_{max} = 30°.

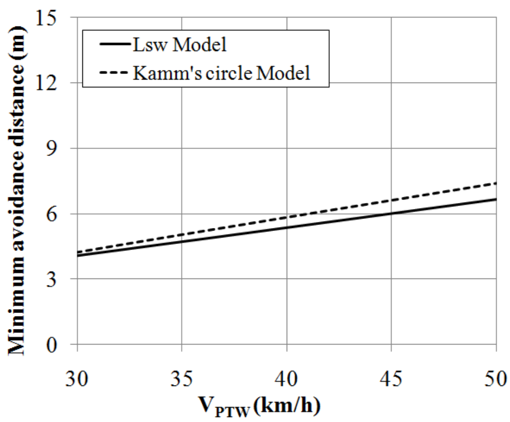

Figure 3c. Comparison between the L_{sw} curve and the Kamm's circle curve considering a roll angle φ_{max} = 45°.

Case b.

When the adherence coefficient is the same the curves are almost overlapped even with different roll angles (Figures 4a, 4b and 4c).

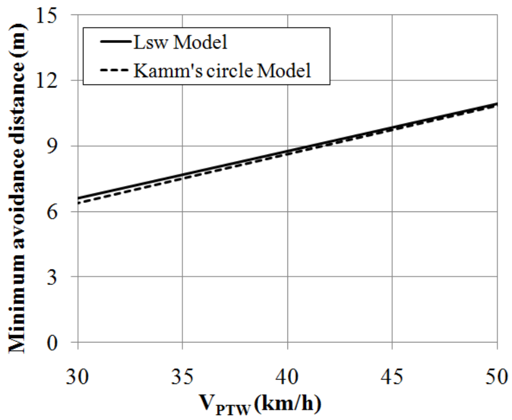

Figure 4a. Comparison between the L_{sw} curve and the Kamm's circle curve considering an adherence coefficient μ = 0.36.

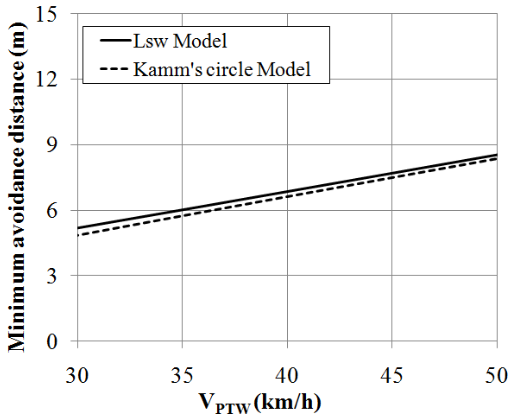

Figure 4b. Comparison between the L_{sw} curve and the Kamm's circle curve considering an adherence coefficient μ = 0.6.

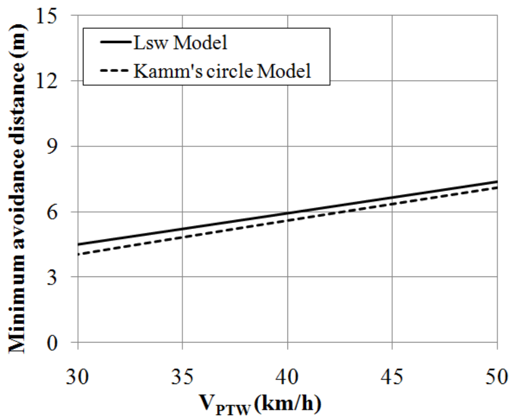

Figure 4c. Comparison between the L_{sw} curve and the Kamm's circle curve considering an adherence coefficient μ = 0.8.

Even if gaps of few centimeters are detected at low velocities between the displayed curves, the minimum swerving distances are the same at different velocities. This aspect is highlighted at low values of μ where the models overlap over the velocity range.

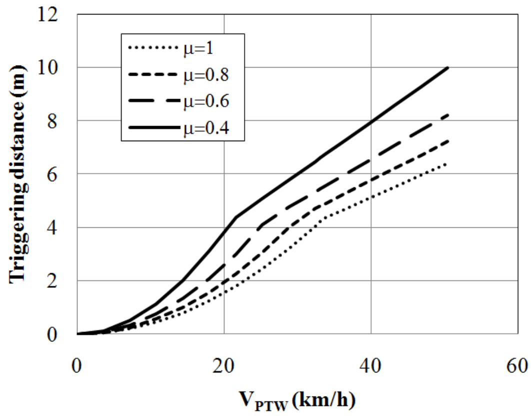

Figure 5. Minimum avoidance distance as a function of the PTW velocity (V_{obj}=0).

Potential benefits

The potential benefits of the AB were calculated based on the basic braking model and the L_{sw} method considering the hypothesis of high adherence coefficient: μ=1. When the adherence is low, e.g. in the case of wet surface, the minimum avoidance distance is higher (Figure 5).

As a consequence the collision becomes unavoidable at higher distance and the triggering could occur earlier, thus increasing the potential effectiveness of the AB. However the measurement of μ is still challenging. The approach consisting in taking μ=1 when the actual adherence is lower than 1 does not allow the full exploitation of the AB in all the conditions, although it is precautionary for those cases where the adherence is high. The comparison between L_b and L_{sw} shows that the swerving maneuver is more effective than braking at high velocity (Figure 6). The L_{sw} distance depends on the velocities and it is affected by the maximum achievable roll angle and the obstacle width (Figure 7).

When the maximum roll angle is higher, the minimum swerving distance is lower whereas the wider obstacle produces an increment in the swerving distance. The maximum roll angle in case of fair adherence it is up to 45° but it can be limited for a specific PTW by the actual lateral shape. The obstacle width in a car following configuration can vary from 0.6 m representing a single track vehicle up to 3 m representing a heavy load truck. Focusing on the urban scenario where the speed limit is 50 km/h the swerving maneuver is relevant in the range between 30 km/h and 50 km/h. Therefore the validation of the swerve model was conducted in that speed range.

The benefits are calculated as the reduction of kinetic energy at the impact produced by the AB system compared with the case where the rider does not react. The AB deceleration takes place at the instant when the actual distance is equal to the

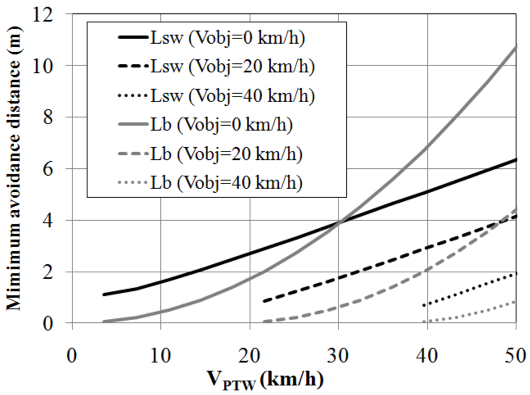

Figure 6. Comparison between the L_{sw} model and the Braking model. Required PTW deceleration d_{req}= 9 m/s^2.

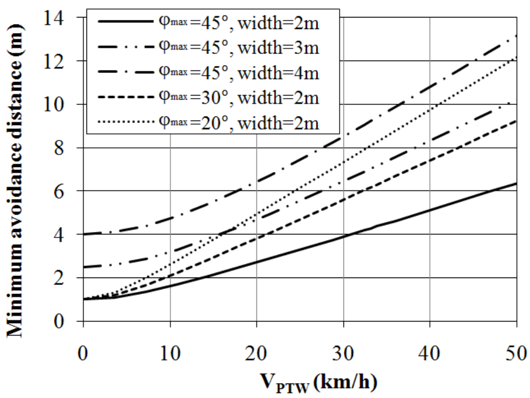

Figure 7. The L_{sw} model taking into account different values of µ and different values of obstacle width.

theoretical avoidance distance. The system will take care of producing a warning signal to alert the rider 0.3 s in advance to the active deceleration. Moreover the hydraulic system should be pre-loaded in order to obtain the active deceleration without any delay.

Calculation of the theoretical energy reduction was made fixing the AB intervention parameters and varying the obstacle width, the max roll angle and the leading vehicle velocity (Figure 8 and 9).

As shown in the pictures the benefits are influenced by the following parameters:

- obstacle width
- leading vehicle and host vehicle velocity
- φ_{max}.

The value of φ_{max} (the max roll angle during the swerving maneuver) affects the potential benefits of the AB. In particular, the benefits are lower for agile vehicles allowing for higher roll angles. The impact energy reduction is influenced by the obstacle width and is significantly higher when the obstacle is wider. For very narrow obstacles the option to inhibit the AB activation has to be taken into consideration since the benefits are minor and

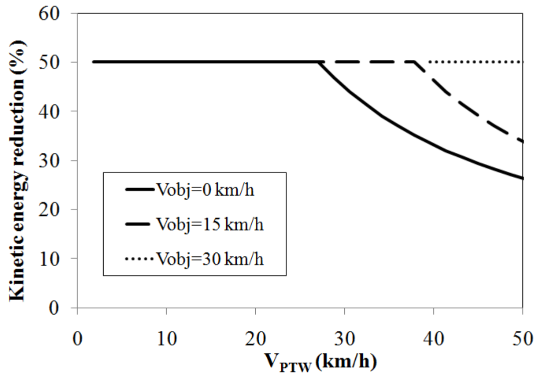

Figure 8. Energy reduction in a collision with different V_{obj}. Required PTW deceleration d_{req}= 8 m/s^2, AB deceleration d_{AB}= 4 m/s^2.

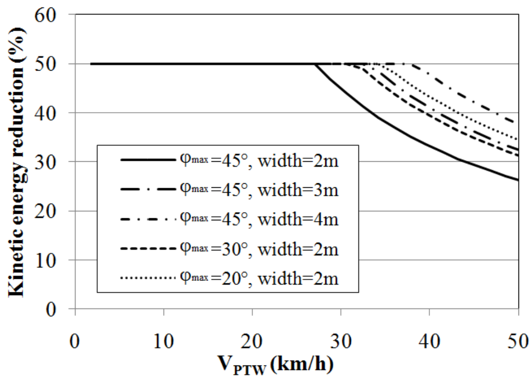

Figure 9. Energy reduction in a collision with different φ_{max} and different obstacle widths. Required PTW deceleration d_{req}= 8 m/s^2, AB deceleration d_{AB}= 4 m/s^2.

the risk for a false triggering is higher. The benefits are calculated considering the PTW aligned with the tail center of the leading vehicle. When the PTW is not centrally aligned the swerve model in Figure 1 can be adopted. The host PTW velocity influences the potential benefits as well.

Swerve detection

A criterion to identify the distance at which the rider begins the evasive maneuver was defined. The detection the maneuver has started is based on the tilt status of the PTW, considering two parameters:

- the roll angle;
- the roll rate.

The authors defined the beginning of the swerving maneuver at the instant t_d when the PTW reached 5° of roll angle or 25°/s of roll rate. Those values were fixed according to a preliminary analysis on the experimental outcomes. The algorithm based on the roll angle detection gives the possibility to identify the swerving maneuver while performing curves that demand high roll angle and the use of the control of the roll rate in addiction enables the detection of maneuvers characterized by low roll

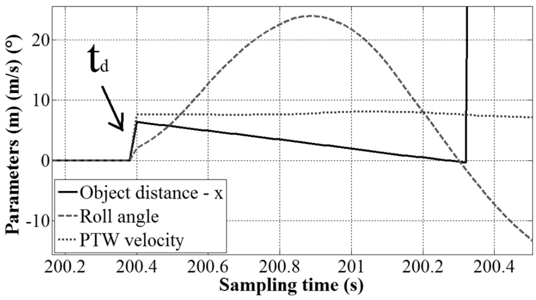

Figure 10. Detection of td instant at the beginning of an evasive maneuver.

angles and quick movements. The Figure 10 shows the detection instant t_d during the emergency evasive maneuver.
The algorithm proposed for the data post processing was used in real time on the control logic system as well. This gave the AB system a tool to identify the beginning of the swerving maneuver and detect the unstable conditions of the PTW, when a AB triggering would be dangerous in theory.

TESTING

An experimental campaign was conducted to compare the theoretical L_{sw} with the swerving spaces of a set of 12 subjects while performing last second swerving maneuvers. The subjects were volunteers with more than 5 years of riding license and different riding experience. The equipment consisted in a 500 cm^3 scooter with high inertia and high wheelbase equipped with sensors including an inertial measurement unit (IMU) and a compact laser scanner located in the front shield (Figure 11). The IMU measured the state parameters of the PTW, whereas the laser scanner measured the distance of the obstacle with fair accuracy. The obstacle distance was also measured with the on board sensor to show a potential solution for the implementation of the AB system. An on board control unit processed the signals and performed the data acquisition.
The tests were performed in empty and free space using a modular obstacle constituted by cardboard boxes (Figure 12). The test trials aimed to investigate the swerving maneuver at different velocities up to 50 km/h and different obstacle widths, the obstacle being static. Before starting the tests, every test rider was given a free amount of time to train with the vehicle and with the avoidance maneuver. The mean settling time was 8 minutes, ranging from 5 to 10. The test run consisted in approaching an obstacle at a target velocity and along a straight trajectory aligned with the centre of the obstacle and performing a last second avoidance maneuver without braking while swerving.
The vehicle started from stationary condition and the obstacle was positioned 60 m far from the PTW.

Figure 11. The scooter and the acquisition system used for the experimental tests.

Figure 12. One of the evasive maneuvers performed in the experimental tests.

Each rider performed several runs at different target velocities and swerved around an obstacle.
The tests were performed with 1.2 m, 1.8 m and 3 m obstacle widths, as summarized in Table 1. The accuracy of the detection of the obstacle position and actual heading/trajectory of the host PTW was not enough to deal with smaller obstacles.

Table 1.
Number of runs performed for each PTW velocity and for each obstacle width.

	30 km/h	40 km/h	50 km/h
1.2 m	4 (left) 4 (right)	4 (left) 4 (right)	4 (left) 4 (right)
1.8 m	-	6	-
3.0 m	-	6	-

A total of 450 tests were performed and 402 of them were considered eligible for the analysis.

Analysis of the swerving maneuvers

The analysis of the data acquired during the tests highlighted different styles among the riders in the first part of the swerving maneuver. The differences regarded the steering angles and the maximum roll

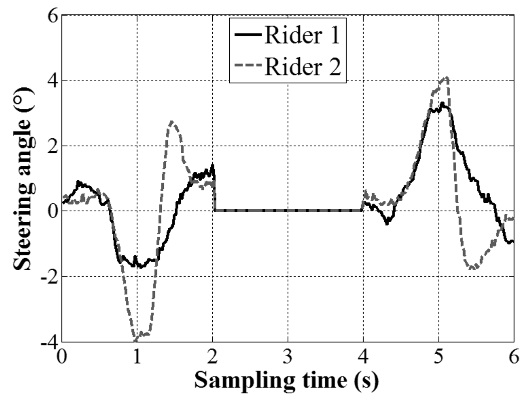

Figure 13a. Comparison of the steering angles between two riders during a right and left side evasive maneuver.

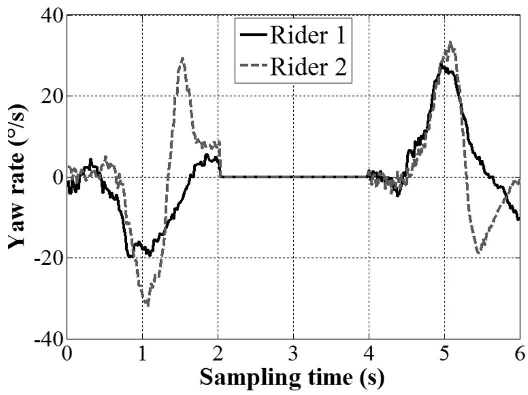

Figure 13b. Comparison of the yaw rates between two riders during a right and left side evasive maneuver.

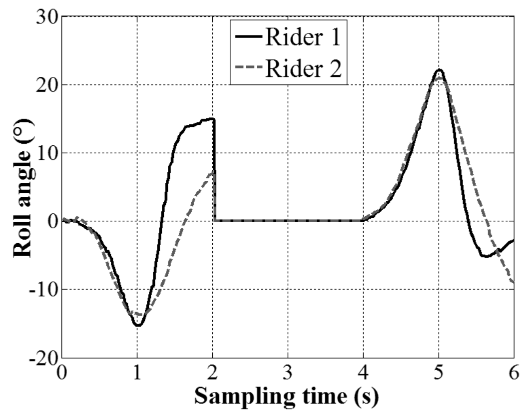

Figure 13c. Comparison of the roll angles between two riders during a right and left side evasive maneuver.

angles achieved while turning. A number of riders applied significantly higher steering rates and large steering angles at the beginning of the maneuver thus obtaining higher yaw rates. This behavior gave the rider the possibility to reduce the radius of the curve trajectory thus reducing the emergency swerving distance. On the contrary other riders applied smaller steering angles associated to higher values of the maximum roll angle. Those riders were compelled to begin the maneuver few meters in advance that the riders that used to apply higher steering angles while turning. Figures 13a, 13b and 13c show the comparison between two riders belonging to the aforementioned classes of driving styles.

Results

For each one of the 402 analyzed runs, the time instant t_d representing the beginning of the swerving maneuver was identified using the swerve detection algorithm in off-line mode.

The quantities V_{PTW} and x_{obj} at time t_d were extracted from the logged data in order to compare the actual swerving space with the theoretical L_{sw} (Figure 14).The index of gap between L_{sw} and x_{obj} was defined as follows:

$$I_g = \frac{x_{obj,t_d} - L_{sw}}{L_{sw}} \tag{9}$$

In Figures 15a, 15b and 15c the results of the tests are plotted in diagrams showing the value of the gap index for each run as a function of the initial PTW velocity. Each diagram groups the runs performed with a certain obstacle width.

Firstly the whole set of test runs reported a positive outcome in terms of predicted minimum swerving distance. In fact the swerving space utilized by each rider in each test configuration was higher than the theoretical L_{sw} for the specific configuration.

Secondly, the model is able to identify the minimum swerving distance with a limited gap between the theoretical value and the *best cases* of the test runs, both for different PTW velocities and for different obstacle widths. A small gap means that the inhibition of the AB due to the possibility to avoid the collision by swerving is removed at a distance just above the best performance in a real maneuver. This means the benefits of the AB are maximized. When the gap is close to zero it also means that the risk of a false triggering case becomes high, since a very skilled rider might overcome the performances of the test riders thus producing a fault of the L_{sw} model. A negative gap denotes that the swerving maneuver was performed in a distance smaller than the theoretical limit. The runs resulted in no negative gap cases. The L_{sw} model was designed for the car following scenario with a moving lead vehicle and the validation should consider the moving obstacle case. Such a validation campaign is dangerous for the rider since a collision with a light trail is sufficient to cause a fall. Albeit the tests described in the present work were conducted with fixed obstacles the results can be extended to the moving vehicle case with the

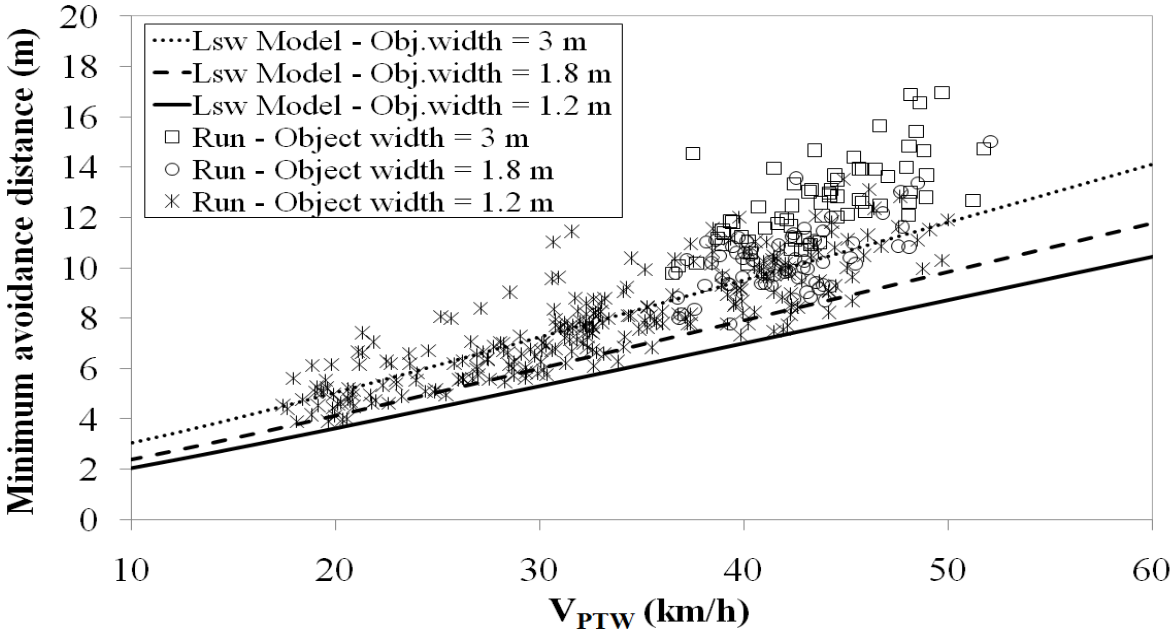

Figure 14. Experimental trials compared with the L_{sw} curves.

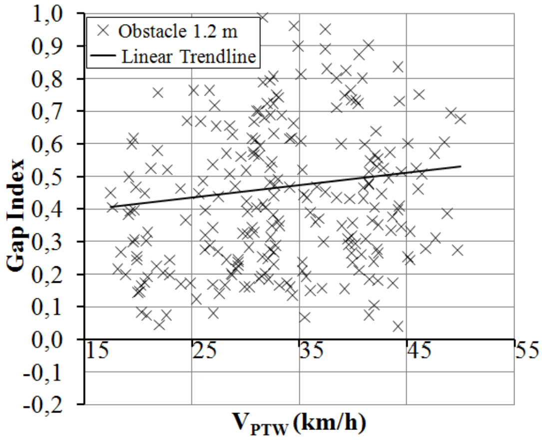

Figure 15a. Gap Index for each run of the experimental test with an obstacle width of 1.2 m

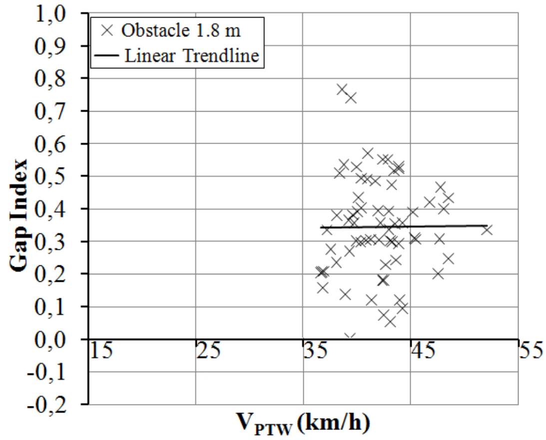

Figure 15b. Gap Index for each run of the experimental test with an obstacle width of 1.8 m

hypothesis that every rider produces the best performances in safer conditions (i.e. with the fixed obstacle). When performing the car following task the swerving spaces are expected to have higher dispersion, always being above the theoretical value L_{sw}. Further research should implement experimental tests dedicated to the validation of the L_{sw} model with a moving obstacle.

CONCLUSIONS

The research for the implementation of the AB is far from the spread in the series vehicles, although the feasibility of the system was proved and the potential benefits are of relevance. Even when the application of the AB is restricted to the basic car following scenario, it is fundamental to prove that the system is reliable and it will not trigger unless

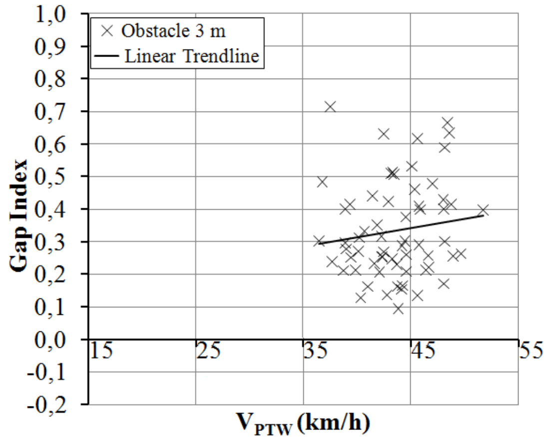

Figure 15c. Gap Index for each run of the experimental test with an obstacle width of 3 m

the PTW is upright and the rider cannot avoid the crash. The feasibility of a last second swerving maneuver is one of the criteria to allow or inhibit the activation of the AB. This work presented an experimental campaign whose results support the validation of the L_{sw} method which estimates the minimum swerving distance with a low computational effort and small margins. The tests showed a good accordance between the theoretical minimum swerving distance and the experimental results conducted with a large scooter. The L_{sw} algorithm is expected to be effective for different kind of PTWs although further investigation is required for a validation on smaller and more agile vehicles.

ACKNOWLEDGMENTS

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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-

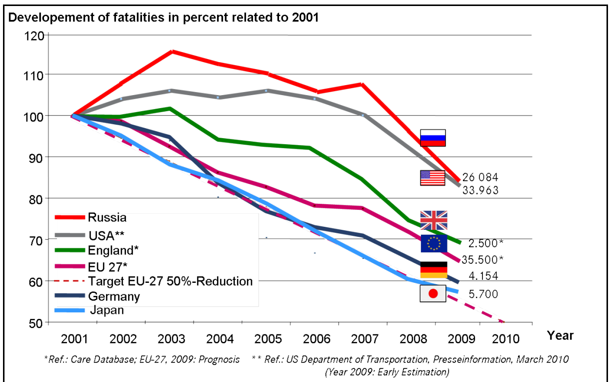

Figure 1: Trend of fatalities in road accidents from 2001 to 2009 in Germany, Great Britain, EU(27), USA, Japan, Russia

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].

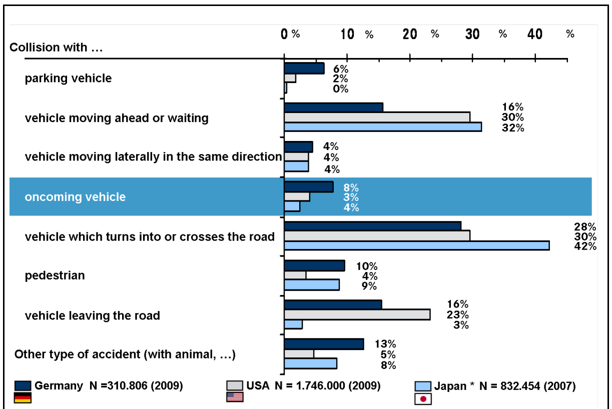

Figure 2: Distribution of the types of accidents involving personal injury. Figures for Germany (2009, DESTATIS), USA (2009, NHTSA) and Japan (2007, IATSS)

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).

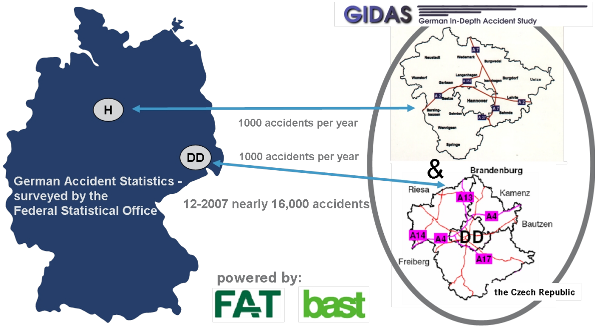

Figure 3: GIDAS - the research areas around Hannover and Dresden

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.

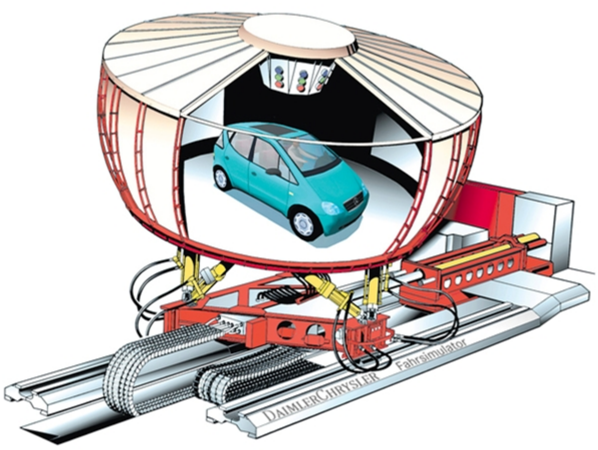

Figure 4a: Schematic diagram of the Driving Simulator of the Daimler AG in Berlin. Simulator was in use during 1985 - 2009.

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.

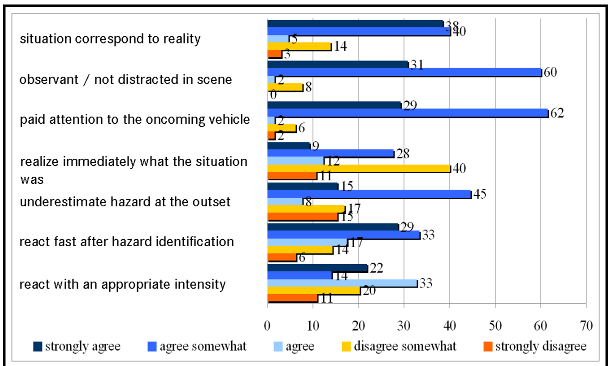

Figure 6: Self-assessment of response by the participants in the situation "Active overtaking"

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.

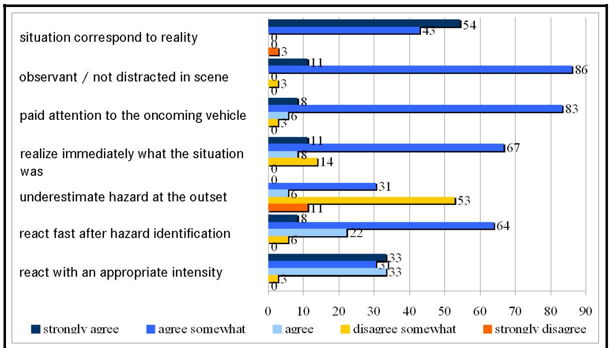

Figure 8: Self-assessment of response by the participants in the situation "Passive overtaking"

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.

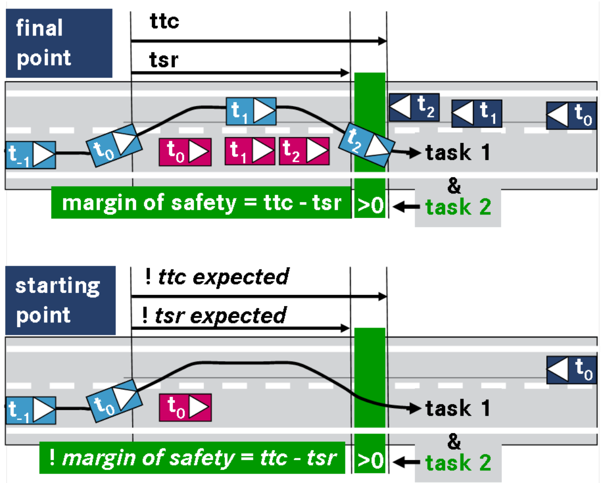

Figure 9: The two control tasks for for the driver while overtaking into oncoming traffic

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.

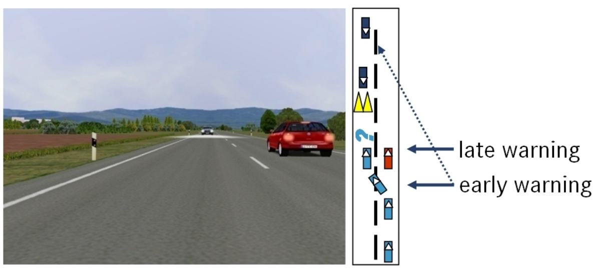

Figure 10: Operating principle of oncoming traffic assistant in the scenario "Active overtaking"

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.

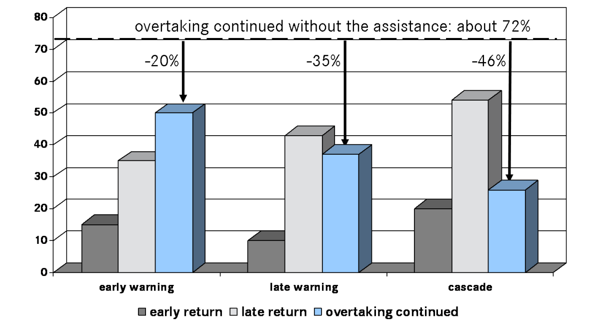

Figure 11: Analysis of overtaking rate with and without oncoming traffic assistant

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.

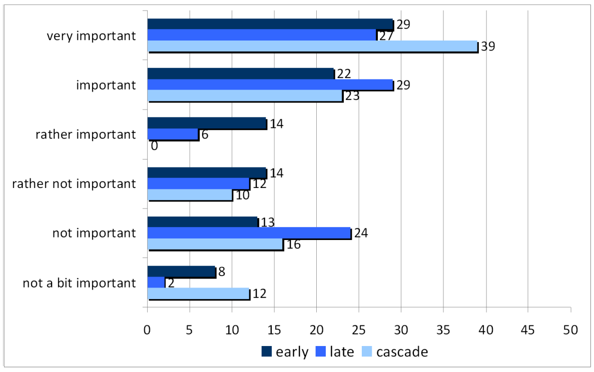

Figure 12 Provided by the participants to the significance of the warnings

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.

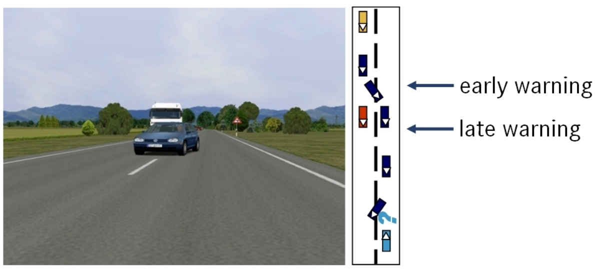

Figure 13: Operating principle of oncoming traffic assistant in the scenario "Passive overtaking"

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.

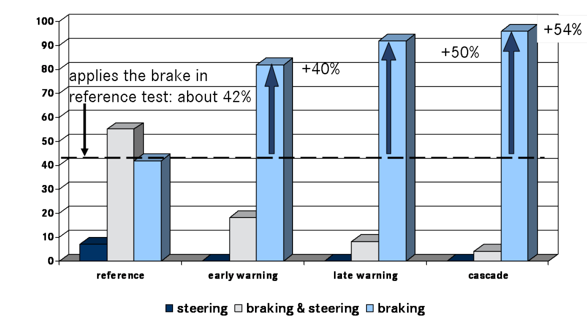

Figure 14: Analysis of the effect of the oncoming traffic assistant in the scenario "Passive overtaking"

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 .

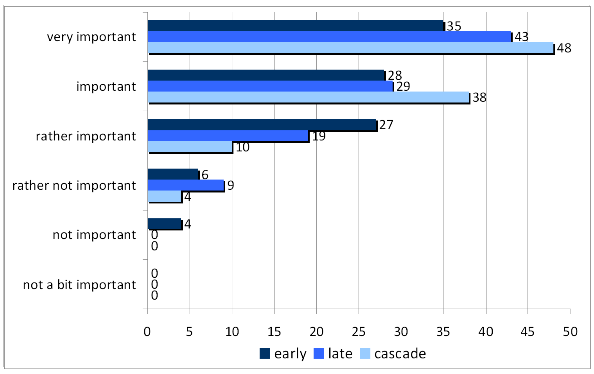

Figure 15: Provided by the participants to the significance of the warnings

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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