EVALUATION OF PEDESTRIAN TARGETS FOR USE IN AUTOMOMOUS EMERGENGY BRAKE SYSTEM TESTING - A REPORT FROM THE HARMONISTION PLATFORM 2 DEALING WITH TEST EQUIPMENT

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ABSTRACT

It is well known that most accidents with pedestrians are caused by the driver not being alert or misinterpreting the situation. For that reason advanced forward looking safety systems have a high potential to improve safety for this group of vulnerable road users. Active pedestrian protection systems combine reduction of impact speed by driver warning and/or autonomous braking with deployment of protective devices shortly before the imminent impact. According to the Euro NCAP roadmap the Autonomous Emergency Braking system tests for Pedestrians Protection will be set in force from 2016 onwards.
Various projects and organisations in Europe are developing performance tests and assessment procedures as accompanying measures to the Euro NCAP initiative. To provide synthesised input to Euro NCAP so-called Harmonisation Platforms (HP's) have been established. Their main goal is to foster exchange of information on key subjects, thereby generating a clear overview of similarities and differences on the approaches chosen and, on that basis, recommend on future test procedures.
In this paper activities of the Harmonisation Platform 2 on the development of Test Equipment are presented. For the testing targets that mimic humans different sensing technologies are required. A first set of specifications for pedestrian targets and the propulsion systems as collected by Harmonisation Platform 2 are presented together with a first evaluation for a number of available tools.

INTRODUCTION

Motivation

According to the World Health Organisation Global status report on road safety 2009, pedestrians account for more than 19% of road fatalities in the EU-27. Studies showed that a majority of accidents with pedestrians are caused by lack of attention and misinterpretation of the situation [1]. For that reason Autonomous Emergency Braking systems for Pedestrians (AEB-P) that use forward looking sensors to detect dangerous situations have a high potential to improve safety for this group of road users. These systems combine reduction of impact speed by driver warning and/or autonomous braking in combination with protective devices upon impact.

Some AEB-P systems are already on the market [refs], and their number is expected to increase rapidly over the next years. According to the Euro NCAP Roadmap AEB-P systems will be evaluated as from 2016 onwards [2].

Harmonisation Platforms

Procedures will be defined by the PNCAP group using information from a number of ongoing projects and organisations including:

1. *Advanced Forward-Looking Safety Systems (vFSS):* Cooperation between OEMs, research and insurance groups world-wide developing test and assessment methods for forward facing safety systems related to accidents with pedestrians and cars. vFSS also develops and applies methods on system effectiveness.
2. *Advanced Emergency Brake systems (AEB)*: Cooperation between insurance organisations Thatcham and IIHS with support from research groups, suppliers and OEMs. Aims and goals are identical to vFSS.
3. *Assessment methods for Integrated Pedestrian Safety Systems (ASPECSS)*: EU FP7 Project consortium of OEM's, suppliers, test houses, research organisations and universities. Research on test methods considering driver behavioural aspects (warning), pre-crash performance evaluation, crash performance evaluation and system effectiveness.
4. *Allgemeiner Deutscher Automobil-Club (ADAC)*: ADAC defined an evaluation method for AEBS considering the warning and autonomous braking actions to inform consumers on the system performance. The method was applied to various systems offered to the market and reported in the media.

To streamline input from the various projects so-called Harmonisation Platforms (HP's) have been established. The goal is to exchange information on key subjects and report to PNCAP. The projects will run independently but via the HP's they are well informed of mutual developments. Three HP's have been established:

• HP1 Test scenarios
• HP2 Test equipment
• HP3 Effectiveness analysis

The specifications in this report have been generated through HP2 integrating information from ASPECSS, vFSS and AEB as well as recommendations from ADAC. A set of specifications defined by vFSS was used as basis for further discussions and refinements in ASPECSS and AEB. The result will be integrated in the HP2 documentation to Euro NCAP in support of first decision making on a test set-up.

Objectives

The objective of this work is to establish specifications for test targets used in AEB-P testing and to provide a first evaluation of currently available tools.

Approach

To arrive at technology-independent test procedures the targets should represent relevant physical properties for the most common sensors like radar, video, Infra-Red and PMD. As a first step in defining the specifications experts on relevant sensing technologies were brought together to define requirements. Next a large scale event was organised in which a total of 16 vehicles with different sensing technologies on board evaluated a number of available targets on their detectability. Based on a subjective evaluation it was concluded that those dummies that met the initial specifications were detected best by all vehicles. The radar reflectivity, however, was not fully incorporated and needed further investigations. For this purpose dedicated testing was arranged in the European Microwave Signature Laboratory of the European Commission's Joint Research Centre. Volunteers and targets were scanned in different postures and from different view angles. Moreover the influence of clothing and personal items like phone and jewellery were studied resulting in a further refinement for the specifications with respect to this technology.
As the test target is integrated in a test set-up with propulsion system HP2 considers this item as well. A second workshop was held to evaluate the testability of proposed test scenarios and the capabilities of possible test set-ups, including some good performing dummies.

Contents

The paper will outline activities from HP2 on the target specifications and evaluations done so far. In view of their relevance for the specifications of the target and test set-up the paper starts with a brief overview of test scenarios as identified from accident surveys. This is followed by an overview of sensors most often used in AEB-P systems and a list of specifications for the pedestrian targets with respect

to these sensors. Here particular emphasis is given to efforts made in relation to radar sensors. Next an overview of available test set-ups and some general performance information for different types of propulsion systems is given. Finally the performance of available test targets and propulsion systems as evaluated in test events is presented and discussed.

CHARACTERISTICS OF TYPICAL ACCIDENT SCENARIOS – INPUT TO TEST SET-UP

Real world accident surveys and case analysis form the basis for the defining the test scenarios in AEB, vFSS and ASPECSS. Some relevant findings in relation to the test set-up and target definitions are provided below.

The AEB group has published outline procedures for AEB-P [3]. Test scenarios were identified based predominantly on analyses of British collision data, with supplementary analyses of German and US data. The principal collision data analysis used the cluster analysis technique to identify groups of collisions with similar characteristics. Two separate cluster analyses were performed; the first used the national STATS19 database for Great Britain, while the second used the (in-depth) on-the-spot database [3]. Figure 1 shows accident scenarios identified along with representativeness information. Lateral crossing scenarios with and without occlusion appear to be the most relevant scenarios. Identical findings were made by vFSS and ASPECSS [4] (see Figure 2 and Figure 3) with a remark that the latter also considered information from France in addition to UK and German databases.

Based on the accident surveys test scenarios are being proposed by all projects. The main characteristics that relate to the test set-up are:

- Proposed tests in all projects currently focus on lateral crossing scenarios.
- vFSS and ASPECSS differentiate between child and adult dummies. For the adult the 50th percentile male stature is assumed while for the child a data related to a 6-7 YO child are taken.
- Apart from the size, different speeds are assumed for children, adults and elderly. See Table 1 for data obtained from a literature survey by ASPECSS [4].
- For the obstruction AEB and ASPECSS assume two cars in a row. The first one being a large SUV and the second one a family car. vFSS proposes a well defined contour shape for reproducibility purposes.

Combining accident data from other international sources	UK STATS 19 n=10,574 cluster analysis frontal collisions	UK OTS n=175 cluster analysis frontal collisions	Germany UDV n=234 (N=18,571) 3rd party vehicle claims 2002-2006 frontal collisions	USA IIHS 1997-2006 FARS & GES all car-pedestrians
Pedestrian walks from nearside	51%	30%	32%	27%
Pedestrian walks out from behind obstruction	14%	15%	7%	
Pedestrian runs out from the far side	9%	6%	28%	
Pedestrian walks along in the dark	3%	14%	8%	9%
Pedestrian walks out into the path of turning car	6%	14%	18%	-

Figure 1 - Summary of accident scenarios derived from AEB project [3].

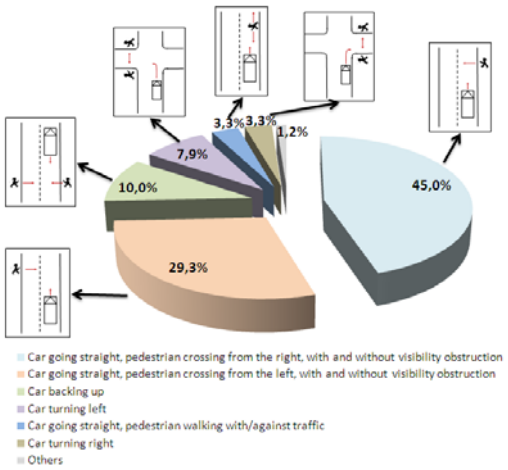

Figure 2 - Design-relevant accident scenarios (vFSS Group)

Accident Scenarios	Description	Light condition	KSI (84%)	Fatalities (83%)	All (70%)
	Crossing a straight road from near-side; No obstruction	Day Night	**15** **10**	8 15	**16** **7**
	Crossing a straight road from off-side; No obstruction	Day Night	8 12	**7** **23**	9 7
	Crossing at a junction from the near- or off-side with vehicle turning or not across traffic	Day Night	5 3	3 1	4 2
	Crossing a straight road from near-side; With obstruction	Day Night	7 2	1 3	3 1
	Crossing a straight road from off-side; With obstruction	Day Night	5 2	1 2	6 2
	Along the carriageway on a straight road; No obstruction	Day Night	8 7	5 14	9 4
	TOTAL	Day Night	48 36	25 58	47 23

Figure 3 - Summary of accident scenarios regarding killed and seriously injured (KSI), killed pedestrians and all pedestrian casualties identified in ASPECSS project [4]

Table 1 - Pedestrian speeds used in ASPECSS [4]

Speed	Adults and children (m/s)	Elderly (m/s)
Walking	1.4 (≈ 5 km/h)	1.2 (≈ 4 km/h)
Running	2.8 (≈ 10 km/h)	2.0 (≈ 7 km/h)

Figure 4 - Case example for the lateral distance analysis using GIDAS (white arrows indicates moving direction of the pedestrian)

- Although not fixed the maximum speed of the vehicle under test, and thereby maximum impact speeds to the target, is around 60 km/h. A survey from vFSS into the vehicle speeds in crossing scenarios showed that over 90 % of the initial vehicle speeds in this configuration is below 60 km/h (see Figure 5). In view of the high impact speeds expected the test target should be either "crash forgiving" (meaning no damage introduced to the test vehicle upon impacts) or of a rescue type (meaning that the dummy is taken out of the vehicle path just before a possible impacts).
- An important parameter in the test set-up is the lateral distance between a subject vehicle and an obstruction in car-to-pedestrian crashes (see as example Figure 4). Little information is available on this. The ASPECSS project assumes a distance of 100 cm between the exterior of the subject vehicle (excluding side mirrors) and the obstruction
- A general observation made by all project is that a higher proportion of pedestrian casualties killed or seriously injured was found when hit by a car in 'dark' lighting conditions. Issue with this testing is the control of the illumination conditions. First proposals for a set-up were made by vFSS.

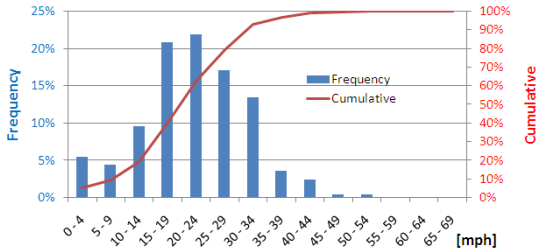

Figure 5 - Initial vehicle speed of crossing scenarios (vFSS Group)

OVERVIEW OF KEY SENSOR TECHNOLOGY

A sensor is "a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument". AEB-P uses surround sensing sensors to detect dangerous traffic situations. Sensors most commonly used for detection of pedestrians include RADAR (Radio Detection and Ranging), Video camera (Stereo and Mono), LIDAR (LIght Detection And Ranging), PMD (Photo Multiplexing Device), FIR (Far Infra Red) and NIR (Near Infra Red) sensor. A short description of these sensors is provided below in relation to requirements to be met for proper detection of the specified test targets.

Radar

RADAR is an object-detection system which transmits and receives radio waves in a way to measure both the location of nearby objects and relative speed of moving or fixed targets. The detected object will reflect part of the energy of the emitted radar wave. Depending on the following characteristics, it is possible to classify automotive radar sensors in the following categories: short-range radars (SRR), mid-range radars (MRR) and long-range radars (LRR).

SRR's operate mainly in the frequency range around 24GHz and have a typical maximum detection range up to ~40m with a wide horizontal observation zone of more than 90 degree. Depending on the operational bandwidth applied they can achieve a target separation capability of ~0,15m and high range accuracy. Hence they can determine the exact position of potential obstacles in the near vicinity of a vehicle.

LRR typically use the 77GHz frequency band and can detect traffic objects on the road ahead or behind up to more than 200m with a rather small antenna beam of ~±8 degrees. The LRR performance is well suited for long range applications like Adaptive

Cruise Control (ACC), but performance drops for targets close to the vehicle (i.e. below20m) due to lower range measurement quality and smaller field of view.
MRR are bridging the gap between SRR and LRR and represent a good compromise to do both functions like ACC and also pedestrian protection, pre-crash sensing and emergency brake support. MRR's operate in all the available frequency bands (24 GHz, 77 GHz and 79 GHz) with different modulation principles and a variety of field of views and antenna concepts
In contrast to video cameras that capture 2D or even 3D images of the road all current RADAR systems scan the environment with several fixed or mechanically/electronically steerable beams. Consequently, overall resolution capability is inferior to image-based devices and characteristics like shape and posture of a pedestrian are of negligible importance. Hence, the most important factor is the radar reflectivity of the pedestrian (or the dummy, respectively), that is expressed in terms of Radar Cross Section (RCS) in square metres. The higher the RCS of an object, the better it can be detected by the RADAR.
Pedestrian dummies shall best represent the RCS of a human, both in absolute value and also in distribution over space. A small corner reflector that is often used as a test target in the RADAR community is not suitable to represent the RCS of a pedestrian because the whole reflection zone is concentrated on a very small spot and a future possible fine target signal analysis to detect the position and movement of extremities is no longer possible. A dummy with the shape of a pedestrian and similar distributed RCS values for all parts of the body is therefore desired.

Camera

Camera sensors are an increasingly important part of active safety systems. They sense lane markings, obstacles and traffic participants with similar methods like human beings by evaluating the content of 2D or 3D road images.
CMOS and CCD are the two main sensing techniques used in active safety camera sensors. With one video sensor the image "depth" can be only estimated by stadia metric means. With stereo video cameras the distance can be directly extracted for each position of the image. Direct speed measurement is not possible, neither with mono nor with stereo concept.
The camera image is usually processed by sophisticated vision algorithms to recognize the

Figure 6 - Example of detecting a crossing pedestrian with a mono video system

relevant objects in the Region of Interest (RoI). The detection and classification algorithms are trained on the visual appearance of real objects and therefore it's important that the visible characteristic of the defined test object matches the ones of the real object as good as possible (i.e. pedestrian shape, posture, movement, extremity articulation, etc.).
The most basic requirement for cameras relates to the overall dimensions of a pedestrian, its posture and contrast to the environment. While some current algorithms only use contour or chamfer lines to detect pedestrians on the road the more advanced video systems already use a-priori information like the expected movements of the legs (i.e. gait recognition) to increase the classification rate for pedestrians. Figure 6 gives an example image of a pedestrian being detected by a mono camera.

PMD-Sensor

A Photonic Mixing Device (PMD) is an optical sensor that enables the real-time capture of distance and greyscale information in the same unit. Distance information is based on the Time of Flight (ToF) principle and active scene illumination is done in the near infrared range with 850 nm wavelength. Outdoor operation is possible and so automotive environmental perception up to several metres is possible. Similar to the video camera system the key factor for test target requirements is reflectivity, this time in the NIR range. The reflection properties and tautness of the cloth surface, together with the shape and posture of the dummy are main properties to be specified.

LIDAR

LIDAR (LIght Detection And Ranging) is a technique used for remote sensing and measures the

distance to objects by transmitting short laser pulses. LIDARs commonly use the time of flight (TOF) principle for distance measurement, where a laser pulse is emitted and the elapsed time is measured until the reflected signal is received again. The time delay between transmission and reception is directly related to the distance due to the proportionality between TOF and distance. LIDARs use laser or LED light sources with wavelength in the NIR range and have detection ranges up to 200m. Compared to RADAR sensors the beamwidth is much smaller and sharper. The performance of LIDARs decreases in adverse weather conditions like rain or snow or when the sensor gets blocked by e.g. dirt.
The LIDAR sensor detection performance mainly depends on the NIR- reflectivity of the test objects. The test target must therefore be equipped with adequate reflecting parts. However, too big reflectors could saturate the LIDAR receiver especially in near vicinity situations with a possible malfunction as a consequence. Therefore it's important that the reflection characteristic of the test object matches those of a pedestrian as good as possible. Target requirements relate to reflection properties and tautness of the surface of the respective clothing's.

Sensor fusion

Sensor fusion is the combining of sensory data or data derived from sensory data from disparate sources such that the resulting information is in some sense better than each of the individual sources. The term better in this case can mean more accurate, more complete, more dependable, or refer to the result of an emerging view, such as stereoscopic vision (calculation of depth information by combining two-dimensional images from two cameras at slightly different viewpoints). Sensor fusion can be either complementary (i.e. each sensor provides information that the other one doesn't have) or redundant (i.e. both sensors provide same information that can be compared and used for fail-safe operation). For both cases it is necessary that the test target specifications are optimally adjusted for the individual sensor principles.

TARGET SPECIFICATION W.R.T. SENSOR TECHNOLOGY

The target is meant as a pedestrian surrogate for testing of AEB-P systems. As such it must be able to represent the human attributes in relation to sensors used in the vehicle. The required sensor-relevant dummy attributes as described below were collected from car manufacturers, system suppliers and test houses involved in vFSS, AEB and ASPECSS. A more extensive documentation of the specifications is provided in [11].

Dimensions and posture

Both vFSS and ASPECCS assumed to have two targets, one representing adults and one representing children respectively. Without further justification, e.g. via accident surveys, it was thought to be reasonable by all projects to assume the adult dummy to have size / dimensions of an average male while the smaller one should represent a child in the age of 6 to 7 years old. Anthropometry data for both sizes are readily available.

For the posture it was decided to assume the walking phase between Mid Swing and Terminal Swing (see Figure 7) for the adult. This posture represents the dynamics (e.g. compared to posture ISw) and is used in the Euro NCAP procedure for the testing of deployable bonnets. The leg position also refers to SAE J2782 (Proposed Draft 2009-09: "Performance Specifications for a Midsize Male Pedestrian Research Dummy"). The dummy shall show an inclination of about 5° which correlates with the posture of humans when walking. The face is looking in the walking direction. Figure 8 shows the posture and some main dimensions.

For the target representing children a running posture was assumed as depicted in Figure 9.
When collecting details on dimensions different projects appeared to use information from different sources. ASPECSS used data from the SAE Handbook, while vFSS used information from the RAMSIS Bodybuilder. AEB did not specify dimensions in detail yet but used off the shelf mannequins in their studies done so far. All sources resulted in slightly different overall dimensions, which at itself should not be too much of an issue for the various sensing systems and test repeatability / reproducibility, as long as variations are not too large and postures close to the illustrations in Figure 8 and Figure 9. It is recommended to have a detailed definition of the exact size and posture in a final stage of the test set-up definition. Table 2 provides some characteristic dimensions used in vFSS for reference.

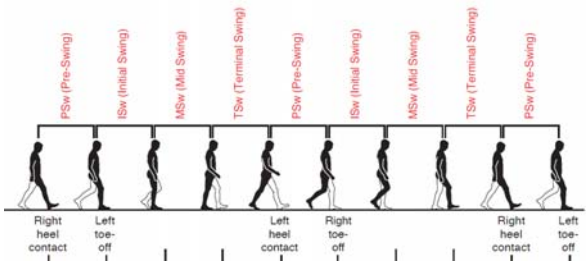

Figure 7 - Phases of the human gait

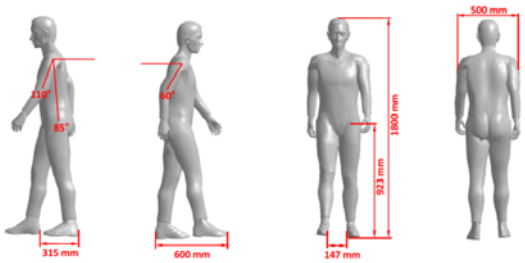

Figure 8 - Adult viewed from left (impact side), right (non-struck), front and rear side.

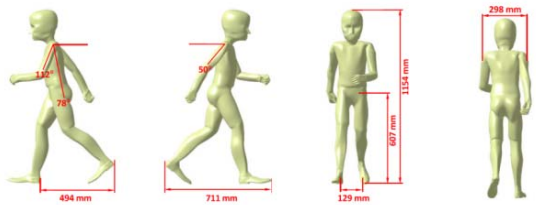

Figure 9 - Child viewed from left (impact side), right (non-struck), front and rear side.

Table 2 – Main dimensions vFSS targets

Description	Child [mm]	Adult [mm]
A-Height	1200 ±20	1800 ±20
C-Shoulder width	489 ±25	500 ±20
D-Hip point height	600 ±20	923 ±20

Clothing and surface

Camera sensors - The dummy must be clothed with a long-sleeved shirt and trousers which have different colours. The clothing used should ensure a minimum contrast with the scene including asphalt and air for both colour and black & white (grey scales) cameras. vFSS specifies that the contrast ratio of the grey pixel values of the clothing to the background must be at minimum 50% in the given lighting, but other projects like AEB are still investigating this item. Preferred colours could be based on real life situations like blue jeans in combination with a light collared shirt. Clothing has to be loosely fitted and not form any planar wrinkles. The dummy should wear shoes or have a marking representing shoes for the camera.

PMD and IR sensors - For sensors like PMD there must be no reflecting parts on the dummy or its clothing. The IR reflectivity (around 850 nm wavelength) of the clothes must be within the range of 40 to 60%. At the selection of the clothes it has to be ensured, that the IR reflectivity measured with the 45° probe must not differ for more than 20% from the reflectivity measured with the 90° probe.
The IR reflectivity (around 850 nm wavelength) of the visible skin surface parts has to conform to original human skin within the range of 40 to 60%. As an option the dummy can be equipped with a wig to represent the head hairs. The IR reflectivity (around 850 nm wavelength) of the wig has to conform to original human hairs within the range of 20% (dark-haired) to 50% (fair hair).
The skin temperature (at locations with clothing measured below the clothing) of the dummy immediately prior to each test run must be 32° C +/- 2° C. The thermal emission must not exceed 10 W/m²K. All visible parts of the dummy mounting and guidance system must have a temperature deviation of max +/- 5° C from the ambient temperature

Radar based technologies - Object characteristic description for radar sensors are probably among the most complex ones to be realised. The object surface that is illuminated by a radar beam and reflects radiated energy back to the emitter is the so-called Radar Cross Section (RCS). The RCS depends on many parameters like target surface properties, illumination angle (both horizontal and vertical), multipath reflections from elements in the lower surface, influence of local object details like sharp edges, etc. In addition, the theory and data processing of radar signals is less comprehensible and evident for humans than the analysis of images from a video camera device, which are apparently understandable with a single twinkling of an eye. RCS requirements for cars were already derived in previous efforts done by the EU FP7 project ASSESS [5], vFSS and HP2 by evaluation of reflection measurements on mid-size cars and from expert input. The analysis of back scattered signals from many different vehicle specimen is of particular relevance to determine a representative average RCS value with a given typical standard deviation that can be used to define the key parameters for a typical target.

The challenge to determine the RCS of a human being is treated in literature only a few times. Absolute mean RCS values of humans taken from literature are in the range of -8 to +4.8 dBsm [6], [7]. Yamada determined the mean value of the human RCS in the 76 GHz band to -8 dBsm with a variance of ±10 dB [8]. Albeit these results the knowledge in the field of human reflection characteristics is not sufficient enough to specify a pedestrian dummy in more detail. Partly the published values were contradictory; partly the number of different investigated persons was too low. Open issues like the influence of different positions of the limbs or the effect of wearing different clothing's w.r.t. the RCS of a human need to be addressed in more detail. Human RCS was never measured in parallel in the two relevant automotive frequency bands at 24GHz and 76 GHz, by using exactly the same measurement setup and conditions. The second unsolved challenge after having defined the human reflection characteristics by a representative RCS value (or range) is how to transfer or map this radar-relevant parameter to pedestrian dummies.

To address these topics the EU FP7 ICT Project MOSARIM (www.mosarim.eu) conducted a measurement campaign to establish a reference library with RCS signatures of both humans and pedestrian dummies in many different postures and outfits. The various pedestrian dummies were provided via HP2 from the different manufacturers or organisations. All measurements took place in August 2012, at the European Microwave Signature Laboratory (EMSL) [9] of the European Commission's Joint Research Centre (JRC). The diagrams and results presented in this section are extracted from the Reference Library of RCS Signatures published by JRC in 2012 [10].

Figure 10 shows a picture of the measurement setup. The test objects were placed on a turntable with a distance of 3.4 m to the horn antennas of the measurement equipment. The antennas were placed on a tripod with adjustable high and measurements were performed in the two relevant automotive frequency bands 23-28 GHz and 76-81 GHz simultaneously. RCS signatures were measured over the whole 360° azimuth angle using steps of 1° for dummies and steps of 5° for humans.

To determine the RCS characteristics of the humans and dummies three different analyses of the measured data were made. The angular distribution of the RCS integrated over the measured frequency bands is given in 360° polar plots. To provide the possibility

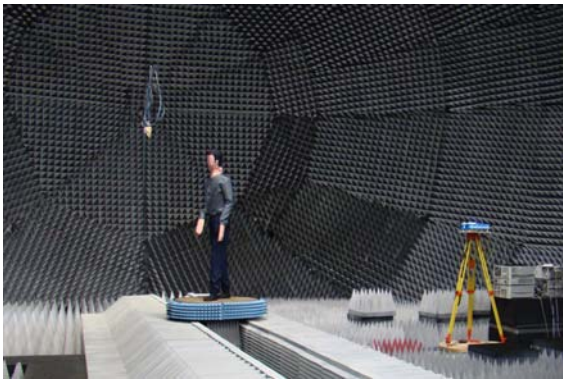

Figure 10 - Setup of the RCS measurements in the EMSL in Ispra, Italy

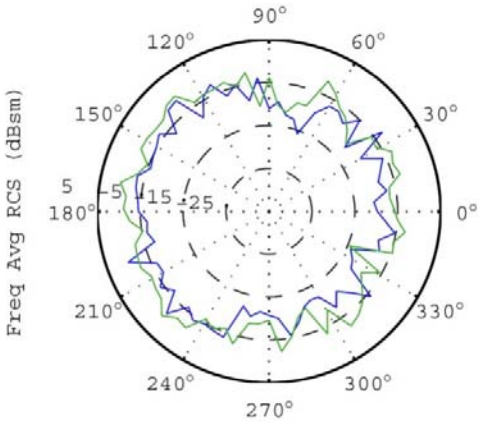

Figure 11 - Polar plot of frequency-averaged RCS of a human for the 23-28 GHz band (green) and the 76-81 GHz band (blue) [10].

for deeper analysis of the scattering centers so called range profiles were computed. In these plots the range of the different scattering centers and their corresponding RCS values, expressed in dBsm (decibels referenced to one square meter) vs. the azimuth angle in degree, are displayed. To break those higher level analyses down to easy comparable values the overall frequency/azimuth average RCS value was additionally calculated.

Figure 11 displays the RCS value in polar plot, averaged over the two measured frequency bands from a standing human wearing thin cotton clothes, facing the antennas at an azimuth angle of 0°. Azimuthal measurement points are in steps of 5° and show distribution around a mean value with a variance of approximately 10 dB. Nevertheless the RCS values seem to be slightly increased when the front and rear side of the human body are looking towards the measurement unit because for this

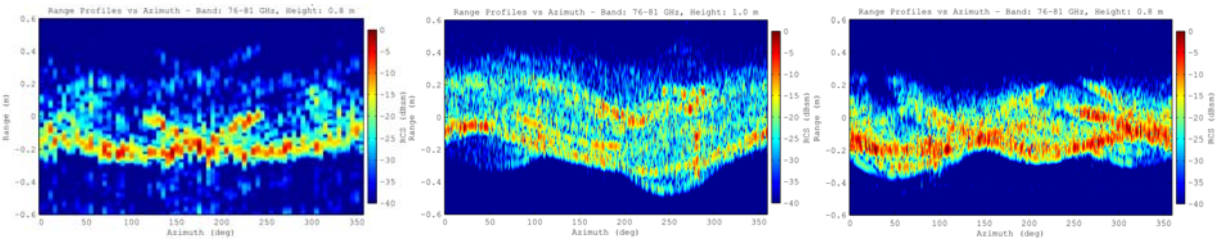

Figure 12 - Range profiles of Human and Dummies [10]: a) Human in standing position (left); b) Dummy with spotty scattering centres (middle); and c) Dummy with distributed scattering capabilities (right)

configuration the radar-illuminated surface of the body is highest.

To determine the overall averaged RCS value (both over the two distinct frequency bands and the azimuthal angle) two test persons wearing a selection of different clothes were measured. Results did not show significant difference on the overall averaged RCS value when the test persons were wearing different thin clothing's like cotton shirt and blue jeans (where cloth thickness is much smaller than the wavelength). Because it was supposed that thicker clothes could have a more significant effect on the RCS value, additional measurements while wearing a 150 µm thick PVC coated nylon rain coat and a 250 µm thick PVC coated polyester rain coat were done. Table 3 gives an overview of the measured RCS values. For the cotton shirt the lowest RCS was observed whereas the highest RCS was observed for the thick polyester rain coat. Thereby a difference between highest and lowest averaged RCS of about 2.5 dB was noticed. Thick clothes obviously increase the RCS especially in the 76-81 GHz band. Simple averaging of the measured values given in Table 3 leads to global frequency/azimuth averaged RCS values of -4.5 dBsm for the 23-28 GHz band and -5.5 dBsm for the 76-81 GHz band. These values are recommended for future AEB-P testing targets.

In Figure 12 the range profiles vs. azimuth for a human and two available pedestrian targets are given. From Figure 12a it can be derived that the significant range profile between the aspect angles from 125° to 250° is caused by the symmetric shape of a standing human body. The contrary radial movements and distance change of the arms, legs and left and right parts of the body, provoked by the movement of the turn table are well visible as additional contributions to the RCS value around the 0m range line. Both dummies consist of synthetic hard-foam. Some small parts of aluminium tape were used to add several scattering centres to the less reflecting foam body of the dummy 1 (see Figure 11). Dummy 2 was dressed with a jump suit consisting of fabric and aluminium. Thereby a so called distributed RCS over the whole body of the dummy is achieved. In the range profile of Figure 12b a higher level of fluctuation of the RCS over azimuth can be observed. This could lead to an unstable detection of dummy 1 during movements. It seems that RCS for this dummy is not only generated by surface reflections but also by some internal parts. In contrast to this the range profile of dummy 2 with distributed scattering capabilities given in Figure 12c shows significant similarities to the human range profile. The main part of the reflected power is backscattered by the surface and the same significant characteristic as for the human in Figure 12a from

Table 3 - Frequency/azimuth average RCS of two humans wearing different clothes (in dBsm)

Setup	23-28 GHz		76-81 GHz	
	Person 1	Person 2	Person 1	Person 2
Cotton	-4.0	-5.2	-6.1	-6.9
Thin Rain Coat	-4.0	-4.8	-5.2	-6.6
Thick Rain Coat	-4.1	-4.6	-3.5	-4.8

Figure 13 – Reflective foil used for scattering on one of the targets (spotty scattering centres)

125° to 250° can be observed. Further some kind of sinusoidal behaviour, which was caused by the turntable related position changes of arms and legs, can be observed. This is due to the fact that the posture of the dummies is not 100% rotation-symmetric to the turn-table centre.

In conclusion of the shown measurement results two important facts can be outlined for a sound dummy specification. First, the global frequency/azimuth average RCS is recommended to be in the range of the measured human values. Secondly, for the realization of appropriate reflection characteristics, comparable to humans, the whole surface of the dummy must be capable to reflect electromagnetic waves in the relevant frequency bands. Furthermore, by distributing the reflection capability over the whole dummy's surface, the problem of detection losses caused by reduced illumination due to limited sensor beam elevation angle is avoided, because each individual part of the dummy is capable to reflect the radar waves. Dummies with distributed RCS are also more suitable to be used in future possible enhanced AEB-P test scenarios where turning manoeuvres or intersection accident scenarios are addressed. For such scenarios the dummy may be viewed under constantly changing aspect angles. Another fact is that the Micro-Doppler effect, caused by limb movement, could be addressed by simply adding moving capability to the dummy's legs and arms. This effect could possibly be evaluated by future radar based AEB-P systems to better classify detected objects as pedestrians.

As a conclusion of all the facts stated above a requirement for distributed reflection characteristics of the dummy would lead to a higher level of sustainability of the dummy specification process. RADAR-specific dummy characteristic specification for first Euro NCAP AEB-P testing from 2016 onwards is expressed in Table 4. Recommended values are averaged in frequency and angular domains. For a final specification of the radar characteristics either standard deviation/variances or lower and upper bounds still have to be defined to assure optimal congruence to the RCS pattern of a pedestrian. Furthermore the RCS of children are still to be measured.

Table 4 - RADAR-specific dummy characteristic specification (Basic requirements for 2016)

Averaged in freq. & ang. domain	23-28 GHz		76-81 GHz	
	mean	variance	mean	variance
RCS for adult in dBsm	-4.5	t.b.d.	-5.5	t.b.d.
RCS for child in dBsm	t.b.d.	t.b.d.	t.b.d.	t.b.d.

TEST SET-UP / PROPULSION SYSTEM

With regard to the test set-up four types of rigs may be identified [11] (see Figure 14):

- Portal test rigs
- Road-integrated rail systems
- Self-propelling movable platform system
- Cable pedestrian test rig having the cable running over the surface or the dummy suspended from cables.

A survey into currently available test set-ups by ASPECSS [11] showed that most set-ups can handle speeds off running adults as specified in Table 1. The self-propelling movable platform systems are generally designed towards a high flexibility. Theoretically almost every pedestrian scenario is realizable with this technology. In contrast, portal test rigs are designed to represent one specific situation, namely pedestrian crossing the street, with very high accuracy and reproducibility. High accuracy may also be provided with recent cable rig (cable running over surface) platforms for this situation.

For the overridable platforms it should be ensured that vehicles with little ground clearance, e. g. sport cars, could have problems as the vehicle under test has to overrun the platform in impact test scenarios. In case of a test set-up in which the target might be impacted (non-rescue set-up) any damage to the

Figure 14 - Examples of test set-ups: Portal rig (top left), movable platform (top right) and cable pedestrian rigs with dummy suspended from cables (bottom right) and pulling cable running over surface (bottom left).

vehicle under test should be avoided as this may affect the system performance due to offset in orientation of sensors. This means that the dummy should be crash forgiving. Requirements are difficult to define but in general it can be stated that parts should have a maximum weight of 5 kg and be covered in soft foam. Due to the complexity of crash phenomena exact masses and surface stiffness are test set-up dependent and need to be explored by the test houses themselves via extensive testing possibly supported with simulations. For the rescue set-up, which is only possible when using a portal rig, it should be taken into account that the rescue manoeuvre should be realised as late as possible to give adequate information on speed reductions at the moment when the target would have been struck.

Influences on sensor systems

Although the propulsion systems may affect the readings from all types of sensing systems the influences on radar measurements are the most likely ones. Especially as most of the facilities are made of metal. Movable platform facilities are probably to influence radar measurements because of the little distance between platform and dummy. All in all, if parts of the facility (especially in the relevant area for the test scenario) could be detected by a radar system, it has to be ensured that this area is covered by a radar non-reflective cover. This is also true for portal rigs.

In case of positioning of the dummy on a moving platform it should be realized that the height of the target is affected by the height of the platform. Moving platforms currently available on the market have a height of around 90 mm. The standing height of the dummy should be corrected for this. This is partially overcome by the use of an outrigger with smaller ground clearance as proposed by the AEB consortium.

For portal rigs attention should be given to the attachment of the target from the top. Systems like cameras may detect the rod or ropes and algorithms may be misled by these items classifying the target as a non human object. The connecting rod should have low contrast with the environment. Also the height of the dummy above the ground should be well controlled. Any gap between the dummy and the road surface may cause issues for sensors like camera. Various groups have defined a maximum value for the gap between dummy feet and road surface. vFSS specified a value of maximum 15 mm whereas some AEB partners assume an even smaller gap of maximum 7 mm.

For visual (and other) systems the stability of the dummy is also an issue. Any swinging due to acceleration or deceleration may cause issues in the (reliability) of the detection. As camera algorithms may check on the position of the centre of gravity of a person as it needs to be within the base between the feet. In general stability issues relate more to test set-ups with crashable dummies (whether platform or test rig based).

As far as articulations are concerned solutions for portal rigs and movable platforms have been proposed. TRL in the UK developed a platform that allows for one of the two legs to move (see Figure 16, lower row centre). For portal rigs various dummies with articulations are currently offered. It needs to be checked how realistic and adequate the current articulations are though.

For testing of IR sensors all visible parts of the dummy mounting and guidance system must have a temperature deviation of max +/- 5° C from the ambient temperature to differentiate between the set-up and the target.

TESTING EVENT EVALUATING TARGET SPECIFICATIONS

On July 26-27 2012 a workshop was held at BASt in Bergisch Gladbach (Germany). The workshop was organized by ASPECSS in consultation with HP2. Goal was to identify promising concepts for a pedestrian target dummy for Euro NCAP testing and evaluate the correctness of specifications as defined.

Based on a previous approach applied by the vFSS project for car targets a range of test objects was subjected to a range sensing technologies integrated in various test vehicles.

Figure 15 show the targets considered in the event. In total 12 targets were evaluated, 5 of which representing a child and 7 and adult. For direct comparison all dummies were provided with identical jeans and shirt. The clothing was selected to meet specifications on reflective characteristics for PMD and other sensors as set in the previous chapter. Although slight variations occurred in overall stature, all dummies were at or close to the stature range specified. Regarding the posture, however, variations occurred; some dummies not representing the MSt walking phase (see Figure 15). Most of the dummies had radar reflectivity due to a) internal components made from metals and b) reflective foil applied. However, as the detailed data on RCS on volunteers was not available at that point in time no specific fine tuning was applied before this workshop.

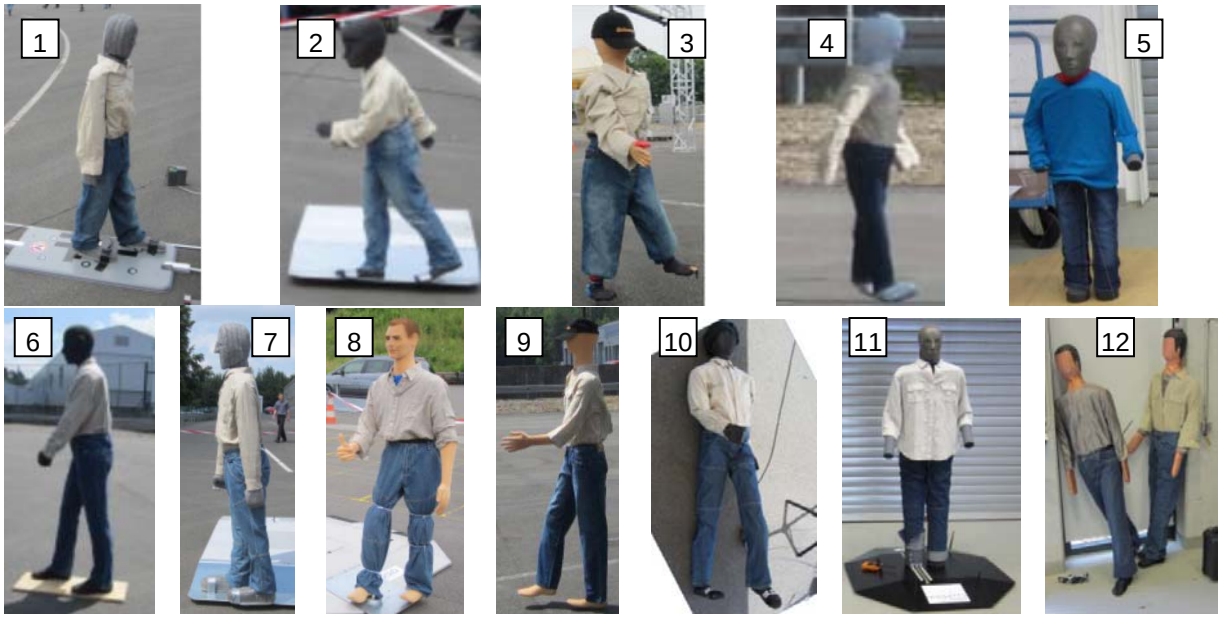

Figure 15 - Dummies evaluated: child dummies (top row) and adult dummies (bottom row)

To investigate the influence of the propulsion system on the detection, four available systems were considered in the event (see Figure 16):

1) UFO platform available from DSD
2) Portal rig used by Continental
3) Ultra flat platform with cable propulsion available from 4a engineering
4) Platform under development at TRL which includes facility for articulation of one leg

Test runs were made with 16 vehicles equipped with radar (7 vehicles), mono camera (8 vehicles), PMD (1 vehicle), stereo camera (4 vehicles) and FIR (1 vehicle).

As a first step a high level assessment of the dummies was done by test engineers. Based on the online sensor readings and system triggering they awarded marks from 1 (very good comparable to a human) to 4 (not comparable to a human) for the respective technologies. The result of this subjective evaluation is given in the boxplots of Figure 17. A boxplot is a

Figure 16 - Propulsion systems

standardized statistical plot for a data set. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. In general it was found that the dummies which are closer to the specifications set perform better. In particular the posture influenced the recognition, those targets closer to the MSt posture being better recognised. Child dummies tend to get less well recognised than the adults. These findings were largely confirmed by sensor readings as shown for instance using confidence levels in the detection as shown in Figure 18.

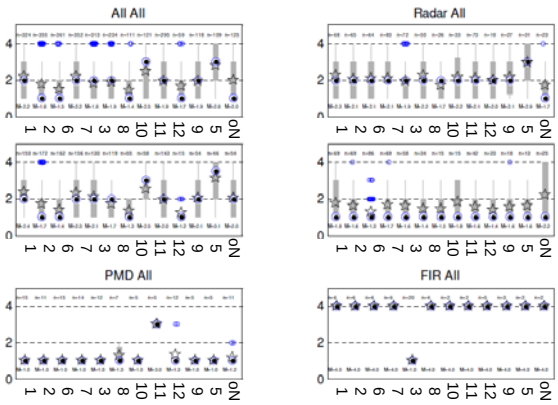

Figure 17 - Dummy assessment by test drivers (numbers refer to dummy/target numbers indicated in Figure 15)

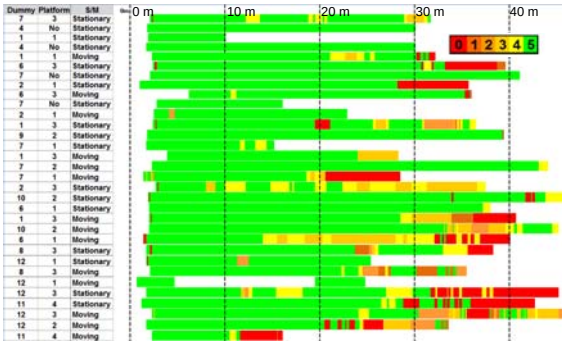

Figure 18 Performance of some test targets in terms of confidence levels (5 is high, 0 is low) versus distance to target.

Despite is limitations and caveats - e.g. for visual systems at least, background is important and was not well controlled thus some apparent differences between equipment may in fact be a function of differences in the background – the event gave confidence in the specification set as basis for further developments.
An identical type of assessment was made for the various propulsion systems available during the event. The best options (smallest influence on sensor readings) appeared to be the portal rig and the ultra-flat platform.

TESTING EVENT EVALUATING WHOLE TEST PROCEDURE

After identifying the most promising targets currently available, a second testing event with several vehicles capable of reacting to pedestrians was conducted at the IDIADA proving ground near Barcelona. Main goals were to validate the dummy specifications and test setups with real cars and identify testability, repeatability and reproducibility of proposed test scenarios with the available test setups.

Test setups

Lateral crossing scenarios with adult and child targets were considered. Two test set-ups were available: a) Portal rig with a moving crane from which the dummy hangs down; b) Movable platform on which the dummy is mounted. In both cases, the dummy movement is started so to meet the test vehicle at the specified impact point. For some test scenarios, especially the running child scenarios, the dummy starts to move behind an obstruction formed by two parked cars. Lateral distance of the parked cars and the vehicles under test was assumed to be one meter.

Test vehicles

While a broad variety of vehicles with or without AEB-P function took part at this workshop, only those four that had inertial measurement facilities with accuracy of 3 cm on board were selected for further evaluation. These vehicles used the following AEB-P systems:

- A prototype vehicle with quick 3D sensor and 6-piston ESC pump, capable of detecting a pedestrian in less than 0,3 seconds, and of achieving full brake deceleration in less than 0,35 seconds, manually driven,
- Two prototype vehicles with state-of-the-art mono camera systems (one with additional radar fusion) capable of detecting pedestrians in less than 0,5 seconds and regular ESC systems capable of achieving full brake deceleration in around 0,5 seconds, one vehicle manually driven, the other vehicle robot-controlled,
- A production vehicle with state-of-the-art stereo camera system and radar fusion, capable of detecting a pedestrian in less than 0,5 seconds and achieving full brake deceleration below 0,5 seconds, vehicle was robot-controlled.

Achieved speed reductions

The scenario reproducing a child running across the road from behind an obstruction is the most demanding one. Compared to other scenarios the child is visible relatively late, leaving only very little time for detection, classification and braking. Only one vehicle did show performance at all in this scenario. Centre impacts (50%) in test with this vehicle lead to a speed reduction of 10 km/h at a test speed of 20 km/h, and for 75% impact configuration (near the far side corner of the vehicle) the accident was avoided. No reaction was observed for 25 % overlap (near the near side corner of the vehicle).
For the adults only unobstructed scenarios were tested. All vehicles reacted properly and the speed reductions for all scenarios (walking elderly, walking adult, static pedestrian) matched the expectations derived from the assumption that braking should commence when the accident becomes unavoidable at a TTC of 0.5 seconds (See Figure 19). Note that in some cases, the achieved speed reductions reached the expectations even with relatively slow systems with regard to detection performance and brake force build-up. This high performance was reached by braking significantly early, especially when the pedestrian was more than 0.5 meters before the

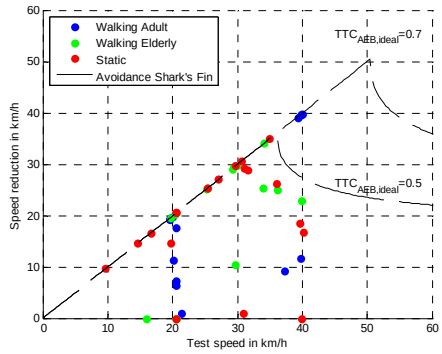

Figure 19 - Speed reductions for unobstructed cases (adults)

vehicle path. That is not a bad thing by itself; however it needs to be balanced against excessive numbers of false activations in real traffic situations.

Repeatability and Reproducibility

Due to the limited time during the workshop, the data gained is not yet sufficient for a full reproducibility & repeatability study. However, the general results from the workshop suggest that there is no significant difference between the two test rigs involved. On the other hand, the results show that there is some variation in AEB performance even when all conditions are kept equal, but it should be kept in mind that the cars attending the workshop were mainly prototype systems. Those cars that were equipped with robot speed and steering control showed a slightly lower variance in performance than those cars where this was not the case.

DISCUSSION

Various projects are currently developing test set-ups for AEB-P testing. This includes test targets. In the Harmonisation Platform 2, dealing with test equipment for AEB-P, information specifying the targets was collected and currently available dummies evaluated in testing events. For sensors like PMD and camera the definition of a first set of specifications was relatively straightforward. Based on experts input requirements were defined and those dummies meeting these requirements appeared to be detected well by the systems. Radar reflectivity is more complicated to deal with and, as no detailed data were available, a measurement session at the European Microwave Signature Laboratory was performed to reveal specifications. In general, the radar reflectivity of pedestrians is in a large range, depending on clothing, metal parts etc., but a characteristic pulsing of reflectivity in connection with the moving extremities has been observed. Radar reflectivity of the target can be introduced in different ways. The target might have some inherent reflectivity from metal parts included (e.g. to provide overall stiffness and joints for body part positioning) or by applying reflective foil or suits. Comparison of range profiles for humans and dummies with spotty and continuous reflection characteristics showed that the latter option is prefer. Continuous reflections can be released using a suit from reflective materials.

In a large scale testing event with various vehicles and targets the specifications defined were evaluated by rating the detection of the dummies by the various sensing systems. Generally it seemed that the better performing dummies are those with a posture similar to that of a walking adult, predominantly legs apart with an upright pose as included in the specifications. For the child dummies there is some difference in performance, again depending on the posture (the legs apart gave better detection). The detection was influenced by the test set-up. For instance when using a portal However, not all differences in performance are related purely to posture and movement, there are scenarios were the same dummy was recognised late or early seemingly based on the background. Therefore further evaluation is recommended addressing items like contrast to the background in more detail.

A main challenge in the current start-up phase of defining pedestrian targets is to specify a basic parameter set for the main characteristics of the test targets that encompasses all the needs of the different sensing technologies and principles, while leaving room for future extensions and evolutions as required and needed. As an example the articulation of arms and legs can be mentioned. Future camera and radar based systems might use information from arm and leg motions in object classification and interpretation of the situation. Implementation of the articulations in a repeatable and reproducible test set-up is a technical challenge though and although foreseen for the long term it is envisioned that initial set-ups will rely on targets that do not include this capability.

As it looks now characteristics for the most relevant sensors can be incorporated into a single adult and child version of the dummy. In case not possible the alternative is to define different dummies for different sensor technologies. However, this will lead to problems by testing forward-looking safety systems which use sensor fusion for detection.

To allow for a comparative evaluation of the safety systems there is a high demand on reproducibility of test scenarios. This means that a high accuracy of the

vehicle / dummy position and velocity measurement is indispensable. Especially since this information is often used as a trigger criterion for the dummy's movement. Projects like ASPECSS prescribe a position measurement accuracy of 0.1m and a velocity measurement accuracy of 0.1 km/h which is realizable with relative measurement methods like radar or lidar sensors on the test facility or dGPS position measurement (outdoor). Further work on this topic is required however, also considering variation in the test environment on different days and at different facilities.

As far as the test set-up is concerned various options are offered including self-propelling movable platforms and portal rigs. With the platforms almost every pedestrian scenario is (theoretically) realizable while portal test rigs are designed to represent the pedestrian crossing the street scenario only. In the portal rig set-up rescue manoeuvres of the target can be applied to avoid any impacts on the vehicle and thereby damages influencing the sensor performance. A disadvantage of this though is that the test scenario can't be evaluated until the dummy impacts the test vehicle, hence the final speed reduction at impact is to be extrapolated from test data.

CONCLUSION

Specifications for test targets to be used in testing of accident avoidance systems have been defined. The targets are objects that mimic humans for different sensing systems. To arrive at a technology-independent test procedure they should represent relevant physical properties for the most common sensors like radar and camera.

First specifications were set on the basis of expert input. This was then checked in testing event was organized in which a various dummies and propulsion systems were subjected to tests with a large number of vehicles that have various sensing technologies on board. During the event it was found that those targets that best met the specifications performed good, meaning that they were well recognized by most sensing systems. In relation to the characteristics for the radar sensors detailed measurements on volunteers and targets were conducted in the European Microwave Signature Laboratory. From these measurements more detailed specifications related to this sensor were defined. This included the requirement to have distributed reflection characteristics over the entire body. Further evaluations on the specifications are currently ongoing, addressing items like variability in clothing and need for representation in the targets.

In a second event, evaluating the testability, it was found that currently test set-ups exist capable of realising lateral crossing scenarios. Tests using vehicles with operational AEB-P systems showed that running child scenarios as for instance defined by ASPECSS are quite demanding. The systems do achieve good speed reductions though in scenarios with adults (without obstruction). Unfortunately no relevant data on repeatability and reproducibility could be collected so far. Further investigation into this topic is needed but this does not affect the sensor specifications set as such. Future studies should consider variation in the test environment resulting from environment conditions like variations in lightning between different days.

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A COMPARISON OF VEHICLE ALERT MODALITIES' TIME-TO-COLLISION WARNINGS TRIGGERED BY THE VEHICLE'S CONTROLLER AREA NETWORK SYSTEM

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Paper Number13-0103

ABSTRACT

Currently, the time-to-collision (TTC) is determined as the time when external instrumentation measures a data flag from the Controller Area Network (CAN) signal or at the time an alert modality can be used to evaluate the performance of a vehicle's Forward Collision Warning (FCW) system for the National Highway Traffic Safety Administration's (NHTSA's) New Car Assessment Program (NCAP). Many vehicle manufacturers assess FCW performance using the digital signal from the CAN to determine the onset of a warning which can then be used to determine compliance with TTC timing requirements listed in NHTSA's performance test procedure provided at www.regulations.gov in docket number NHTSA-2006-26555-0128. NHTSA has observed that the onset of an FCW alert can be substantially delayed when compared to the activation time of the CAN signal. The purpose of this paper is to compare the timing of the CAN signal to the actual visual and audial alerts obtained during the same trial, to determine the extent of these differences, and how they vary by vehicle manufactuer.

The CAN signal and two alert modalities (visual and sound) for seven vehicles were collected by Dynamic Research, Inc., and the subsequent TTCs were calculated using the test procedures and equations established by the agency. Data from the seven vehicles were analyzed for three separate test configurations. Initial analysis did not separate the vehicles by manufacturer; however, upon noticing a linear trend between the CAN signal and visual alerts, the data was grouped by manufacturer for further analysis.

A strong linear relationship (R^2>0.8) was discovered between visual and CAN signal warnings, which correlates to a constant amount of delay between the CAN and visual alerts for all seven (7) vehicles as well as the audial and CAN signal warnings for four (4) of the seven (7) test vehicles. For the remainder of the vehicles, an insonsistent delay was exhibited within models. The audial–CAN relationship was not discovered until vehicle data was separated by manufacturer.

Vehicles that exhibited a constant delay from when the CAN data flag was issued to when the visual or the audial alert was measured were more likely to pass the TTC requirements. Certain models had visual and audial alert modalities occur after the minimum safe TTC has passed. As a result, this paper will also attempt to conjecture potential reasons for the differences delay in the FCW alert modalities timing compared to that of the CAN data flag.

INTRODUCTION

The most frequent type of crash involving multiple vehicles is a rear-end collision. This type of crash accounts for approximately 30% of all light vehicles (less than 10,000 lbs. gross vehicle weight rating (GVWR)) crashes (National Highway Traffic Safety Adminstration, 2006). Of these, 60% are attributed to inattentive drivers. Inattentive driving, combined with tailgating, contributes to 90% of rear-end collisions (Mohebbi, Gray, & Tan, 2009). Recent findings illustrate that rear-end crash frequency have increased to 31.5% from 2006 to 2009. Of these crashes, 29.5% resulted in injuries and 5.4% resulted in fatalities. Of these fatalities, 12% of them were caused by inattentive or fatigued drivers (National Highway Traffic Safety Adminstration, 2009).

In an attempt to lower the frequency of rear-end collisions, technology has been developed and implemented into vehicles for early detection and warning of potential collisions. These systems are typically called Forward Collision Warning (FCW)

systems. The “lead vehicle” ,also referred to as the principal other vehicle (POV), is detected by the subject vehicle (SV) using on-board systems based on radar, camera, or a combination of radar and camera system. These systems continually monitor the speed, distance, and closing rate between the vehicles, and if a collision risk is detected, the vehicle warns the driver through a visual, audial, or haptic warning. For the alert to be effective, the warning must be issued sufficiently early during the conflict event so that the driver can react by braking or maneuvering the vehicle to avoid or mitigate the crash.

To help ensure the capability and robustness of FCW systems, the National Highway Traffic Safety Administration’s (NHTSA’s) New Car Assessment Program (NCAP) developed performance tests and criteria to evaluate FCW systems. The system must meet the minimum performance specifications to obtain government recognition on the agency’s website, www.safercar.gov. The performance tests (www.regulations.gov, NHTSA-2006-26555-0128) are designed to objectively measure the system’s ability to warn a driver of an imminent crash with enough time to avoid or mitigate the severity of the crash. The FCW test procedure is designed to test the ability of an advanced technology to detect an imminent threat in different driving scenarios. The test procedure contains three tests that were designed to duplicate the three most common rear-end crash scenarios, (1) stopped lead vehicle, (2) suddenly decelerating lead vehicle, and (3) slower moving lead vehicle. To objectively test the FCW system, a metric called the time-to-collision or TTC was developed. The TTC is defined as the time it would take for a collision to occur at an instantaneous speed, distance, and acceleration associated with the driver’s vehicle and the nearest lead vehicle. In practice, the FCW system continually updates the estimate TTC values as kinematic conditions between the SV and POV change. Each OEM then determines when to issue an alert to the driver based on the changing TTC estimates (as well as other proprietary factors). As noted, to be effective, the warnings must come sufficiently early (as measured by TTC) to be effective. These minimum values were determined by considering how the warning may interact with the driver, braking speed, and the ability of the vehicle to avoid a crash with a driving maneuver (www.regulations.gov, NHTSA-2006-26555-0120).

Due to an increasing number of vehicles with this advanced technology, NHTSA asks vehicle manufacturers to submit data validating each applicable vehicle’s FCW system by utilizing the test procedure developed by the agency. Vehicles are accredited with an FCW system upon submission and verification of the data. To highlight this accreditation, NHTSA places a checkmark next to this advanced technology on the agency’s website. In order to assure the quality of the submitted data, NHTSA randomly selects vehicles with an accredited FCW system and tests them using the agency’s developed performance tests and criteria. If a vehicle alerts the driver with a TTC greater than the minimum allowable TTC specified by the current NHTSA performance test and criteria, then the vehicle maintains its accreditation on the website. If the vehicle is unable to meet the minimum specifications, then the technology checkmark is removed from the website.

Currently, NHTSA allows manufacturers to self-validate the capability of a vehicle’s FCW system by calculating the TTC variable based on issuance (and subsequent detection) of a warning message (or signal) on the vehicle’s Controller Area Network (CAN). This signal is used to trigger the alert modality for the driver interface through the vehicle’s dashboard, speakers, seat, etc. Since the information of the signal (what the system interprets as an imminent threat to the vehicle, when to alert the driver, etc) is proprietary to the manufacturer, it is extremely difficult for non-OEM personnel to interpret that information. Therefore, many test contractors have begun to use the onset of a visual, audial, or haptic alert to determine compliance with NHTSA’s TTC threshold requirements. This method is preferable since its timing reflects the time at which a driver would see, hear, and/or feel the warning.

It was during the agency’s random testing that NHTSA observed the delay of the onset of an FCW alert through the driver-vehicle interface when

compared to the activation of the CAN message signal. This paper will investigate the timing differences (as measured by TTC) between CAN message signals and their corresponding visual and audial alert TTCs, observed differences among various FCW systems evaluated, and whether such differences can be attributed to the type of driver-vehicle interface system employed.

METHODS

Data from seven (7) vehicles representing four (4) manufacturers were selected for this analysis (note that this paper uses the word "make" to refer to the subsidiary of a car manufacturer. For example, Lexus is a make of the manufacturer Toyota.). The capabilities and performance of each vehicle's FCW system were tested using the NHTSA's FCW performance test procedure described below. The first test consisted of the SV approaching a stopped POV. The second test consisted of the SV following the POV at a constant time gap. At a specified headway distance (gap between the front bumper of the SV and the back bumper of the POV), the POV suddenly decelerates. In the third test, the SV approaches a slower traveling POV. The three FCW tests are designed to evaluate the vehicle's ability to recognize common crash scenarios and inform the driver in a timely manner. In order to pass the NHTSA's FCW performance test, the vehicle must provide an FCW alert before the minimum allowable TTC established by NHTSA.

Prior to testing, the SV is delivered to the testing facility to be weighed and instrumented. Light and audial (microphones) sensors are placed in the vehicle to capture the alert modalities at the time of the alert. The CAN alert flag that states a warning has been issued is detected by accessing the diagnostic port on the vehicle or by tapping into the CAN system using manufacturers'. Currently, NHTSA's FCW test procedure allows for OEMs and contractors to validate the system using either the CAN message signal or by directly measuring an alert through the driver-vehicle interface. The earliest warning, as measured by TTC, is used to evaluate system performance.

Test 1: SV Approaches a Stopped POV

The SV is driven at a nominal speed of 45 mph (72.4 km/h) directly behind the stopped POV (Figure 1). The test begins when the SV is 492 feet (150 meters) from the POV (headway distance, s_{sv}) and ends when the FCW alert occurs or when the TTC falls below 90 percent of the TTC pass/fail criteria of 2.1 seconds.

$$TTC_{Test\ 1} = \frac{-s_{sv,initial}}{v_{sv,initial}} \quad (1.)$$

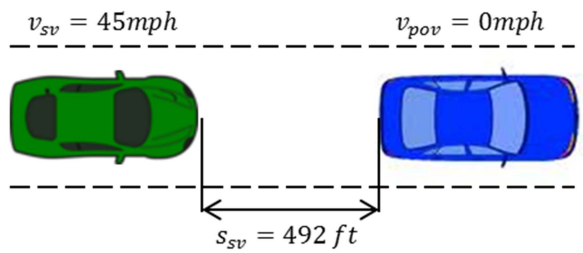

***Figure* 1. FCW Test 1 diagram.**

Test 2: SV Approaches a Decelerating POV

The test begins with the SV and POV traveling in a straight line at 45 mph (72.4 kph). The headway distance is maintained at 98.4 feet (30 meters) with the SV trailing directly behind the POV (Figure 2). Using a brake controller, the POV begins the braking maneuver. The POV is decelerated to 0.3 G within 1.5 seconds. The test ends when the FCW alert occurs or when the TTC falls below 90 percent of the TTC pass/fail criteria of 2.4 seconds.

$$TTC_{Test\ 2} = \frac{-\left(v_{pov,initial} - v_{sv,initial}\right)}{\left(a_{pov} - a_{sv}\right)} \ldots \frac{-\sqrt{\left(v_{pov,initial} - v_{sv,initial}\right)^2 + 2\left(a_{pov} - a_{sv}\right)s_{sv,initial}}}{\left(a_{pov} - a_{sv}\right)} \quad (2.)$$

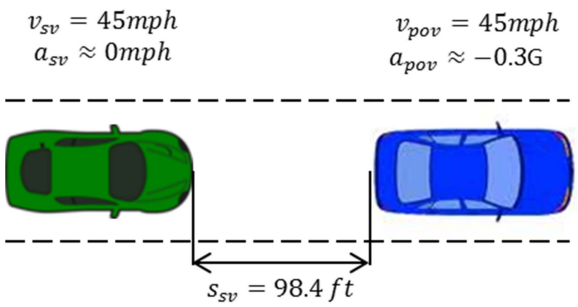

***Figure* 2. FCW Test 2 diagram.**

Test 3: SV Approaches a Slower Moving POV

The final FCW test consists of the SV approaching a slower moving POV vehicle (Figure 3). In this test, the SV is traveling at 45 mph (72.4 kph) while the POV is traveling at 20 mph (32.2 kph). The test begins when the headway distance is equal to 329 feet (100 meters) and ends when the FCW alert occurs or when the TTC falls below 90 percent of the TTC pass/fail criteria of 2.0 seconds.

$$TTC_{Test\ 3} = -\frac{(s_{sv,initial})}{(v_{sv,initial} - v_{pov,initial})} \qquad (3.)$$

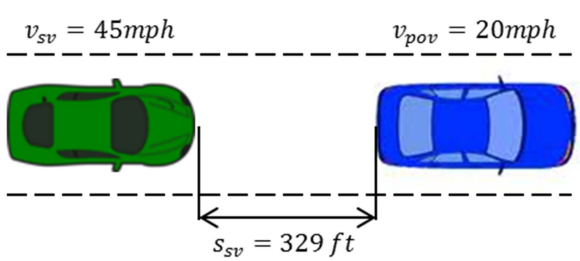

***Figure 3.* FCW Test 3 diagram.**

For an individual test to be valid, the following parameters must hold throughout the test validation period:

1. The speed of the SV cannot deviate from the test speed by more than 1.0 mph (1.6 kph);
2. The speed of the POV for test two (2) cannot deviate from the test speed by more than 1.0 mph (1.6 kph) for a period of three (3) seconds prior to breaking;
3. The speed of the POV for test three (3) cannot deviate from the test speed by more than 1.0 mph (1.6 kph);
4. The lateral distance between the centerline of the SV relative to the centerline of the POV cannot exceed 2.0 feet (0.6 meters);
5. The yaw rates for the SV and POV must stay between -1 and 1 degrees/second; and
6. No braking may be applied to the SV prior to the FCW alert or before the headway distance falls less than 90 percent of the minimum allowable distance.

Prior to analysis, all test data is filtered and synced to 100 Hz sampling frequency.

In order for a vehicle with an accredited FCW system to keep its checkmark on www.safercar, the FCW alert TTC must occur at a minimum of 2.1, 2.4, and 2.0 seconds for FCW test one (1), two (2), and three (3), respectively, and the system must pass a minimum of five out of seven trials.

LIMITATIONS

There are several limitations to this study. While there were several trial runs for each test and vehicle, only four (4) vehicle manufacturers were represented in this study. Furthermore, manufacturer C, only had one vehicle tested for model year 2012 while the other manufacturers had two vehicles each. Each trial recorded the TTC at the moment a CAN, visual, and audial alert was detected.

Table 1.
Population Distribution by Make and Model

	Model No.	
Make	1	2
1	n = 5,5,5	n = 5,5,6
2	n = 7,7,7	n = 7,7,7
3	n = 7,7,7	
4	n = 7,7,7	n = 7,7,7
	n = FCW test 1(LVM), test 2 (LVD), test 3 (LVS)	

Data was also limited by vehicle speed, thus limiting possible variations in results at different speeds.

RESULTS

A strong linear correlation (i.e., consistent amount of delay) was discovered between resulting visual warnings and the CAN activation signal for all test vehicles (Figure 4) and between the resulting audial warnings and CAN activation signal for four of seven test vehicles (R^2 value > 0.95) while the remaining vehicles had R^2 values of 0.67, 0.47, and 0.08 (Figure 5). The linearity of the audial warning resulting from the CAN activation signal (on select vehicles) was not discovered until the vehicle data was analyzed by make and model.

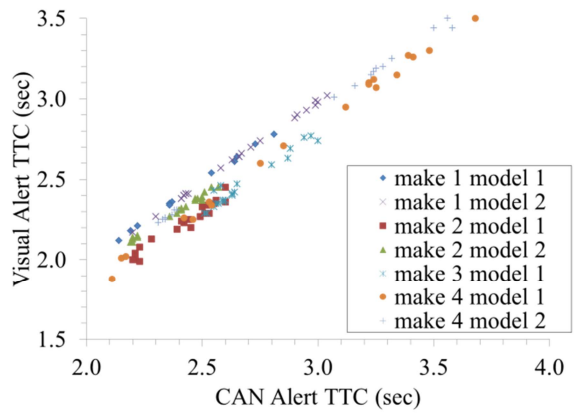

Figure 4. **CAN vs. Visual Alert TTCs by Make and Model.**

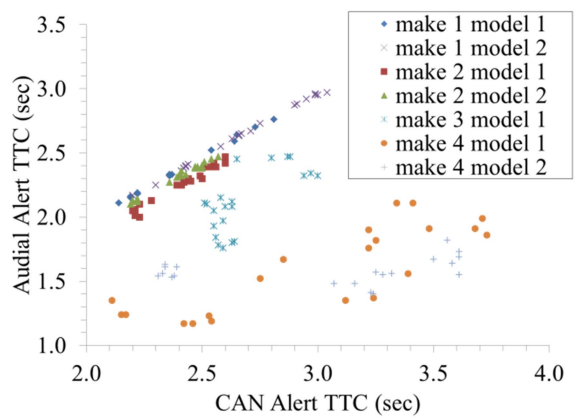

Figure 5. **CAN vs. Audial Alert TTCs by Make and Model.**

Furthermore, data showed a high percentage of failures for each FCW alert modality despite exhibiting a linear relationship with the CAN signal. All but one trial of the CAN activation signal data met the allowable TTC requirements set forth in the NHTSA's performance test procedure. However, as indicated below (Figures 6 and 7), more of the visual and audial alerts were triggered below the minimum specified alert TTC when compared to the CAN alert TTC.

Horizontal dashed lines are placed in Figures 6 and 7 to mark the minimum acceptable TTC for a given FCW test. Bars below these lines had an average failed TTC. Note that even if the average TTC may have failed the minimum test specifications, the vehicle may still have passed the NHTSA FCW test by passing at least five (5) of seven (7) trials.

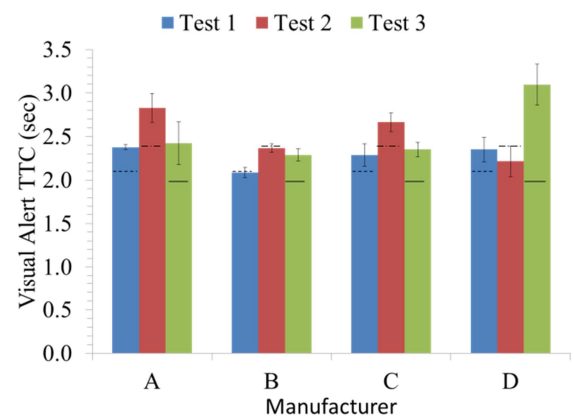

Figure 6. **Average Visual Alert TTC by Manufacturer.**

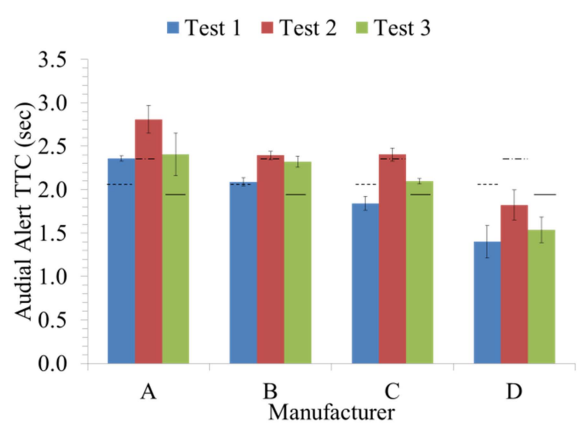

Figure 7. **Average Audial Alert TTC by manufacturer.**

Tables 2 and 3 illustrate the differences between makes and models of various manufacturers and the differences between audial and visual alert timings. For each vehicle, the CAN triggers both the audial and visual FCW alert.

Table 2.
Average Visual Alert Differences Between Manufacturers

Manufacturer	Test 1 (sec)	Test 2 (sec)	Test 3 (sec)
Min. TTC	**2.1**	**2.4**	**2.0**
A	2.37±0.02	2.82±0.16	2.42±0.24
B	2.08±0.05	2.36±0.04	2.28±0.06
C	2.28±0.12	2.66±0.10	2.35±0.08
D	2.35±0.14	2.21±0.17	3.09±0.23

Table 3.
Average Audial Alert Differences Between Manufacturers

Manufacturer	Test 1 (sec)	Test2 (sec)	Test 3 (sec)
Min. TTC	**2.1**	**2.4**	**2.0**
A	2.35±0.03	2.80±0.16	2.40±0.24
B	2.09±0.04	2.39±0.04	2.32±0.06
C	1.84±0.07	2.40±0.07	2.09±0.03
D	1.40±0.18	1.82±0.17	1.53±0.14

For manufacturers C and D, there is a large difference between the visual and audial alert times for each of the three FCW tests. Furthermore, the average TTCs for these manufacturers as well as manufacturer B could have resulted in failed FCW tests if the vehicle was required to meet specifications for multiple alert modalities (Table 2 and 3).

Manufacturers A and B did not have a substantial delay in TTC from the CAN activation. Furthermore, the audial and visual alerts occurred almost simultaneously. Conversely, manufacturers C and D had substantial delays between the onset of the visual and audial alert times (Table 4).

Table 4.
Change in Average TTC for Visual and Audial Alerts Compared to CAN TTC

Manufacturer	Visual ΔTTC (sec)			Audial ΔTTC (sec)		
	T1	**T2**	**T3**	**T1**	**T2**	**T3**
A	0.01	0.01	0.01	0.03	0.03	0.02
B	0.12	0.14	0.15	0.12	0.12	0.12
C	0.22	0.21	0.20	0.73	0.47	0.43
D	0.13	0.11	0.10	0.94	1.68	1.66

An F-test was performed to determine if the mean CAN, visual, and audial alert TTC were significantly different from each other for a given make. Makes B, C, and D had significantly different means (p-value < 0.0001); while only Make A did not have statistically significant different mean TTCs.

DISCUSSION

The data suggests that there were differences not only between the different manufacturers, but also by the same manufacturer. Furthermore, the data suggests there could be substantial delays (Table 4) between the onset of the CAN alert message and the visual and audial FCW alerts.

Two potential theories for the delay will be explored below. The first theory proposes that the delay and differences could be a result of the temporal and spatial characteristics of the CAN bus system. The second theory suggests that the delay could be deliberate and part of the FCW detection algorithm.

Today's vehicles may have up to 70 electronic control units (ECUs) that control various subsystems such as the infotainment center, air bags, transmission, radars and cameras, etc. Many of these ECUs' functionalities require input from other ECUs within the vehicle. In order to receive this

information, a signal must travel from one ECU to another through a physical connection. Due to the physical nature of the connection in the CAN bus systems, information travels along a single wire (Figure 8). Communications are constantly occupying space on the CAN bus system going from ECU to ECU.

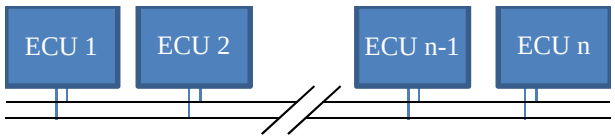

Figure 8. **Drawing of a CAN bus system in vehicle.**

Upon detection of an obstacle or a vehicle, the signal from the ECU that detects/processes the obstacle will need to send a signal to the ECU controlling the alert modality. This signal may have to interrupt other communication currently on the CAN bus communication line and make its way to the ECU that controls the alert modality. Without specific knowledge of the vehicle's CAN network, it is impossible to know the exact ECU and its location for the alert modality. It could possibly be on the same ECU that detects the object or an ECU located 5, 10, 15 feet or more (in cable length) from the origin of the signal. The physical distance between ECUs, the speed of the signal transmission, and other traffic on the CAN bus wires could cause some of the delays observed in the data and between different alert modalities.

The other potential reason for the observed delays and differences in the data is the possibility that manufacturers intentionally include a delay within their algorithms. This may be intended to keep the FCW system from aggravating the driver. If a driver becomes irritated with an FCW system because the alerts are occurring at high rates, then the driver may deactivate the system.

Evidence of the built in delay can be seen with the audial alert timings. All of the manufacturers displayed relatively low visual ΔTTCs for each FCW test; however, the corresponding audial alerts for each trial were substantially delayed for manufacturers C and D. The same CAN signal could theoretically be used to activate both alert modalities, or once the visual alert is signaled, another CAN signal from the ECU containing the visual alert is sent to the ECU containing the audial alert. One can speculate that the "intentional" delay could relate to the possible burden the audial alert has on a driver over the visual. The small, in-dash or HUD visible alerts that many models implement may be perceived as less abrasive than the high pitch beeps of an audial alert.

OBSERVATIONS

From the analysis of the data, it was observed that only four (4) of the seven (7) vehicles show a direct timing relationship to the CAN activation signal for both the visual and audial data (Figures 4 and 5). Furthermore, we observe that the differences between the activation timing of the visual and audial warnings from the CAN activation vary between manufacturer and test condition (Table 4). The majority of vehicles' visual alert modality timing occurred prior to the audial alert modality. This paper theorized two possible factors contributing to the delays between the CAN signal that activates the alert modalities and the actual measured timing of these alerts. The first suggested a physical delay due to the structure of the CAN bus system employed in vehicles. This is essentially a built-in delay resulting from the speed of the signal transmission and data processing. The second theory describes the possibility that some manufacturers may purposely delay one of the alert modalities (when multiple are present in the system). Test data showed significant delays between the timing of the visual and audial warnings from manufacturers C and D. These delays occurred during each test configuration. The delays may be purposely applied by manufacturers C and D, but it should be noted that due to the limited number of vehicles tested, and that this observation was discovered in post-test analysis, we cannot definitively state if these differences are a result of either theory or real-world testing scenarios. Observations such as these add to the importance of NHTSA's performance testing of FCW test systems.

In summary, both the visual and audial data, by make and model, illustrated a degree of linearity between the CAN and the alert modalities. This linearity

suggests that vehicle manufacturers have a degree of control as to when FCW alerts should occur once the CAN message signal is received. This could theoretically be achieved through the physical design of the CAN bus system or the FCW alert processing algorithms that vehicle manufacturers apply. In order to account for all possible reasons for driver distraction (i.e. changing the radio, looking to side view mirrors, changing lanes, etc.), manufacturers should consider minimizing any delay onset between the CAN signal and the FCW alerts, as well as between multiple FCW alerts.

ACKNOWLEDGEMENTS

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GLOBAL HARMONISATION OF TEST PROCEDURES FOR DRIVER ASSISTANCE SYSTEMS

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Paper Number 13- 0234

ABSTRACT

INTRODUCTION

In the past, the vehicle brake developed in leaps and bounds. The initial two-wheel brake was upgraded to the four-wheel brake, which was followed by the brake force booster. The introduction of the ABS was a significant step in the further development of the wheel. For the first time it was possible to control the braking power at each individual wheel. The new, advanced driver assistance systems (ADAS) enabled the vehicle brake to go into action without the driver having to do anything. These advanced driver assistance systems can analyse individual traffic situations and, in an emergency, apply the brakes automatically if the driver is not paying attention. This action can reduce speed and therefore mitigate the consequences of accidents. Ideally, there will not even be a collision, because the ADAS slows the speed of the vehicle down to zero.

PRINCIPLES

Advanced driver assistance systems (ADAS) not only prevent accidents, they also make it possible to reduce the effects of accidents, for example by reducing the collision speed. There are various approaches which are able not only to warn the inattentive driver but also to apply the brakes automatically. The action of the ADAS depends on the traffic situation and the philosophy implemented in the design of the ADAS. In particular, the underlying philosophy is an important aspect.
If the system reacts very quickly with a warning, the driver is warned in good time. This warning is always based on a prediction of the behaviour of current road users and their movement parameters. These parameters can change and therefore the traffic situation can ease, so the driver does not get into any trouble.

If the system reacts very quickly by applying the brakes, a predicted collision is completely avoidable. In this case, too, the situation can ease, because the driver, instead of braking, initiates a steering manoeuvre. This steering manoeuvre may correspond to the normal traffic situation.

The earlier the warning or braking, the more uncertain the reliability of the underlying prediction. Warnings or automatic actions on the part of the system in situations which the driver regards as non-critical or in which the driver intends to take a different action can lead to problems of acceptance. It makes sense to gear the design of an ADAS towards actual occurrences of accidents which demonstrate situations in which drivers do not deal correctly with the traffic situation.

There are a number of activities currently underway to develop procedures to test ADASs. The purpose of these testing procedures is to demonstrate the functionality or effectiveness of the ADAS. A test standard is therefore needed which depicts the actual occurrence of an accident but which does not ignore the normal traffic situation in which the accident occurs.

Various companies and institutions have decided to work together to develop proposals for procedures to test selected ADASs. Allianz Zentrum für Technik, Audi, Bundesanstalt für Straßenwesen (The Federal Highway Research Institute – BASt), BMW, Daimler, DEKRA, Ford, GDV, Honda, KTI, Opel, Porsche, Toyota and Volkswagen make up the Advanced Forward-Looking Safety Systems Working Group (vorausschauende Front Schutz Systeme – vFSS). The aim of the Working Group is to develop proposals for forward-looking driver assistance systems which are based on real world accidents. The testing procedure is intended to be independent of sensor technology. The vFSS Working Group is currently focusing on systems for forward-looking pedestrian safety and longitudinal traffic safety when cars are involved in a frontal impact. In the future, other ADASs (lane departure warning, intersection assistance, etc.) will be included.

The vFSS Working Group used both published reports of EU projects and publicly available accident statistics from Germany, [1] [2] [3]. These were supplemented by analyses from the in-depth accident databases of GIDAS (German In-Depth Accident Survey), UDV (Accident research carried out by the insurer), AZT (Allianz Zentrum für Technik) and DEKRA.

FORWARD-LOOKING LONGITUDINAL TRAFFIC SAFETY

Traffic situations involving a conflict with the vehicle in front are normal in traffic. Only a tiny minority of these situations is critical and only a minority of critical situations ends in a collision.

Longitudinal traffic safety – accident analyses

The accident analysis findings given below are just some of a series of findings and describe the scale of the problem and the most important factors in rear-end collisions.

Analyses of German accident data from 2005 to 2008 show the significance of rear-end collisions. Longitudinal traffic accidents account for 39% of accidents resulting in minor injuries (serious injuries and fatalities 27% and 35% respectively). Longitudinal traffic accidents are the most frequently cited type of accident resulting in mostly slightly injured persons and the second most frequently cited type of accident resulting in fatally injured persons. A further subdivision of longitudinal traffic accidents results in an accumulation of collisions involving oncoming traffic resulting in mostly serious injuries and fatalities. The sub-group of accidents involving oncoming traffic accounts for just 9% of longitudinal traffic accidents resulting in fatalities and 11% of longitudinal accidents resulting in serious injuries. However, they account for almost two thirds (65%) of longitudinal traffic accidents resulting in minor injuries.

Analyses of GIDAS accident data show that, in longitudinal traffic accidents, only a small minority of drivers initiate rapid deceleration. Deceleration of at least 6.0 m/s^2 is demonstrable in under 28% of approaching passenger cars, Figure 1. A further circa 24% demonstrably did not brake and 24% executed only partial braking. It can be speculated that the driver was not paying attention and/or incorrectly assessed the situation. There is potential here for an appropriate driver assistance system.

- Driver-related accidents
- Turning
- Turning into or crossing intersections
- Crossing the road
- Accident as a result of stationary traffic
- Longitudinal traffic

In stationary traffic

- Vehicle moving forwards or waiting (depending on the traffic)
- Travelling in the same direction in parallel traffic
- Oncoming
- Leaving the carriageway
- Other kinds of accidents

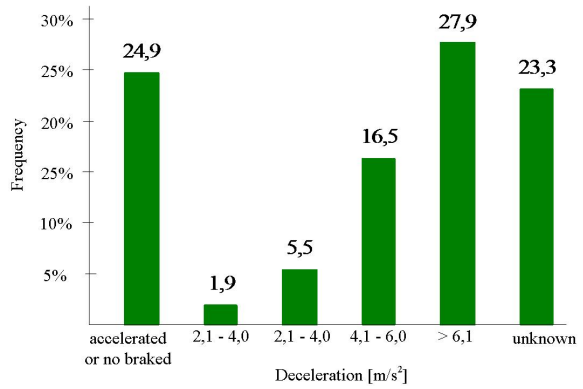

Figure 1. Distribution of brake retardation values of cars when approaching a two-track vehicle (data source: GIDAS).

An analysis of accident situations indicates three fundamental collision scenarios which, together, account for more than 80% of analysed collision situations. The scenarios are:

1. approaching a vehicle in front that is moving more slowly;
2. approaching a stationary vehicle;
3. approaching a braking vehicle.

The accident scenarios can be transposed directly into test scenarios. The proposal developed by vFSS contains these scenarios and suggests speeds for test conditions (Table 1). These test scenarios can essentially be identified in proposals put forward by other institutions working in this area.

Table 1.
Accident scenarios derived from GIDAS with proposed speeds for test scenarios

Scenario			Impacting (approaching) vehicle	Impacted vehicle
		100% = all rear impacts	Frontal impact	Rear-end collision
1	Approaching a stationary vehicle	46.6%	v0 = 50 km/h	v0 = vk = 0 km/h
2	Approaching a moving vehicle	14.1%	v0 = 90 km/h	v0 = vk = 45 km/h bv = 0 m/s²
3	Approaching a braking vehicle	22.4%	v0 = 50 km/h Distance to target D = 15 m	v0 = vk = 50 km/h bv = 4.5 m/s²

Longitudinal traffic safety – test constraints

Numerous constraints have always to be complied with when tests are carried out so that the results can be compared. An in-depth examination of the "standard constraints" is beyond the scope of this paper. Examples of standard constraints are ambient temperature, condition of the vehicle, appropriate choice of route, and others.

When accident scenarios are converted into test scenarios there are a number of contradictory aspects which are to some extent categorised differently by the various institutions working in this area. One possible aspect is keeping the planned tests to a strict minimum so as to save time and costs. Another aspect is sampling the widest possible range of speeds so as to demonstrate the efficiency of the tests as comprehensively as possible.

Another important aspect during testing is that of the warning. Should the warning be tested and evaluated at the same time? Essentially, the system should attempt to make the driver aware of the problem, if there is enough time. The warning must not come so early that the driver feels uncomfortable, categorises the ADAS as annoying and possibly switches it off. This could happen if the predicted situation fails to arise, but the driver has already recognised it in advance. A warning given less than 1.2 seconds before the calculated time to collision is ineffective, because the reaction time of the normal driver is no longer sufficient.

A very early warning may give rise to an undesired vehicle reaction, causing a problem both for the driver and for other occupants. Such braking manoeuvres can generally be overridden by the driver, but they disturb the driver and they could, in an extreme case, create a dangerous road traffic situation.

The target conflict depicted in Figure 2 between steering and braking in a critical situation is something which only the driver can resolve. At the indicated speed of 60 km/h a moderate braking process (6 m/s^2) needs approximately 18 m, and a moderate swerving manoeuvre can be carried out up to 12 m before the obstacle. The graph in 3 shows, for a deceleration of 6.0 m/s^2 an intersection point at approximately 30 km/h. Below this speed, the braking process is more relevant than steering for the prevention of accidents. The influence of humans is also of relevance. A sporty driver can prevent an accident at a later point through steering.

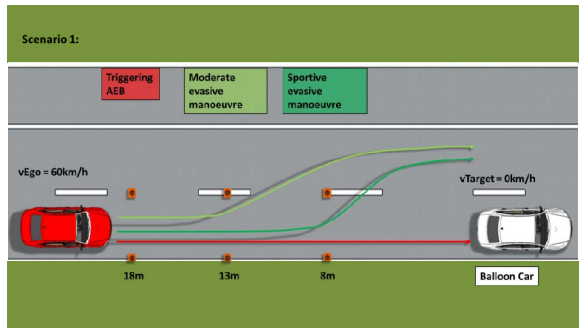

Figure 2. Presentation of the dilemma between braking and steering.

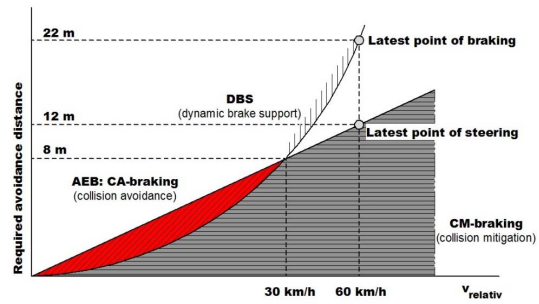

Figure 3. Theoretical resolution of the conflict between braking and steering (a = 6m/s^2).

Longitudinal traffic safety – development of suitable test targets

A defined target is required for a testing procedure. The target must be recognised by the driver assistance system regardless of the underlying physical principle. It should exhibit the physical properties monitored by the sensors.

The activities of vFSS also included actions to compare various targets. In comparative tests, the systems of vFSS members were supposed to react to various targets. Tests carried out by other institutions and those of vFSS showed that, in the implementation of a target for all sensor types, the properties of actual vehicles have to be reproduced exactly, so that all sensors have the same chances of recognising a target. Ultimately, a test is not intended to investigate how the vehicle reacts to the target but how the system in the vehicle behaves in real life. A target is also supposed to produce the radar reflectivity of an actual vehicle from slightly modified directions, while at the same time reproducing the optical properties (including the shadows cast). The properties should be reproduced in the target as accurately as possible. A radar echo that is too small is just as unfavourable as one that is too big. A reflector that is positioned too far inside

the target can lead to the ADAS assessing a situation incorrectly, thereby influencing the result of a comparison test. During target braking, the vehicle brakes too late or insufficiently.

Forward-looking pedestrian safety

Pedestrian safety has become increasingly important in recent years in vehicle safety in particular during the development of new vehicles. Initially, activities focussed on passive safety, the main impact of which was on improved vehicle front-end design in relation to accidents involving pedestrians. In recent years there have been clear evolutionary steps in the development of driver assistance systems. These were made possible as a result of, among other things, the new capabilities of sensor systems and the improved performance of processors in conjunction with advances in knowledge about the real-life occurrence of accidents involving pedestrians.

Pedestrian safety – accident analyses

Accident analyses are primarily based on German accident data. The results of the analyses are supplemented by available results from Japan and European projects [4][2]. Further results are available for the United Kingdom out of the EU APROSYS project [3].

In Germany, a total of 320,614 accidents involving pedestrians were recorded by the police in 2008. These accidents led to 413,524 injured people (4,477 fatally injured + 70,644 seriously injured + 338,403 slightly injured people). The majority of these people were injured during the day (n = 299,526), which is almost three in four. The share of people injured during the night is less than one third of the total number of injured people (n = 11,237). A detailed analysis reveals that almost twice as many pedestrians were injured during the day than during the night (22,272 during the day compared with 11,151 during the night)). The same analysis reveals an almost opposite result in the case of fatally injured pedestrians. While 256 pedestrians were killed during the day, 397 pedestrians were killed during the night.

The high share of pedestrians fatally injured during the night is not unique to Germany. According to European accident statistics a similar picture emerges throughout the EU [2]. In the 18 EU countries investigated, in 2007 more than half (52.6%) of fatally injured pedestrians were killed during the night. A specially developed analysis of accident figures from Japan reveals that a very high share (68.6%) of accidents in which pedestrians were killed occurred during the night. Overall, Italy, France, Spain, Germany, the United Kingdom and Poland are the nations with the highest number of fatalities in accidents involving pedestrians on European roads. Essentially, accidents that take place when pedestrians are crossing the road represent the most common accident situations. This is the case in Germany and in the United Kingdom in at least 75% of accidents involving passenger cars and pedestrians. Japanese analyses indicate a similar significance, albeit not quite the same significance as in Europe.

The results of the analyses carried out by GIDAS, UDB, AZT and DEKRA deepen the insights gained from the general statistics. The databases show virtually the same typical scenarios for accidents involving pedestrians and passenger cars. These scenarios include crossing the road with and without sight obscuration, turning-off situations (to the right or left) and pedestrians moving onto the carriageway in the same or opposite direction to the movement of the car (accident in a linear flow of traffic). All the analyses show that crossing the road without sight obscuration was involved in at least 60% of accidents. At least a further 10% was accounted for by pedestrians crossing the road with sight obscuration.

Table 2.
Absolute frequency of pedestrians injured and killed depending on the light conditions in Germany 2008 (source: StBA)

Germany 2008	Day	Night	Night : Day
Injured	22,272	11,151	circa 1:2
Fatalities	256	397	circa 8:5

Table 3.
Distribution of typical accident situations involving passenger cars and pedestrians, various sources

	Germany			United Kingdom		Japan
	GIDAS	UDV	AZT	STATS 19		?
crossing without obstruction	59.0	65.0	71	58.6	At least 75% of all accidents	36.5%
crossing with obstruction	27.4	12.0	13.2	17.9		0.4%
turning accident	6.9	23.0	15.8			(11.7%)
along carriageway in/against direction	2.1	8.0		11.1		11.9%

In 60% of accidents between passenger cars and pedestrians the front of the vehicle is the area of impact. An analysis of GIDAS data reveals, like the official statistics, a higher number of accidents occurring during the day and a higher share of fatal accidents occurring during the night. The consequences of accidents for pedestrians are generally more serious during the night. The accident analyses distinguish six typical scenarios. The first scenario describes a pedestrian approaching from the right who crosses the carriageway (adult, 1.72 m tall, v = 5 km/h). The speed of the passenger car is between 45 and 50 km/h. The driver reacts by initiating a braking manoeuvre.

In the second situation, the passenger car is travelling at between 55 and 60 km/h and the pedestrian approaches from the left and crosses the carriageway. The driver of the passenger car brakes before the collision. There are two variants of the scenario. Some of the accidents take place during the day and involve children running (height 1.2 m, v = 10 km/h), while some of the accidents take place during the night and involve adults walking (v = 5 km/h).
The third scenario is a left turn involving a pedestrian coming from the right in the side street. The passenger car is travelling at between 20 and 25 km/h. The adult pedestrian is walking. The driver of the passenger car brakes before the collision. The fourth scenario is a right turn. The passenger car is travelling round the bend at between 10 and 15 km/h. The walking pedestrian comes from the right. The driver reacts by initiating a braking manoeuvre.
The fifth scenario is similar to the first scenario. A running child (v = 10 km/h) comes out from behind a sight obstacle, while the car is travelling at between 45 and 50 km/h. The driver brakes before the collision. The sixth scenario replicates an accident on a secondary road. The pedestrian is walking along the edge of the road in the same or opposite direction to the passenger car (speed >70 km/h). The accident typically occurs when it is dark and very often ends with the pedestrian being very seriously injured.

An important aspect is the type of obscuration. An analysis of GIDAS data shows that sight was obscured in 42.7% of accidents between passenger cars and pedestrians, 30.5% of which were caused by a stationary vehicle.

Another important aspect is whether and how strongly the brakes were applied. The accident reconstructions in GIDAS were able to answer these questions in a good 80% of cases. Approximately 30% of all car drivers did not brake. A total of 34.9% (26.2%) of passenger cars involved in accidents during the day (during the night) braked at more than 6.0 m/s^2. Approximately 20% braked at up to 6 m/s^2. The generally somewhat weaker braking during the night, together with the higher start speeds, lead to higher collision speeds.

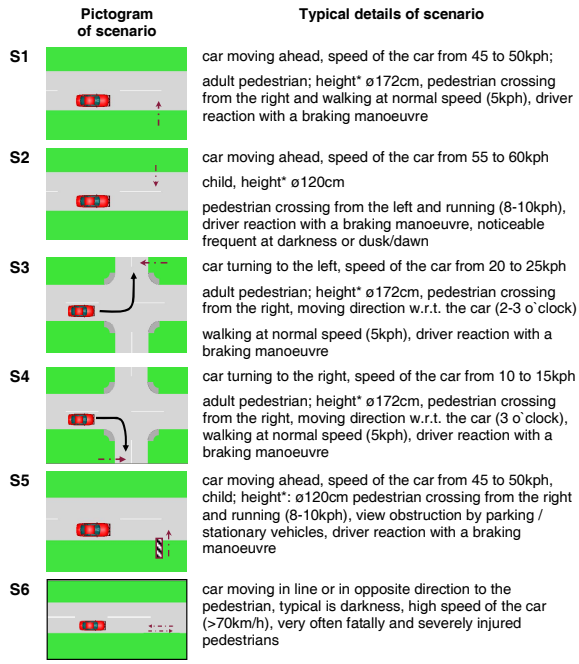

Figure 4. Typical scenarios of accidents involving passenger cars and pedestrians (source: UDV).

The analysis of the events leading up to an accident contains a time-to-collision (TTC) value, which reveals the time to collision under constant current constraints. When an object can first be recognised is important for driver assistance systems. In the case of accidents that take place when pedestrians are crossing the road, an analysis of these values shows that half of the objects (pedestrians) would have been visible and hence detectable as much as 3 seconds before the collision (Figure 5). Pedestrians that are clearly visible (without sight obscuration) would have been detectable 3 seconds before the collision in as many as 70% of cases. Obscured objects cannot be detected until the TTC = 0.9 seconds in 70% of cases. This is the limit value for the detection of pedestrians. At this point there does not need to be a call for reaction on the part of the driver and/or the assistance system. Not until there is a call for reaction, which there would be, for example, as soon as the kerb is crossed, should there be a reaction.
A particular feature of pedestrians who cross the carriageway is temporal avoidability, which is present under certain circumstances. In contrast to rear-end collisions, before the collision the pedestrian

is not always in the path of the passenger car. If the pedestrian arrives before the passenger car at the crossing point of the trajectories of both parties, he may have left it before the passenger car reaches it (Figure 6). If the passenger car arrives before the pedestrian it may have continued its journey before the pedestrian reaches the possible collision point.

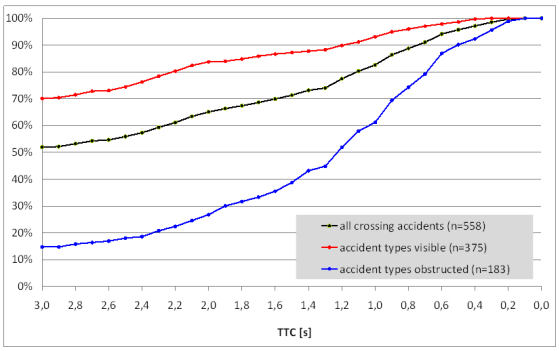

Figure 5. TTC values for the detection of pedestrians by the ADAS FAS (source: GIDAS).

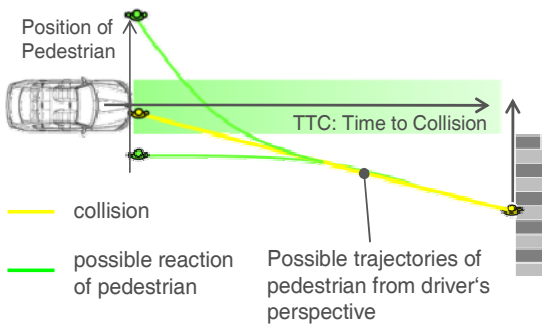

Figure 6. Possible trajectories of the pedestrian from the driver's perspective (source: Audi).

Pedestrian safety – derivation of test scenarios

The accident analysis contains a number of interesting findings. The task consists in implementing these findings in a testing procedure. One of the objectives of vFSS is to replicate the occurrence of an accident as comprehensively as possible with a limited number of tests. These tests should be designed independently of technology so that no system is disadvantaged. The accident scenarios shown above form the basis for this. Provided the ADAS to be investigated has a sensor arrangement that is symmetrical to the longitudinal axis of the vehicle, a test with a dummy coming from the right would be sufficient. Therefore, accident scenario S2 could be covered in a test that covers accident scenario S1.

Theoretical investigations of the turning scenarios S3 and S4 highlight the large number of parameters of the turning situation. These parameters include the speeds of the pedestrian and the passenger car, the cornering radius, the nature of the bend, the lateral displacement of the pedestrian at the starting position of the passenger car, the angle of opening and the position of the sensor (at the front of the vehicle or behind the interior mirror). In individual parameter combinations the pedestrian appears in the detection range of the sensor when the vehicle starts to turn, only to leave it, owing to unfavourable relative movements, before reappearing in the detection range shortly before the collision. In some cases, the pedestrian is not in the detection range of the sensor until shortly before the time of the collision (~0.1 s). At present no parameter combinations can be named which depict the event of the accident. No data is yet available on this. The parameter combinations of the theoretical considerations give different results depending on the combination. A slight change in parameter leads to significantly different results, which means that a system performance cannot be derived from it.

Accident scenarios S3 + S4 could also be seen as special cases of S5. When the vehicle is turning, the sensor can only recognise the pedestrian from a specific point. The effect of the turn would be that of a sight obscuration.

Scenario S6 does not pose a real challenge for the ADAS. A pedestrian who moves in the path of a vehicle without the relative transverse motion will be detected by the sensor. The system will react in a particular instance depending on the system design implemented.

On the basis of these arguments, what remains for a testing procedure is to replicate accident scenarios S1 and S5. In the new proposed procedure, the height of the pedestrian as well as the speed of the pedestrian and the passenger car are replicated in such a way that variations of these parameters are included. The vFSS Working Group proposes to use two sizes of pedestrians (child + adult) with two speeds (5 + 10 km/h) and a passenger car speed (40 km/h) for performance tests. These are supplemented by a preliminary test and a night test.

The actual performance tests consist of four test variants with TTC values of 1.3 and 2.7 s with two tests with and two tests without sight obscuration with a running child and a walking adult. A night test with defined lighting conditions shows whether the ADAS is able to act when light conditions are poor.

Should the ADAS react to the situation, this will open up the potential for this system to react in the case of accidents that happen at night, resulting in a higher potential benefit.

The preliminary test demonstrates, on the one hand, that the ADAS also functions at lower and higher speeds ($v_{passenger}$ car = 20 km/h and $v_{passenger}$ car = 50 km/h) than the speed specified for the performance test. There are also no-fire-tests to test the recognition of non-critical situations. They include a test with a group of pedestrians (adult + child) standing near the path of the vehicle and a test with a car passing a parked vehicle.

The tests replicate reality and the occurrence of the accident as far as possible. Dummies must exhibit the property or properties corresponding to the ADAS. In the case of an infrared sensor, the dummy that is used must have the body temperature that corresponds to that of a human. The test must not be limited to one or just a few physical properties of the dummy. If the ADAS uses the oscillating movement of the legs to recognise a pedestrian, the test must also be able to do so. The dummy used for the individual test does not have to exhibit all physical properties, just those that that correspond to the ADAS.
Two test variants are conceivable:

1. Test with contact between the dummy and the vehicle
2. Test without contact between the dummy and the vehicle.

vFSS favours the contactless variant. Shortly before the collision, the dummy is protected by means of a Dummy Rescue Manoeuvre (DRM). A DRM protects the vehicle and the dummy against damage. A repair costs time and money. The dummy does not have to be extremely light. The advantage of the variant involving the collision is that the test looks more realistic, which is also suitable for PR campaigns.

A further aim of the test is to ascertain the reduction in speed caused by the ADAS. This reduction in speed is synonymous with the benefit in the accident situation addressed by the ADAS. The injury-shift method that is already implemented continues to apply. The ascertained reduction in speed can be converted into a reduction in injury depending on the performance of the sensor (angle of opening, suitability for use during the night, etc). The conversion procedure is based on original accident data from GIDAS. The digital case files are calculated taking into account, amongst other things, the angle of opening of the sensor. Consideration is also given to the passive properties of the individual impact regions at the front of the vehicle [5]. The result is a set of curves which derives the reduction in the severity of the injury from the reduction in speed measured in the test depending on the parameters of the ADAS. The set of curves shown is only valid for one of several conceivable configurations. Each configuration has its own set of curves.

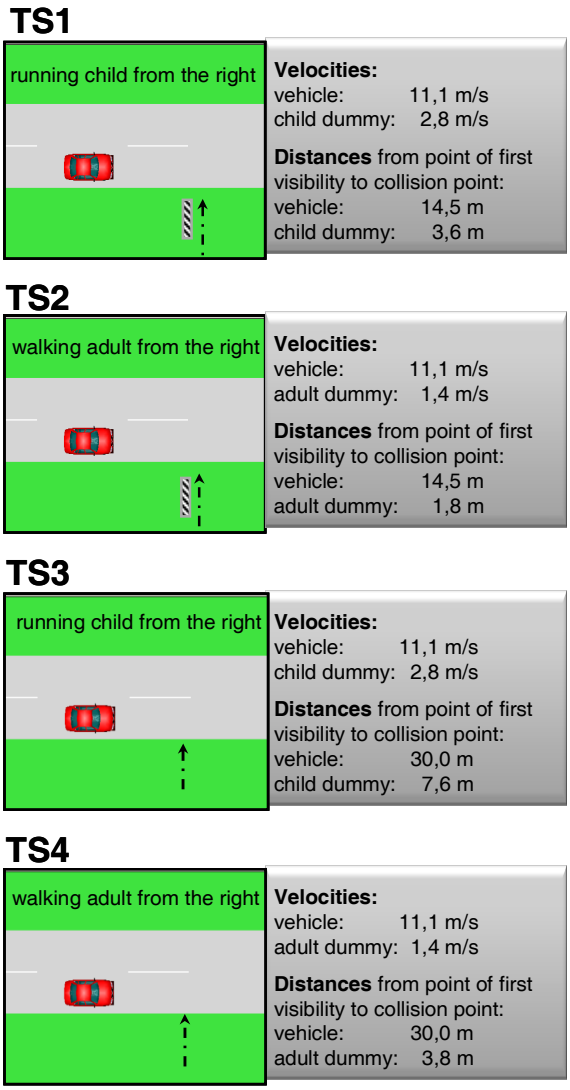

Figure 7. Test scenarios derived from an accident involving a passenger car and a pedestrian.

SUMMARY

The vFSS Working Group set itself the goal of developing proposals for procedures based on real world accidents that were independent of technology. The accident analyses reveal the importance of accidents in longitudinal traffic and of accidents involving passenger vehicles and pedestrians. Discussions were less about the basic accident scenarios than the different levels of importance attached to them internationally. The scenarios can, in principle, be played out anywhere.

There are six typical scenarios of accidents involving passenger cars and pedestrians and three scenarios for rear-end collisions.
In the three scenarios for rear-end collisions there are differences in speed of up to 40 km/h and a deceleration of 6 m/s^2. The three accident scenarios can also be replicated by means of test scenarios.

In the six scenarios of accidents involving passenger cars and pedestrians, the most common scenario is that of the pedestrian crossing the road. An important point to note is that considerably more accidents involving (injured) pedestrians occur during the day but the majority of fatal accidents take place during the night. Sight obscuration is implicated in a number of these accident situations. The six accident situations can be transferred to four test scenarios involving pedestrians of different heights (child and adult), pedestrians moving at different speeds (5 and 10 km/h), two TTC values (1.3 and 2.7 s), with sight obscuration included in some cases. The test speed of the passenger car is 40 km/h. In addition to the performance tests of the four test scenarios there are four preliminary tests with higher and lower passenger vehicle speeds (v = 20 and 50 km/h) and two no-fire tests. The test proposal also includes a night test to demonstrate the potential benefit of the ADAS. The test proposal is supplemented by a procedure based on the injury-shift method to convert the reduction in speed into a reduction in severity of injury.

The testing procedures must be geared towards actual occurrences of accidents, without neglecting the "normal accident situation". They must be system neutral so as not to disadvantage future developments. The targets applied must reflect reality so as to ensure that realistic results are achieved.

The international harmonisation of testing procedures is a major objective. In Europe a number of important institutions have exchanged ideas and information on harmonisation platforms on the topics of accident scenarios, target specifications and the evaluation of findings. The players are in general agreement with regard to scenarios and target specifications. Some questions remain unanswered, however, such as: Should the pedestrian be tested with or without contact? Should the TTC value, the speed, or both be varied? How is a warning function to be included in the evaluation?

OUTLOOK

A problem that has not yet been mentioned is the processing of the warning by the ADAS for the driver. No thought has been given here to the aspect of the optimal optical, acoustic or haptic signal. Hopefully, a driver will rarely encounter a situation where he receives a warning of an imminent rear-end collision or a pedestrian crossing the road. It is a moot point how appropriately the driver will react to this warning despite the rarity of the event if he has, at some point in the past, internalised the reaction as: "This signal is warning me of a rear-end collision or a pedestrian."

Another important aspect which will be certainly discussed more in the future is Periodic Vehicle Inspection (PTI). Driver assistance systems which are already on the market or will be put on the market in the future must be regularly checked in order to ensure that they are functioning properly and correctly. The aim must be to develop a standardised and harmonised procedure.

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DEVELOPMENT OF EQUIPMENT TO EVALUATE PRE-COLLISION SYSTEMS FOR PEDESTRIANS

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ABSTRACT

Pre-Collision Systems (PCS) for avoidance/mitigation of pedestrian crashes have begun to be equipped on certain high-end passenger vehicles. At present, there is no common evaluation standard to evaluate and compare the performances of different PCS for pedestrian collision avoidance. The Transportation Active Safety Institute (TASI) at Indiana University-Purdue University-Indianapolis has been studying the establishment of such an evaluation standard with the support from Toyota Motor Corporation. To create a test environment for conducting PCS tests with pedestrians, common relative motion patterns of pedestrians and vehicles before crashes were identified. These motion patterns further define the requirements of the test equipment for PCS testing. The mannequin manipulation equipment was designed to provide sufficient motion range so that the mannequin motion can replicate pedestrian walking and running at the representative speeds. Various mannequin manipulation structures were considered and evaluated to ensure the safety and portability of the equipment and to minimize PCS sensing interference. Due to the potentially short intersection time period between the mannequin and vehicle in most test scenarios, the motions of the vehicle and the mannequin need to be precisely coordinated by a computer and must be based on sensor triggers. The final PCS test equipment design consists of a central computer, a mannequin with moving limbs, a crane system that can move the mannequin across or along the road, and infrared based start/stop sensors. Accurate data recording and the synchronization of mannequin motion and vehicle motion are based on the atomic clock in the Global Positioning System (GPS). This paper describes the design and development of the equipment for coordinating the relative motion of the mannequin and the test vehicle.

1. INTRODUCTION

Pre-Collision Systems (PCS) for pedestrian crash avoidance have been equipped on some high-end passenger vehicles. There are many studies on PCS pedestrian safety [1-4]. However, there is not a common evaluation standard to evaluate and compare the performances of PCS for pedestrian collision avoidance. The Transportation Active Safety Institute (TASI) at Indiana University-Purdue University-Indianapolis has been studying the establishment of such a standard with the support from Toyota Motor Corporation. One task surrounding the development of such a standard is the creation a set of test equipment for PCS pedestrian evaluation.

To create test equipment for conducting the PCS test with pedestrians, the possible types of relative motion between vehicles and pedestrians were identified. Then the representative motion speeds of vehicles and pedestrians were estimated. This information was used to generate the work space specifications of the mannequin manipulation equipment for vehicle testing. The wirelessly controlled mannequin manipulation equipment was designed to coordinate the operations of all system components for executing the PCS evaluation scenarios.

This paper is organized as follows: section 2 describes and analyzes the feasible test scenarios and speed ranges of the vehicle and the mannequin. Base on the result of section 2, section 3 gives an overall design of the mechanical structure of the system. Section 4 describes the computer network and control

structure of the whole test system. Section 5 demonstrates the experiment results. Section 6 concludes the paper.

2. EQUIPMENT REQUIREMENTS

To develop the equipment for PCS pedestrian collision avoidance evaluation, the most important task is to determine test scenarios which provide the specifications of the equipment. There are 12 types of common relative motion patterns between vehicles and pedestrians that can lead to crashes (see Table 1). For each type of relative motion patterns s, there is a set of tests to evaluate how PCS warning/braking are activated. The PCS performance is determined not only by how well it warns/brakes when there are imminent crashes but also how well it does not warn/brake when there are not imminent crashes (e.g., a pedestrian walks towards the street and stops at the curbside). Therefore, for each type of vehicle/pedestrian relative motion, there is also a set of tests to check if PCS does not activate when it should not activate. So there are a total of 24 types of test scenarios (see Table 1). Non-bold entries of Table 1 describe the motion directions of the mannequin.

The size of the mannequin workspace is determined by two factors. The first factor is the pedestrian motion speed and duration for all specified test scenarios. Literature suggested that the average pedestrian running speed is about 4.3m/s. Assuming that the mannequin needs to move at least 4.5 seconds during a PCS test along the road to give PCS sufficient time to detect the mannequin, the travel distance of the mannequin needs to be 19.35 meters long. However, travel speed of 4.3m across the road is too high for the PCS to respond to the imminent crash. First, the width of one lane road on highways is 3.7 m wide and many local streets are narrower. So it takes less than one second for the mannequin to cross the road. Second, most PCS systems take at least one second to recognize an imminent crash, to make the warning/braking decision and to command the brake system to engage the brake. Third, the PCS should not warn/brake if the pedestrian is not in the lane that the vehicle is moving. Therefore, the maximum cross road speed of the pedestrian is selected as 2.5m/s. Based on this selection, the width of the workspace of the mannequin motion device is calculated as 2.5x4.5 =11.25 m.

The second factor affecting the dimensions of the work space is the interference of the equipment to PCS radar signals. Considering two state of the art automotive radars used on the current PCS systems, the range of the vehicle radar elevations is 4.3°and 4.5°respectively. The range of the vehicle radar azimuth angles are 28° and 23°, respectively. The azimuth resolutions are ±2°and ± 1°, respectively. Assuming that the pedestrian detection range of the radar and video systems in the test vehicle is less than 40 m, when the vehicle is moving at 45 mph (72 km/h or 20 m/s), the pedestrian detected at 40 m away gives the vehicle 2 seconds to respond. The height of objects that the vehicle radar cannot detect at 40 m is 40m x tan(4.5^o) + 0.5 = 3.64 m (≈ 12 ft.). If the equipment can be kept above 3.64 m, the radar will not see the equipment within 2 sec. By the same calculation based on the azimuth resolution, the PCS radar should be able to tell that any object at 1.4 meter away from the road side is not an imminent crash threat. With the height of 3.64 m and width of 11.25 m, the RCS interference from the mannequin motion structure will not affect PCS's decision on warning/braking.

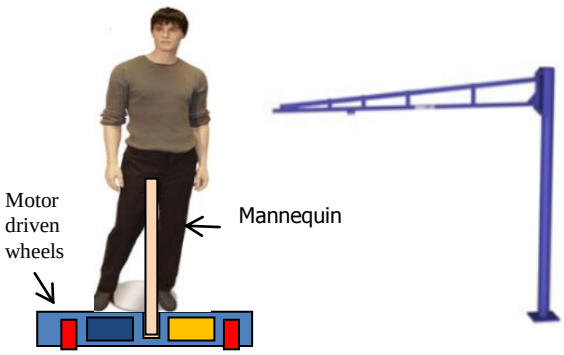
Table 1. Types of test scenarios

		Vehicle motion types					
		Straight		**Left turn**		**Right turn**	
Pede-strian motion types	**Crosses the road (PCS Activation)**	Cross from left to right	Cross from right to left	Cross from left to right	Cross from right to left	Cross from left to right	Cross from right to left
	Along the road(PCS Activation)	Away from the vehicle	Towards the vehicle	Away from the vehicle	Towards the vehicle	Away from the vehicle	Towards the vehicle
	Crosses the road (PCS non-Activation)	Move from left to right on curbside	Move from right to left on curbside	Move from left to right on curbside	Move from right to left on curbside	Move from left to right on curbside	Move from right to left on curbside
	Along the road (PCS non-Activation)	Away from the vehicle on curbside	Towards the vehicle on curbside	Away from the vehicle on curbside	Towards the vehicle on curbside	Away from the vehicle on curbside	Towards the vehicle on curbside

3. THE MECHANICAL STRUCTURE

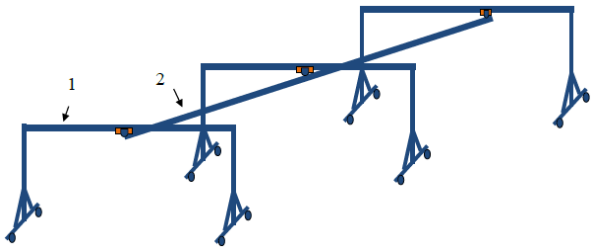
3.1. The Selection of Mechanical Structures

Various mannequin motion devices were considered (see Figure 1), which include self-driven robot, jib crane, 2D bridge crane, 2D motion sled, on-ground track guided sled, and 1D gantry crane.



(a) Robot (b) Jib crane

(c) 2D bridge crane (d) Sled



(e) 1-D gantry crane (1 = supporting beam, 2 = suspension beam)

Figure 1. Various mechanical structures considered for the manipulation of the mannequin motion.

The self-driven robot (Figure 1(a)) has many advantages, such as it has no work space size limitation, can produce 2-dimensional mannequin motion, and is very portable. However, it is not selected due to its following limitations, (1) the motion path may not be accurate due to road surface conditions, (2) the robot base needs to be at least 3 inches tall since the minimum motor diameter needs to be at least 2 inches for the torque needed for the robot motion, which may cause PCS false activation, (3) it can be damaged by the test vehicle and may damage the test vehicle if being run over by the test vehicle.

The jib crane (Figure 1(b)) can produce true 2-D mannequin motion but it is a large structure and requires a permanent installation at the test site. Also due to the concerns in the operation of a large jib crane, the jib crane is not selected for mannequin manipulation.

The 2D bridge crane (Figure 1(c)) also provides true 2D mannequin motion. It is stable with four standing poles and the track length can be extended along the road. However, it is not selected since the speeds of the commercially available gantry cranes are lower than 2.5 m/s and it needs to be permanently installed on the test site.

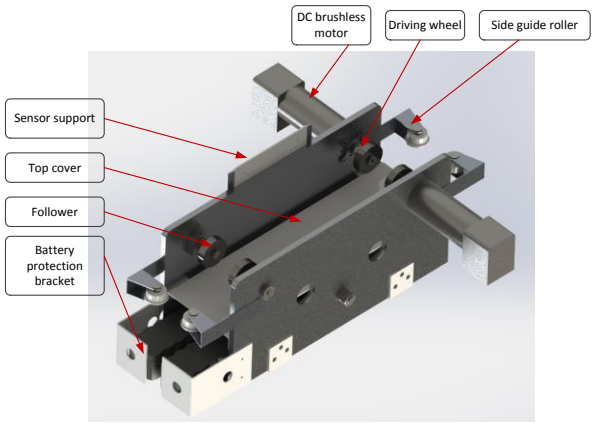
Sled (Figure 1(d)) approach for the mannequin motion manipulation was seriously considered due to its low radar interference, large workspace, and simplicity of the driving system. It can be driven by ropes or guiding track on the ground. When using rope to drive the sled, the operation of the sled and test vehicle is a concern since the rope can be tangled by the wheel of the vehicle. Since we do not own a test site, installing a mannequin guiding track below road surface is not an option to us.

We selected the 1D gantry crane system (Figure 1(e)) for the mannequin motion manipulation. This structure consists of several gantry cranes and a suspension I-beam hanging on multiple gantry cranes. The suspension I-beam can be extended as long as needed for pedestrian walking along the road scenarios by adding more gantry cranes. When testing pedestrian across road scenarios, the suspension I-beam can be pushed to one end of the gantry cranes and the mannequin can be moved along one gantry crane. When testing pedestrian moving along the road scenarios, the suspension I-beam can be moved to the middle of the gantry cranes and the mannequin can be moved along the suspension beam. This structure has several advantages: (1) the track length crossing the road can be over 11 meters and

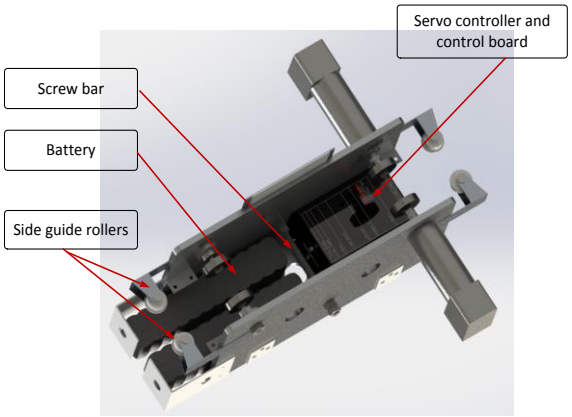
the track length along the road can be extended as long as needed, (2) the mannequin can be moved crossing the road on the supporting I-beam and be moved along the road in suspending I-beam, (3) its overall weight is low and can be assembled and disassembled on the test site easily by 3-4 people. One drawback of this structure is that it cannot provide true 2-D mannequin motion. Since there is not sufficient data in crash databases to specify curved motion of pedestrians on the road, mechanical structure that supports one dimensional motion for crossing the road (with specified angle) and along the road is sufficient for the PCS evaluation.

3.2 Trolley and Harness

Once the 1-D gantry structure is selected, the rest of the mannequin motion manipulation system can be designed. The motion of the mannequin is controlled by a motor driven trolley (Figure 2) which runs on the I-beams of the crane structure. The connection of the trolley and the mannequin is through a harness (shown in Figure 3) which is attached to the bottom of the trolley. The harness consists of six main components, two lengthway support beams, two crossway support beams, two trolley connection beams, eight auto-lock fishing reels, sixteen guiding hooks and four strengthening steel plates. It has a dimension of 1825x2400mm, and weight of 10kg. Eight fishing lines are used to hang the mannequin. With the auto-lock fishing reels and guiding hooks, the height of the mannequin from ground can be adjusted. The harness is designed to reduce the swing and rotation of the mannequin caused by limb motion.



2(a)



2(b)

Figure 2. The mechanical design of the trolley.

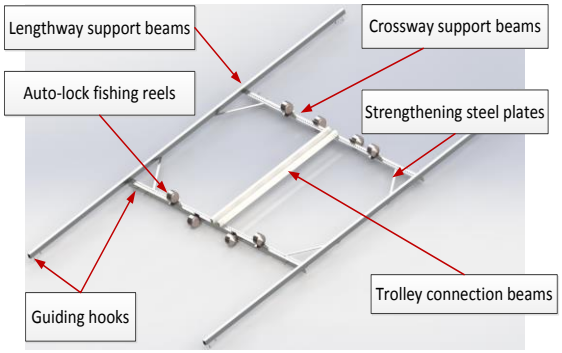


Figure 3. The structure of the harness.

4. COMPUTER CONTROLED SYSTEM OPERAION

4.1. Overview

To support the test of PCS for pedestrian crash scenarios, the operation of all system components need to be coordinated. The motion of the test vehicle, the motion of the trolley, and the motion of mannequin limbs need to be synchronized. The recordings of the test vehicle motion data and mannequin motion data also need to be synchronized. The system consists of a main control computer, two infrared based start and stop sensors, a trolley and a limb moving mannequin. Since the distances between different components are from several meters to hundreds of meters, all components operate on battery power and communicate wirelessly (see Figure 4). The mannequin can be driven by the trolley across the road or along the road.

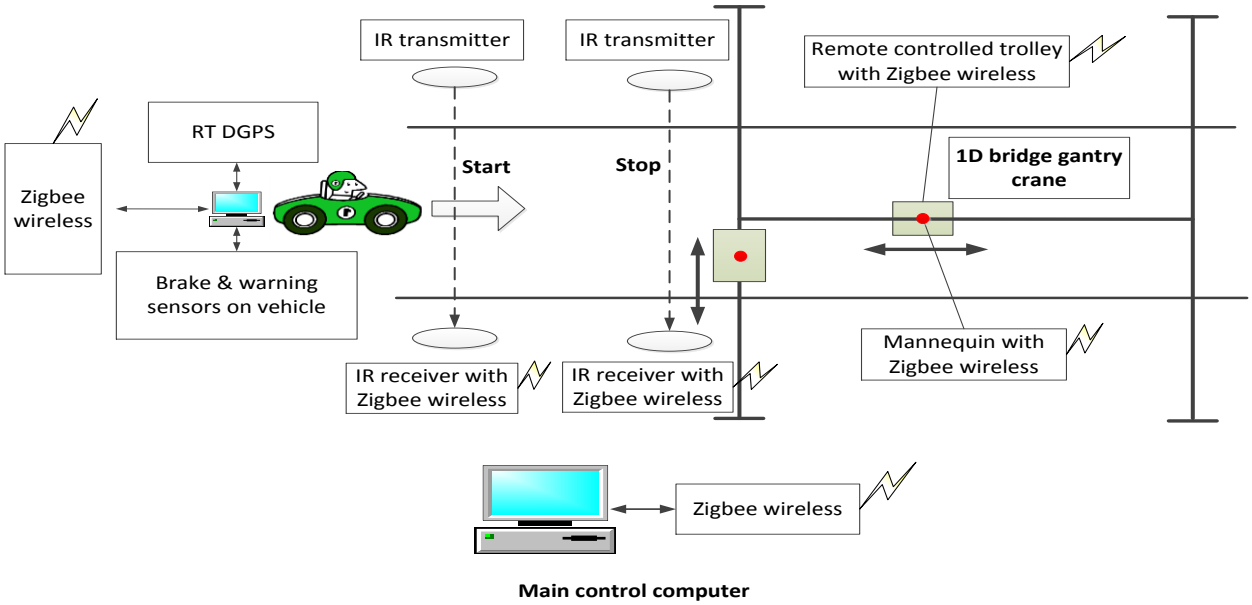


Figure 4. The overall design of the PCS evaluation system.

The main control computer is the core of the system. It coordinates the timed operation of all components in the system and interfaces with the operator. It also plans the motion timing of the mannequin and the trolley, coordinates data recording for the motion data of both the test vehicle and mannequin. The main control computer communicates with all other component devices through a Zigbee wireless communication network. Two long range infrared sensors (IR) are used to trigger the motion of the trolley and the mannequin based on the detection of the arriving test vehicle. One IR sensor detects the arrival of the test vehicle at a particular location and notifies the central computer wirelessly through a Zigbee network. The central computer then sends wireless messages to the trolley and the mannequin to start their pre-planned motion. The timing is calculated so that the vehicle and the mannequin meet at a predefined location. The other IR sensor detects the test vehicle at a distance of about 0.5 second to collision with the mannequin and notifies the mannequin wirelessly to cut off the power of all mannequin joint motors and the trolley in order to prevent motor damage due to overload during the crash. During the test, the trolley sends its GPS time stamped position and speed information to the main control computer periodically. The main control computer stores the time-stamped trolley position data and relays the data to the data recording computer inside the test vehicle. The data recording computer inside the test vehicle stores the combined the time stamped trolley motion data, the differential GPS measured vehicle motion data, and the time stamped various warning/braking signals for further analysis.

4.2. The Trolley Design

Due to the long span of the I-beams on the gantry cranes, the high trolley motion speed, and accuracy requirement, it is difficult to drive the trolley by a stationary motor through a chain or a rope. Therefore, a remote controlled and battery operated trolley is designed. The trolley contains two motors, motor servo drivers, an embedded microcontroller, a GPS timer, a Zigbee wireless communication module, limit sensors, and batteries. The connection block diagram of all components is shown in Figure 5.

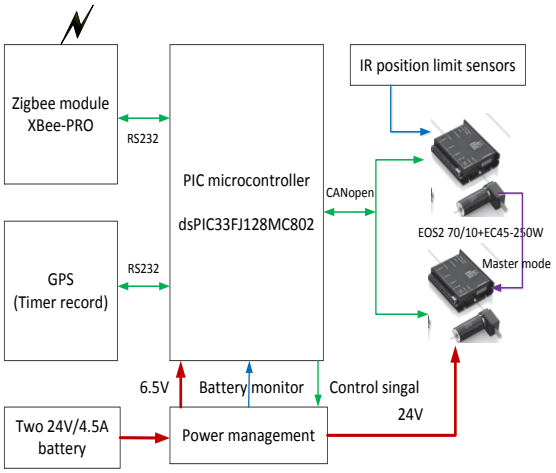


Figure 5. Control system of the trolley.

The embedded microcontroller communicates with the main control computer to get commands to control the motion of motors. The communication between the microcontroller and the main control computer is realized using a Zigbee module. The motor servo controller receives the motion commands from the embedded microcontroller and drives the motor using a PID controller. The communication protocol between the embedded microcontroller and the motor servo driver is CANopen protocol. To increase the load capacity and to reduce complexity of mechanical structure, we developed a direct drive system with two independent motors. Two 250 watts DC brushless motors are used. The motors are powered by two 24 Volt/4Ah NiMH rechargeable batteries. Each motor is controlled by a servo motor controller.

To ensure that two motors work synchronously, the motors are configured in such a way that one motor works in "Master Encoder Mode" and the other works in position or velocity mode. In this configuration, both motors follow the same reference input produced by a single external position encoder. The position encoder of the motors is also used to find the location of the trolley on the beam. To prevent accumulative position errors caused by wheel slip, the trolley controller recalibrates the location of the trolley after each round trip run using an infrared position sensor. The infrared sensor is also used as a safety limit sensor to indicate if the trolley is moving out of working range of the I-beam. A picture of the trolley prototype is shown in Figure 6.

Figure 6. Trolley prototype.

Due to the communication delay, it takes many milliseconds for the trolley position data to be sent to the main control computer for data recording. To ensure that the communication time delay does not cause data inaccuracy, the trolley position and speed data are time stamped by the embedded microcontroller before sending to the main control computer. The embedded microcontroller relies on a GPS timer module to provide the accurate wall clock time. The embedded microcontroller also supports self-diagnostic functions by reporting the heart beats and battery status to the main control computer periodically.

4.3. The Mannequin Design

To make the mannequin move like a real human, the mannequin with limb motion is designed. Motor driven joints are installed at the hips, knees and shoulders. Passive joints are installed at elbows which are driven indirectly by the motion of the upper arm.

The mannequin limb motion is realized by an electrical system that consists of a set of six servo motors, a motor controller, and an embedded microcontroller with a Zigbee networking module. A 7.4 v, 4200 mAh NiMH battery is used to drive the mannequin joints and the control system. The embedded microcontroller board monitors the battery charging levels and report to the main control computer periodically through the Zigbee network. Figure 7 is the connection diagram of the mannequin electrical circuit.

A PC controls the mannequin operation by sending mannequin motion commands to the embedded microcontroller in the mannequin through wireless Zigbee network. The embedded microcontroller passes the command (with desired position, speed and accelerations) to the motor controller which generates the proper PWM signals to all six servo motors according to the input commands.

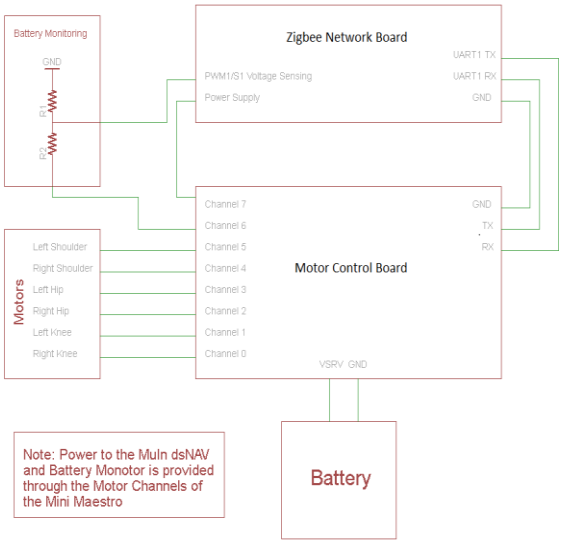


Figure 7. Control system of the mannequin.

Since PCS sensors detect pedestrians partially based on their body sizes and gestures, mannequins not only are built with heights and body sizes representative of the pedestrian public, but also should show major walking gestures. Many methods were proposed for biped robot walking gait planning based on mathematic planning method [5-8]. However, different from biped robots, mannequin's feet do not touch the ground, so that the mannequin limb motion does not require walking stability. Based on the published measured human gaiting data in the field of biomechanics, the gait functions of the hip and the knee in terms of speeds were generated in [12]. Figure 8 shows points and the fitted curve of one walking cycle at the speed of 1.2m/s. Figure 9 shows the stick frame of mannequin walking in one cycle (the sample interval is 100ms).

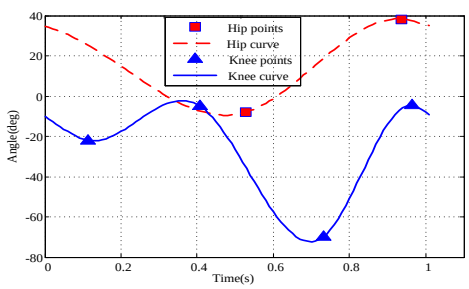


Figure 8. Angle points and fitted curve of mannequin's gait.

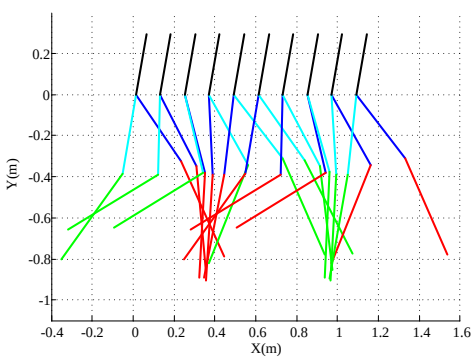


Figure 9. Stick frame of mannequin's one cycle walking.

5. EXPERIMENT

According to the system design as described in previous sections, a mannequin motion system prototype has been implemented. Figure 10 shows the demo of the successful coordinated motion of the trolley, harness and mannequin at the speed of 1.2m/s. Three pictures in the figure are the sequence of instances in one mannequin motion. Figure 11 shows the trolley's actual position and speed and the corresponding desired reference curves. It can be seen that position following is very accurate but the actual trolley speed has some fluctuations. This fluctuation is caused by torsional moment generated by mannequin motion.

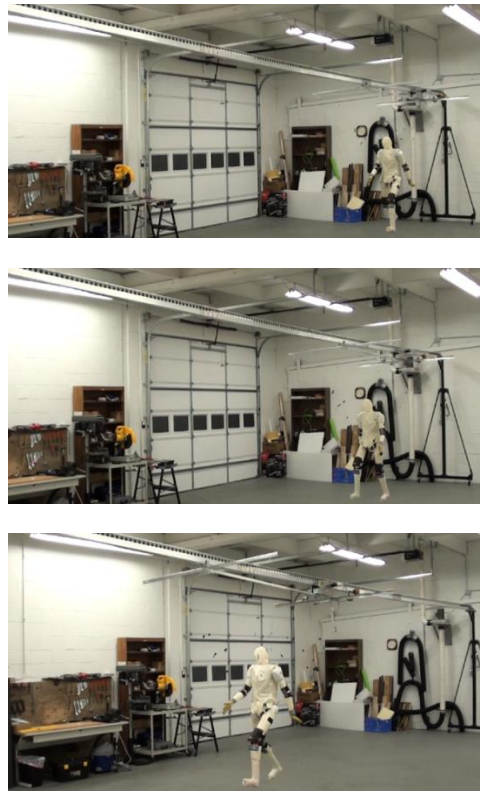


Figure 10. The trolley and mannequin motion at the speed of 1.2m/s.

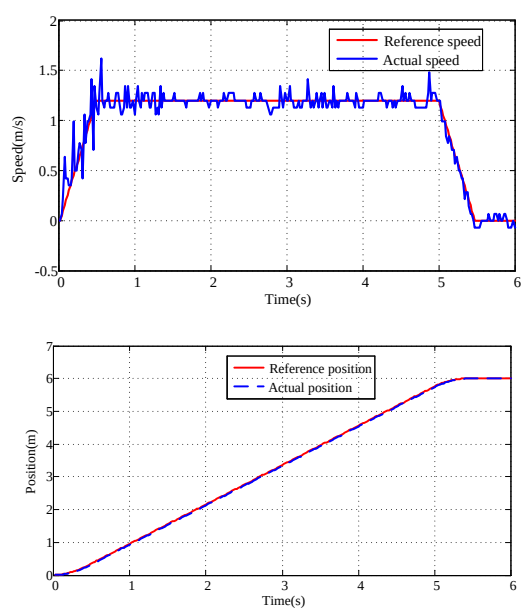


Figure 11. Speed and position following curves.

6. CONCLUSION

Based on PCS pedestrian test scenario types and the representative speeds of the vehicles and pedestrians, the mannequin motion equipment is designed. The equipment can cover the workspace of 11.4 m wide across the road and unlimited length along the road. It can be assembled and disassemble by 3-4 people manually. It is operated using a distributed computer control with the wireless Zigbee communication network. The vehicle and the mannequin motion data are time stamped based on GPS clock and stored synchronously. The whole system is battery operated. A prototype system has been built. The preliminary test was successful.

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ADVANCED SURROGATE TARGET DEVELOPMENT FOR EVALUATING PRE-COLLISION SYSTEMS

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ABSTRACT

This paper presents the requirements, design, and resulting performance of a new surrogate target for evaluating pre-collision systems (PCS) that include crash imminent braking and dynamic brake support. The design addresses several criteria for rear-end crash scenarios, including three critical and conflicting criteria: enabling high relative impact speed, maintaining a radar signature that is representative of real vehicles, and minimizing expenses and complexity of fabrication and usage. Test scenarios for evaluating PCS are developed using analyses of US crash data sets, including General Estimates Systems and the Crashworthiness Data System (including its electronic data recording data). Test procedures were developed, leveraging previous work in this area. Surrogate target design requirements were developed, notably new requirements for "impactability," or the ability to be struck repeatedly without damage or safety risks, and 77 GHz radar scattering characteristics. Robustness to higher impact speeds allow testing in severe crash scenarios. Radar characteristics were addressed using a new data set generated using instrumentation-grade radar to scan the rear ends of 25 actual vehicles at numerous angles. The radar scan data was used to create a recommended set of scattering elements to be applied to a radar-neutral structure. A novel approach to the structure was used, emphasizing low cost, weight, resilience, and, safety in higher speed impacts. This approach is intended to present a radar-representative vehicle target to the PCS under test, while allowing the target to be fabricated easily and inexpensively. The target is intended for PCS development as well as formal testing. Work continues to refine the target's signature for vision- and LIDAR-based systems, and an instrumentation system is being fitted to test PCS vehicles in extended use. This work is significant for its contribution to surrogate target work in the emerging area of PCS with crash-imminent braking and dynamic brake support systems. Higher impact speeds and improved radar signatures will improve the correlation between pre-crash system performance in the real world and the outcome of performance testing on the track. Simpler and lower-cost targets allow wider use and perhaps better PCS designs.

INTRODUCTION

Rear-end crashes are the most common crash type in the US. An average of 855,000 rear-end crashes occurred annually in the US between 2003 and 2008, when considering crashes in which a light vehicle struck the rear-end of another motor vehicle, using the General Estimates System (GES) data set. Pre-collision systems are safety systems that use forward-looking remote sensing to detect the location and motion of vehicles ahead, in order to help drivers avoid or mitigate the severity of an imminent crash with a vehicle ahead. The PCS features of interest in this paper include forward collision warning (FCW), dynamic brake support (DBS), and crash-imminent braking (CIB). When a forward crash is perceived to be imminent, and the driver is braking but not hard enough to avoid impact, DBS automatically provides additional braking to lessen or perhaps avoid the impact. CIB is often called advanced emergency braking (AEB) in Europe, and automatically applies hard braking in the last moments before a crash in order to reduce the severity of, and in some instances, avoid the crash.

The US New Car Assessment Program (NCAP) defines FCW using a set of objective tests in which alerts must be issued no later than a given threshold for scenarios that include the equipped vehicle approaching a stopped vehicle, a slower but moving vehicle, and a decelerating vehicle. US NCAP is considering adding both DBS and CIB to the set of crash avoidance technologies that it addresses, and has released a set of draft test procedures and a strikeable surrogate target. (A surrogate target is a device which is used in objective testing to represent a vehicle, but can be struck by the equipped vehicle without significant damage to the striking vehicle.) There have also been a series of US Department of Transportation (DOT) and European Union (EU) funded projects, as well as privately funded projects.

The question of surrogate target design has been a major theme in the work on evaluation approaches to DBS and CIB. Such targets need to meet several conflicting criteria, including the need for appearing to PCS sensors as actual vehicle appear; the need to be repeatably and safely struck at significant impact speeds, and to be affordable and usable. Most published work has focused on NCAP-like evaluation work, and not focused much on the heavy use required for automaker and supplier development and benchmarking work.

This paper describes a surrogate target design developed jointly by the University of Michigan Transportation Research Institute (UMTRI) and the Michigan Tech Research Institute (MTRI), in conjunction with the Toyota Collaborative Safety Research Center (CSRC). A major goal was that the surrogate target would appear to automative radars and other sensors as a real automobile would appear; another goal was that the system would be impactable at high relative speeds that are seen in actual US crashes, and that the system is usable as an everyday working system by everyday engineers.

TEST SCENARIOS

The surrogate target design must support test scenarios that are to be executed on the test track. Test scenarios were developed based on analysis of the GES as well as the US Crashworthiness Data System (CDES) were conducted, including examination of Event Data Recorder (EDR) data that is available in CDS for those crashes in which drivers approve the sharing of EDR data. GES 2003-2008 data were used, with only light vehicle striking cases considered, with striking vehicle model year required to be 1998 or newer. The focus was on crashes with injuries and fatalaties.

Existing analyses of US rear-end crashes were reviewed, and further analyses of GES data and CDS were conducted. Of particular interest were the pre-crash scenarios, and these were examined using the pre-crash maneuver variables. The pre-crash maneuvers for the vehicle pairs associated with the crash (or first impact, for crashes with more than two vehicles) are shown in Table 1 (only the top ten pairs are shown).

When all pre-crash maneuver pairs are considered and aggregated, the percent of these rear-end crashes are shown in Table 2 as a function of the types of motions that precede the crash sequence. This table shows that rear-end crashes are usually simple in their kinematics: Approximately 77% involve the striking vehicle simply remaining in its travel lane, without maneuvering laterally or changing speed prior to the initiation of the crash sequence. Only 2.6% of these crashes involve any lateral maneuver by the striking vehicle. The struck vehicle is maneuvering laterally only 2.6% of the time as well. Thus these crashes are typically single lane crashes. Furthermore, crashes in which the equipped subject vehicle (SV) is “starting” are typically low-speed crashes, with low chance of injury, and these are not of particular interest for the evaluation that is discussed here. Turning SV cases are likewise not of high interest in evaluation because of the substantial challenge of using vehicle-based sensors to confidently detect threats and predict paths, while yawing at large angles and rates.

Therefore a set of test scenarios are selected which represent 80.4% of the rear-end crashes involving a model year 1998 or later light vehicle striking another vehicle. The speeds of these events are based on the GES travel speed variables, which are associated with the speed before the crash’s precipitating event occurred. These speeds are shown in Table 3. GES data shows that the 80th percentile for the difference in travel speeds between the two vehicles, for injury and fatal crashes, is between 25 and 35 mph, depending on the scenario. (Here, travel speed is the speed prior to the event leading to the crash). These numbers are starting points for determining the initial conditions for objective test speeds and closing speeds. The scenarios that are proposed are shown in Table 4.

Notice these scenarios include cases of “lateral offset.” These are tests in which the SV approaches the target with an offset, so that the center of the SV front bumper strikes the rear bumper off-center, toward one edge at a specified distance. This is

because the CDS data shows that the overlap between the bumpers at impact is less than 50% in about one in three crashes. Another interesting finding from the data (Table 1) is that approximately 10% of crashes are associated with SVs that are decelerating before the precipitating event happens – that is, that although the SV is slowing, it is not slowing enough. At the time of these analyses, the EDR data included only 172 crashes, with EDR data from only one of the vehicles in all but six crashes.

Table1. Rank of rear-end striking scenarios in GES, as described by pre-crash maneuvers

Rank	Pre-crash maneuver		Pct %	Cumul. Pct %
	Subject Vehicle	Struck vehicle		
1	Going Straight	Stopped in lane	41.7	41.7
2	Going Straight	Decel in lane	19.2	60.9
3	Going Straight	Going Straight	10.9	71.8
4	Decelerating in lane	Stopped in lane	7.4	79.2
5	Starting in lane	Stopped in lane	5.7	84.9
6	Decelerating in lane	Decel in lane	2.5	87.4
7	Turning right	Stopped in lane	1.4	88.8
8	Negotiating a curve	Stopped in lane	1.4	90.1
9	Going Straight	Turning right	0.8	91
10	Changing lanes	Stopped in lane	0.7	91.7

Table 2. Rear-end striking pre-crash maneuvers

Pre-crash maneuvers	Stopped	Decel/ accel	Lane-keeping	Turning	Start	Change lanes	Total
Lane-keeping	43.3%	19.7%	11.1%	1.3%	0.7%	0.7%	76.8%
Decel/ accel	7.7%	2.6%					10.2%
Starting	5.7%				0.6%		6.4%
Turning	1.6%						1.6%
Changing lanes	1.0%						1.0%
Total	59.2%	22.3%	11.1%	1.3%	1.3%	0.7%	95.9%

Table 3. Travel speeds and speed differences for injury and fatal crashes. Values are mean and 80th percentile (mph)

Crash type	SV speed	LV speed	Difference
LV stopped	23.9 (35)	0.1 (0)	23.7 (35)
LV slower	42 (65)	26.9 (50)	15.4 (25)
LV decel'ing	33.7 (45)	16.7 (30)	17 (30)
LV cut-in	46 (60)	33.6 (55)	12.8 (25)

Table 4. Crash-imminent test scenarios

Test Scenario	SV (mph)	POV (mph)	Initial headway (sec)	POV (g)	SV (g)
Fixed stopped POV	35	0	n/a	0	0
Fixed stopped POV, lateral offset	35	0	n/a	0	0
Fixed stopped POV, decelerating SV	45	0	n/a	0	0.15
Fixed stopped POV, in curve	35	0	n/a	0	0
Slower POV	50	25	n/a	0	0
Slower POV	35	10	n/a	0	0
Slower POV	25	5	n/a	0	0
Decelerating POV	30	30	2	0.4	0
Decelerating POV	30	30	2	0.2	0
Decelerating POV, lateral offset	30	30	2	0.4	0

TARGET REQUIREMENTS

A set of requirements were developed for the surrogate target. They may be presented in six categories:

Impactability – for impacts from the rear (plus or minus 5 degrees), the target shall

- Be safe for impacts at relative speeds of 35 mph (stopped target) and 25 mph (moving target), possibly with minor damage that can be repaired within hours.
- Survive in good condition for 100 impacts of 15 to 20 mph relative speed.
- Be impactable while traveling 25 mph.

Speeds and decelerations – the target shall:

- Be capable of moving at 30 mph, with a tolerance of 0.5 mph,
- Be capable of decelerations of up to 0.5g, with a tolerance of 0.015g (averaging over 2.5 sec).

Low cost and ease of use. The target shall:

- Be reasonably-priced (less than $US 8000) to support widespread use
- Be suitable for use in both NCAP-level testing as well as development testing with a broader set of testing conditions.
- Be reasonably straightforward to repair and use in test track environments by experienced but not expert staff. After an impact, the target should be usable within a few minutes.

Reflectance – the target shall:

- Appear similar to real vehicles when measured using radar (24 and 77 GHz), as viewed from the rear (and up to 5 deg off-axis, to both the left and right). Soft-covered targets are considered to be unlike real vehicles due to the temporal fluctuations that exceed radar wavelengths.
- Have visual features so that it appears as a vehicle to a vision-based system.

Impacts with lateral offset - the target shall Be impactable when the striking vehicle bumper overlaps only 50% with the target (which occurs in one in three rear-end crashes).

Localization – the target shall support the ability to locate the target within 0.25 m longitudinally and 0.15 m laterally at the moment of impact.

Radar scattering requirements

More detail is warranted on the radar scattering issues. Within this project, Michigan Tech Research Institute used an instrumentation-grade radar at 90 to 98 GHz to scan the rear ends of 25 vehicles including sedans, wagons, SUVs, crossovers, hatchbacks, pickup trucks, and small and large vans. These scans were made from directly behind the vehicles, as well as 1.5 and 3.0 deg away from directly behind; at each of these three locations, scans were made at 0.0 and 1.5 deg elevation.

Analysis of the returns showed that the primary scattering elements of the vehicles were tail-lights, muffler/tailpipes, rear-suspension components (especially when they are visible), license plate shelters (often a convex area), and bumpers. Secondary elements include chassis supports, the joint of the roof and rear-window, side-view mirrors, roof racks, and even rear spoilers. Calibrated high-resolution range-profiles for a vehicle and the surrogate may be compared in Figures 2 and 3, respectively. The scattering characteristics of the surrogates was compared statistically to the vehicles under the same measurement conditions, and a scatterplot comparing real vehicle and surrogate target scattering model parameters is shown in Figure 3. Details of the scanning and the evaluation of the surrogate can be found in [2].

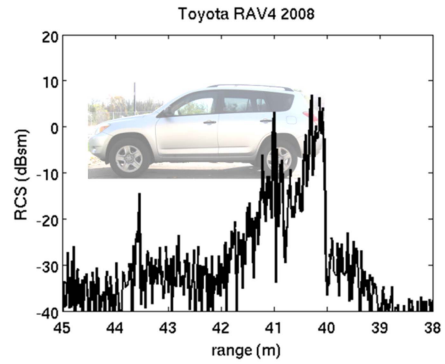

Figure 1. High-resolution, range-profile of one of the sampled vehicles, a 2008 Toyota RAV4.

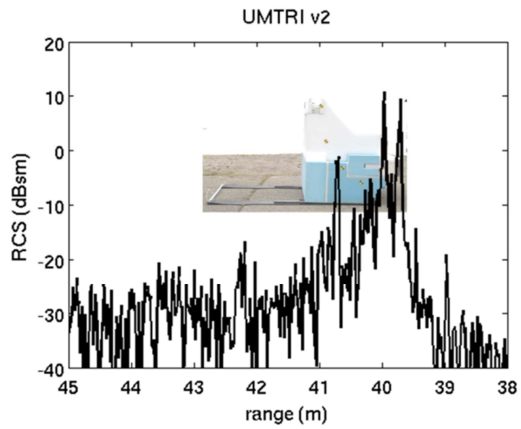

Figure 2. High-resolution, range-profile of the UMTRI surrogate target.

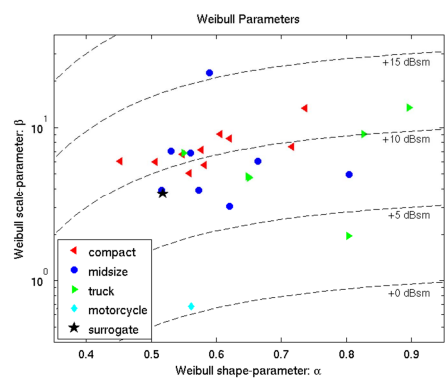

Figure 3. Scattering model parameter values: real vehicles and surrogate target

Table 5 shows a comparison of surrogate target concepts and their ability to support some of the key

requirements. Shaded cells show a problem for various systems, including the towed target concept.

Table 5. Design approaches and requirements

Target Type	Impactability	Speeds & Decels	Cost/Ease	Reflectance	Offsets	Localization
Towed Balloon car	✓	✓	✓	×	✓	O
Towed rail-guided	✓	O	O	✓	×	✓
Drive-over with shell	✓	✓	×	O	✓	✓
Gantry	✓	O	✓	O	✓	✓
Towed sled	✓	✓	✓	✓	✓	O
Go-cart	O	✓	✓	O	O	✓

Table 5 shows six types of surrogate targets that have been constructed and demonstrated for PCS evaluation, and *generically* whether they are clearly able to satisfy each requirement category (check mark); whether they cannot ("*X*"); or whether it is not clear and may depend on the situation ("O"). This table is intended to highlight the basic strengths and challenges that led the UMTRI-MTRI team to its selected approach. Table 5 represents the knowledge of the authors, based on publications as well as visits in 2011, and readers are aware that innovative developments continue and that the requirements in this paper may not be appropriate for all uses. For instance, NHTSA has published a draft set of test procedures as a potential consumer information aid for DBS and CIB, and the tests do not include lateral offsets or decelerating lead vehicles. The table shows that the towed, rail-guided approach they have shown recently would satisfy those needs, but that for testing with impacts at lateral offsets, that selection may present problems.

Balloon cars do not have appropriate radar reflections due to their shape, wind-driven fluctuations, and at least one model is semi-transparent to radar. The towed, rail-guided approach shown early by ADAC in Germany and also used recently by NHTSA provides many advantages, but is not friendly to lateral offset hits. The drive-over approach (e.g., Dynamic Research Inc.) is a very flexible system that addresses several crash types, but it is expensive and the upper "shell" must still be impactable and representative (which is possible). The popular approach of cantilevering a target sideways from a large pickup truck is a straightforward way to begin work and to localize the target very well. Sometimes a radar system will struggle to discriminate the target from the supports, however, and it requires sophisticated "flip up" or "release" mechanisms to allow sizable impacts that do not endanger the drivers, and it is challenging to allow significant target decelerations without triggering these mechanisms. BASt in Germany was one of the early users of a go-cart approach, which is ingenious for its simplicity and target maneuverability. However the challenge of offset impacts and the mass of a system that hosts onboard GPS and computing systems may preclude testing with impacts of 20 mph or more.

For our particular requirements set, we selected a towed sled approach, first suggested to our team by the NHTSA Vehicle Research Test Center staff during an earlier project.

TARGET DESIGN

The surrogate target design concept is a towed, low-weight and impactable target, which carries a discrete set of radar scattering elements that together present the same radar signatures as the real vehicles that were scanned (see Figure 3). The shape of the target, as viewed from the rear, emulates a sedan, with shapes that simulate a trunk, rear window, bumber, rear wheels, and an underbody section. The main body of the target is composed of three types of foam joined with hot glue. The foam includes a rigid polystyrene with moderately reflective radar scattering properties (blue in Figure 3). This provides rigidity and also masks the towing mechanisms from radar. Two types of polyethylene foam that are relatively transparent to radar and lightweight provide energy absorption and flexibility. A polyurethane sheet covers the bumper surface, giving toughness and a slippery reflective surface that mimics real bumpers.

From the radar analysis, a set of eight reflectors were recommended by the radar team: a 4 cm flat metal strip behind the bumper polyurethane covering; a 2 cm flat metal strip at the window-roof join; a license plate imbedded in a concave shelter, with a 3 cm trihedral reflector immediately above the shelter; 3cm trihedrals located at the two tail light locations, as well as two more to represent rear suspension elements. Details of these scatterers were revised based on a radar scanning of the target, in order to better match the parameters of the actual vehicles' scatterer model. The target is 32 Kg.

Figure 3. **Towable surrogate target.**

skids, so that for tests that simulate approaches toward a stationary vehicle, the target slides away easily after impacts. Impacts of 35 mph are safe and results in minor damage to the target; the bumper is detachable and can be replaced within a minute after such high impacts. Impacts of 15 to 20 mph can be repeatedly performed; a target that has seen more than 100 of such hits is still operating without significant deformation. The bumper foam compresses substantially during impact, such that the target springs away from the striking vehicle. Note that the striking vehicle does not need significant protection for testing. After well over 100 hits at speeds up to 35 mph, the team did have to replace a plastic grill on a 2011 Lexus GS350, but a thin plastic film was placed on the hood and bumper area, preventing abrasions.

For moving target tests, the low-friction skids are placed on a simple sled (Figure 4), and the target is towed by a vehicle using about 15 m of low-stretch rope (0.25%). The sled consists of two strips of very tough mining conveyor belt material. The target/sled interface and the sled/rope interface are both attached using tie wraps so that a sizable impact results in the target breaking free from the sled and springing away from the striking vehicle. Should the striking vehicle drive on top of the sled, the sled/rope interface breaks away for safety. (See Figure 5.)

Note that the friction of the sled material is quite high, so that the sled's motion mirrors that of the towing vehicle. Therefore decelerating lead vehicle scenarios can be performed, as the rope remains taut during decelerations of at least 0.5g. The sled supports travel up to at least 30 mph (higher speeds can introduce excessive aerodynamic lift or pitching.)

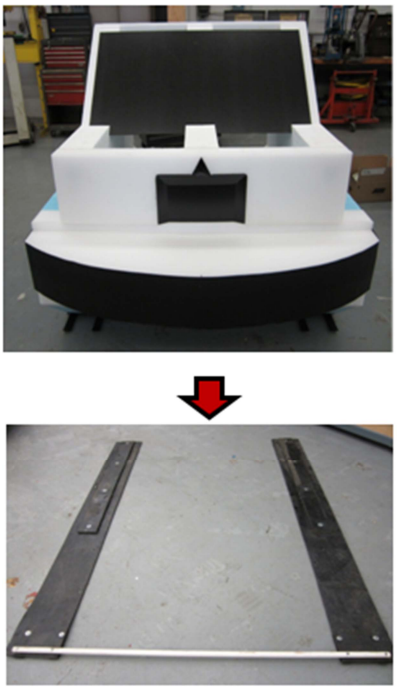

Figure 4. Sled for moving target tests.

Impacts in moving scenarios have been performed at target speeds of 30 mph, as well as strikes at relative speeds of 25 mph without negative consequences.

Figure 5. Vehicle approaching towed sled.

The towing vehicle is outfitted with GPS and acceleration sensors. The lateral position of the target at impact is known through means of a subject vehicle-mounted camera. The longitudinal position of the target is known from the towing vehicle's data.

CONCLUSIONS

Evaluating pre-collision systems requires testing equipment that allows safe, efficient, and accurate execution and data measurement. The crash record and prior literature was examined to define the rear-end crash problem for the purposes of developing objective test procedures to evaluate PCS. This paper summarized the analyses of crash data and the derivation of a set of test scenarios.

Also presented were requirements and the ultimate design for a surrogate target that can be used in test track evaluations of PCS. The surrogate target is a towed, low-weight and low-cost design that includes

several specific radar scattering elements so the target appears to a radar as a normal car would. The design is done using a set of requirements including impactability, cost and ease of use, radar and visual characteristics, ability to use with given speed and deceleration bounds, and the ability to safely hit off-center on the vehicle. Better targets will lead to more accurate evaluation and designs which will enable better designs on the highway.

ACKNOWLEDGMENTS

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SAFETY ADAS - PACEMAKER FOR AUTOMATED DRIVING

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ABSTRACT

Automated driving is no longer blue sky thinking but progressively becoming a reality. The various levels of automation build on the ongoing enhancement of Advanced Driver Assistance Systems ADAS that ease the load (physically and mentally) on the driver in specific use cases. At assistance level, the driver is still obliged to permanently monitor the behavior of the vehicle. Driver Assistance Systems help in handling situations where cognitive or physical responses are overtaxed, be it at the stability level of driving, with Anti-lock Brake System ABS or Electronic Stability Control ESC, or at the guidance level, through "Safety ADAS" functions such as Emergency Brake Assist EBA or Emergency Steer Assist ESA.
At automation levels longitudinal and lateral guidance tasks are increasingly being taken over completely, with the significant change of the driver's role with regard to relieving monitoring obligation, consequently a shift of liability from the driver to the system/vehicle manufacturer.
The following paper provides an overview of the current state of knowledge of the various levels of automation from driver assisted vehicle operation to highly automated driving.

INTRODUCTION

Despite a tangible increase in the volume of traffic in the EU over more than a decade, the numbers of fatalities have been significantly reduced.

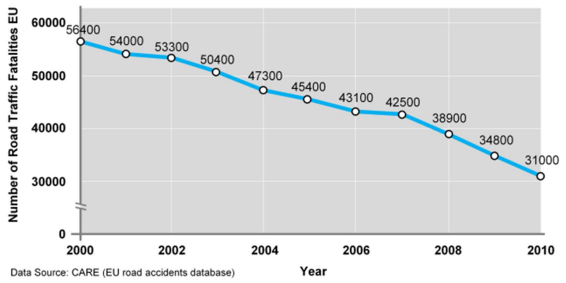

Figure1. Road Traffic Fatalities EU 2000-2010.

Along with traffic policy and road-safety education measures, the main contributory factors here have been safety technology measures such as the continuous improvement of active and passive vehicle safety (see Fig. 1).

Continental has demonstrated with the integral safety system 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 HMI. ContiGuard® covers therefore all safety functions by integration of crash prevention and injury mitigation measures, vehicle surrounding sensors, Human-Machine-Interface (HMI) and Safety Telematics, including driver assistance (see Fig. 2). Instead of "Comfort ADAS", which adresses mainly enhanced driving comfort this paper considers "Safety ADAS", i. e. challenging driving situations where safety of the occupants and other road users is endangered.

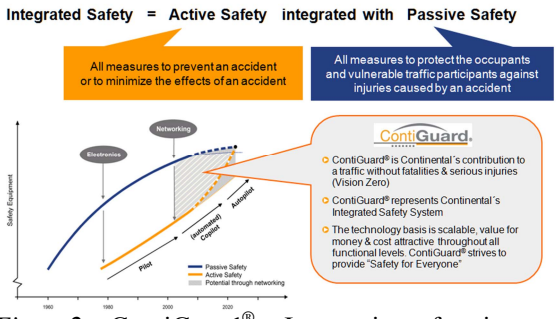

Figure2. ContiGuard® - Integration of active and passive safety.

Driver Assistance Systems (DAS)

At present, assistance systems are largely based on sensors within the vehicle itself, such as sensors for wheel speed, steering angle, longitudinal and lateral acceleration, yaw rate, roll rate, etc. (which serve primarily the assistance systems at the stability level).
Safety systems that have been introduced on a largely standardized basis, such as seat belts, electronic

braking and control systems, anti-lock brake systems ABS, front, side, and head airbags, brake assist features, and electronic stability control ESC already ensure stable, skid-free driving with short braking distances and offer comprehensive protection for the vehicle's occupants.
Driver assistance systems function at all three levels of the driving task: the stability level, cruise level, and navigation level (Fig. 3).

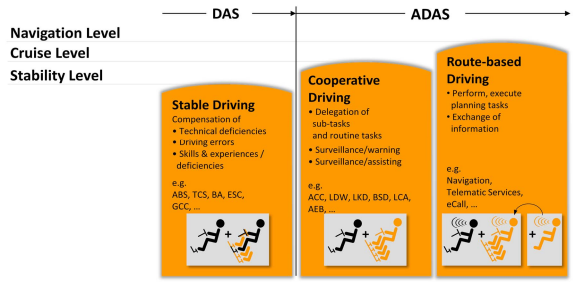

Figure3. The three levels of the driving task and their assistance systems.

These systems compensate for "technological deficits" in the driver's control of the car as a driving machine (one brake pedal, one gas pedal, one steering wheel, but four wheels that are braked, or two or four wheels that are driven or steered, examples: Anti-lock Brake System ABS, Traction Control System TCS, Brake Assist BA, Electronic Stability Control ESC and Global Chassis Control GCC).

From Driver Assistance Systems (DAS) to Advanced Driver Assistance Systems (ADAS)
New generations of vehicles are increasingly being equipped with sensors that monitor the vehicle's surroundings (see Fig. 4), such as those that measure distance (ultrasonic, radar, lidar) and imaging sensors (cameras). In the medium term, these "built-in" onboard sensors will be joined by others that make it possible to communicate with other vehicles (V2V) and the infrastructure (V2I).

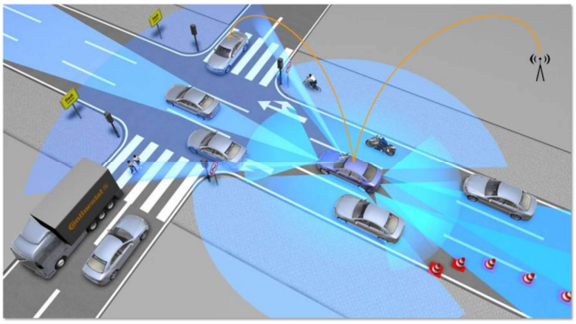

Figure4. Vehicle surrounding sensing - from basic to complex traffic scenarios.

These sensors will expand the "field of vision" of the vehicle's own built-in sensors by not only seeing farther, but even being able to look ahead to what lies "around the corner."

With Safety ADAS such as collision warning, active emergency braking, or lane departure warning and lane keeping – all of which are already offered today in many vehicles – the driver still does all of the driving himself or herself, with situation-specific assistance from these systems.

At the same time, driver assistance functions are becoming increasingly comprehensive, the networking of the functions increasingly intensive, and the physical vehicle operation by the driver is fading more and more into the background. For example, the lane departure warning feature is evolving into a lane keeping assistant that gives-by gentle torque overlay-the driver lane guidance and protects him with active steering intervention from unintended lane departure (see Fig. 5).

Figure5. Lane Departure Warning / Lane Keeping Device, Key Component Camera.

From Assisted Driving to Automated Driving
Automated driving relieves the driver from the task of driving, both physically and mentally, consequently eliminating human error – the sole cause of over 70 percent of traffic accidents. Thus automated driving subsequently leads to/targets accident-free driving. It builds on the Safety ADAS systems as described in the previous chapter.

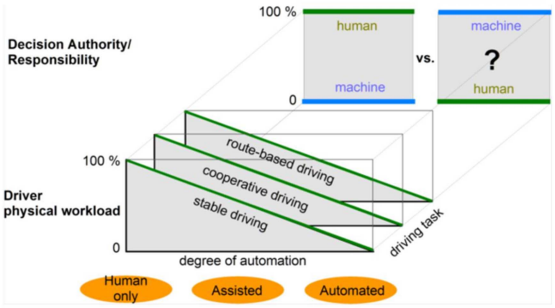

Figure6. Workload vs. Decision Authority/ Responsibility.

It needs to be distinguished whether the driver still has to take on at least a monitoring function, or whether the machine drives completely automatically, without any control by the human driver (see Fig. 6).

CONCLUSION

Automated driving gives the driver freedom to perform non-driving related tasks, making the car a highly attractive means of transportation (see Fig. 7). Time spent driving is no longer wasted, but becoming driver valued time. Safety ADAS forms the basis and in this way acts as a pacemaker for automated driving. Before this goal is reached, however, there are still numerous big challenges that must be overcome in terms of development in the field of surrounding area sensing and interpretation, control of the vehicle's movement and the safety architecture with regard to the consequences of system failures (requires fail-safe as fail-operational). Progress in electronics (computing power, memory, sensors and actuators) will make it possible to overcome these challenges. Electronic components and systems never experience a "reaction delay" – they are always wide awake.

Figure7. Roadmap – From Driver Assistance Systems to Automated Driving. Definitions according to BASt.

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A STUDY OF INFLUENCE FACTORS OF HEAD RESTRAINTS ON NECK INJURIES

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ABSTRACT

Neck Injuries, referred to in this paper as whiplash are among the most frequent injury among occupants in low speed rear end car collision. This paper analyzes the correlations between influence parameters of head restraints and whiplash injury criteria. In this paper, we used DFSS (Design for Six Sigma) method for design optimization of head restrains. Four control factors of head restraints have been selected by function matrix method. The effects of the control factors have been experimentally evaluated by using a sled pulse from 16kph relative velocity which is suggested by Korean New Car Assessment Program (KNCAP). Whiplash tests were repeated once in order to reduce the noise factors of dynamic assessments. By using DFSS, the correlation between control factors of head restraints and injury criteria has been comprehended.

INTRODUCTION

Out of the population of occupants that experienced any kind of injury in rear impacts, most experienced whiplash, which is considered a minor injury as classified by the Abbreviated Injury Scale (AIS,moderate) 2 or less[1]. Whiplash Associated Disorders (WAD) are usually caused by the motion of the head and neck complex relative to the torso. Occupants can suffer headaches and neck pain for a few days or weeks.[2] Many researchers have been studying to establish the cause of whiplash injury. Some of them focusing on anatomical sites such as facet joints, spinal ligaments, intervertebral discs, vertebral arteries, dorsal root ganglia, and neck muscles-within the neck that are potentially injured during rear-end collisions.[3] However, the injury mechanism of symptoms associated with whiplash is not well understood. Various whiplash injury criteria have been proposed, criteria developed by the Insurance Whiplash Prevention Group (IIPG), which is comprised of various insurance industry supported research groups from around the world. For these reasons, New Car Assessment Program (NCAP) is carrying out whiplash testing using the BioRIDIIg dummy. According to an automobile insurance statistics report of Korea Insurance Development Institute (KIDI) in 2005, the number of people injured in rear end impact collisions was approximately 53,000. Of these, 33,000 people reperted neck injuries as the most significant injury. Also, insurance companies in Korea paid premiums of approximately 180 billion KRW(166 million USD) in connection with whiplash related injuries.[4] This paper aims to analyze the correlation between influence parameters of head restraints and whiplash injury criteria. Occupant comfort and visibility are also to be considered when optinizing head restrraints. However, for this paper, we only focused on improving whiplash rating, without regard to the comfort and visibility aspects. In this paper, Design for Six Sigma (DFSS) methods [5] and sled tests are used for design optimization of head restraints, prioritizing on whiplash performance.

ROBUST DESIGN

		Injury Criteria						
		NIC		Nkm		Head Rebound Vel.	Upper Neck Fz	Head Contact Time
		Head X Acc.	T1 X Acc.	Neck Fx	Neck My			
H/R	Form depth				+	++		
	Form Hardness				+			
	Form Elastic				+	+		
	Backset	+			+			++
	Height				+		++	
	4way/2way							+
	Angle of Head Contact Area				++		+	
	Mold	+		+				

Figure1. Function matrix

Head restraints have many design elements including foam depth, foam hardness, foam elastic, backset and height for occupant safety. Of these, we choose control factors and output responses using neck injury criteria which have been proposed by Korea Automobile Testing & Research Institute (KATRI).Figure 1 shows a function matrix to select the control factors of head restraint. We selected foam depth, backset, height, angle of head restraints as control factors.

Table.1
Control factor and parameter level

No.	Control factor	Level 1	Level 2	Level 3
A	Foam Depth	-10mm	Normal	10mm
B	Backset	-10mm	Normal	10mm
C	Height	-10mm	Normal	10mm
D	H/R angle	-10°	Normal	10°

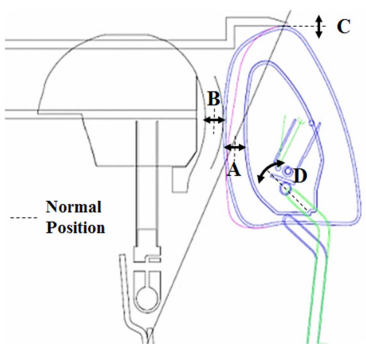


Figure2. Definition of setting the control factors

Control factor and parameter level is shown in Table1. Normal of level 2 means initial manufactures current design position. Definition of setting the control factors is shown in Figure2. Seat tolerance, sled acceleration pulse and dummy positioning are chosen as noise factors. Figure 3 shows P-diagram.

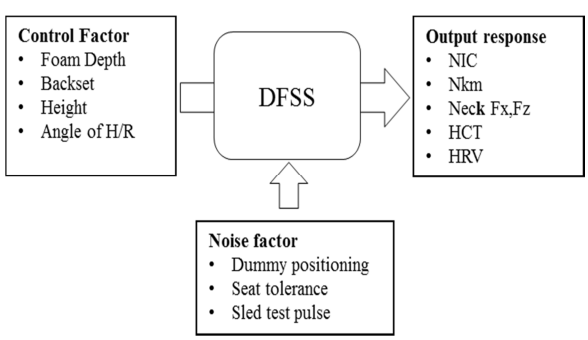


Figure3. P-diagram

Orthogonal array

Orthogonal matrix was composed to determine the main effects of control factors. In general, there are no interaction effects between control factors in mechanical systems. The interaction effect between control factors was not considered. Control factors and level in L_9 orthogonal array is shown in Table 2 and Figure 4.

Table. 2
L9 orthogonal array

Run	Foam Depth	H/R Angle	Backset	Height
1	-10mm	-10º	-10mm	-10mm
2	-10mm	Normal	Normal	Normal
3	-10mm	+10º	+10mm	+10mm
4	Normal	+10º	-10mm	Normal
5	Normal	-10º	Normal	+10mm
6	Normal	Normal	+10mm	-10mm
7	+10mm	Normal	-10mm	+10mm
8	+10mm	+10º	Normal	-10mm
9	+10mm	-10º	+10mm	Normal

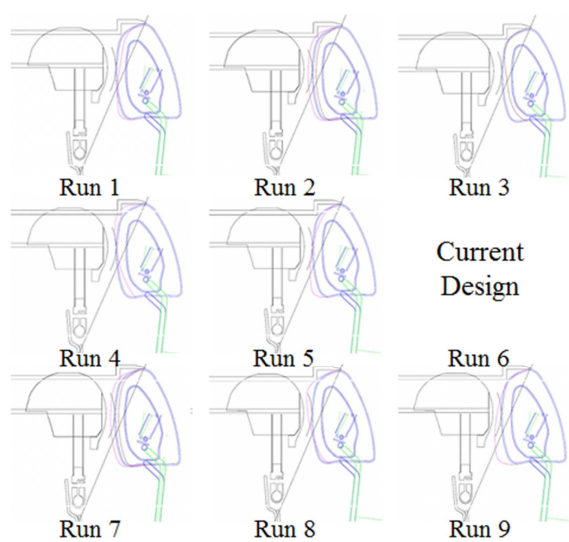


Figure4. Combination of control factors in L9 orthogonal array

Sled test

The main effects of the control factors were evaluated by sled testing. The sled testing conducted only dynamic assessment. Fig 5 shows dummy positioning of dynamic assessment. BioRIDIIg was positioned in the two-way front seat jig and two-way

head restraints. We conducted series of sled tests by using 16kph delta V rear impact acceleration pulse that is representative of KNCAP triangle pulse of whiplash test. The acceleration pulse generated in this sled is shown in Figure 6. Each sled test was repeated once in order to reduce the influence of noise factors from difference of sled test NIC, Nkm, NeckFx Neck Fz, Head Contact Time (HCT) and Head Rebound Velocity (HRV) were measured as injury criteria of dummy.

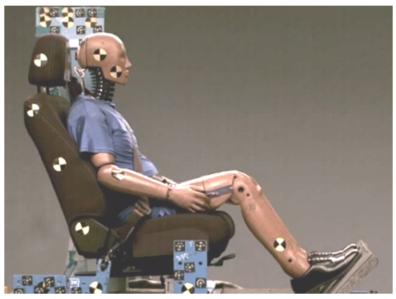


Figure5. Dummy positioning for dynamic assessment

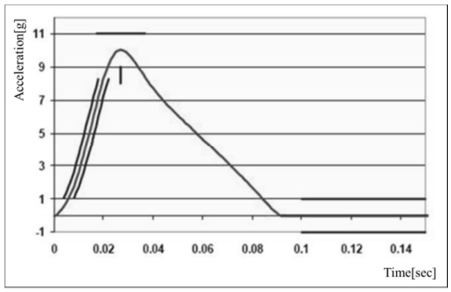
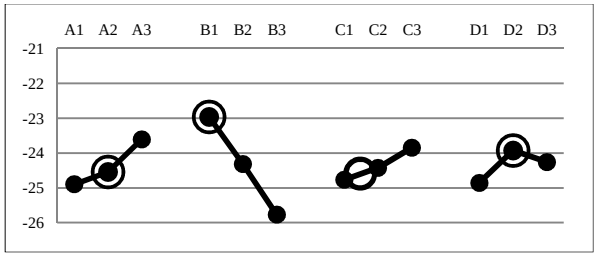


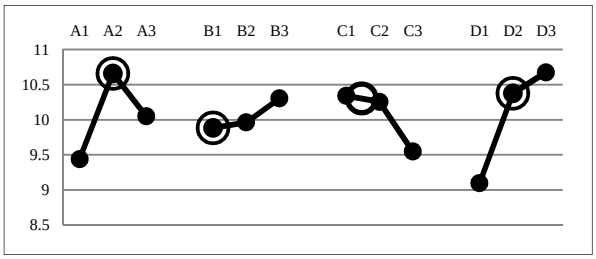
Figure6. Sled Target acceleration pulse

Analysis of signal to noise

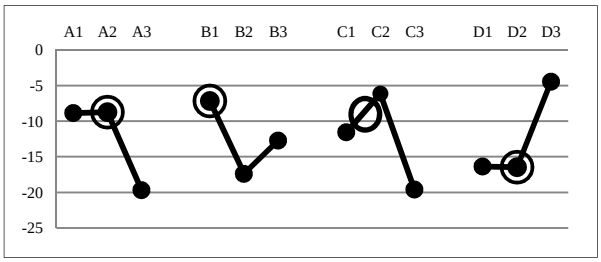
The response plot for (a) NIC, (b) Nkm, (c) Neck Fx, (d) Neck F3z, (e) Head Contact time and (f) Head rebound velocity are shown in figure 7. Horizontal axis is control factors and parameter level. Circle indicates optimal combination of each parameter level for each control factor in response graph.



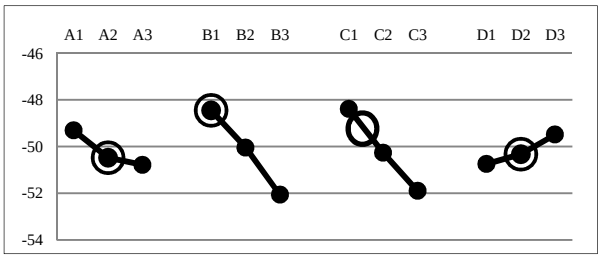
(a) NIC



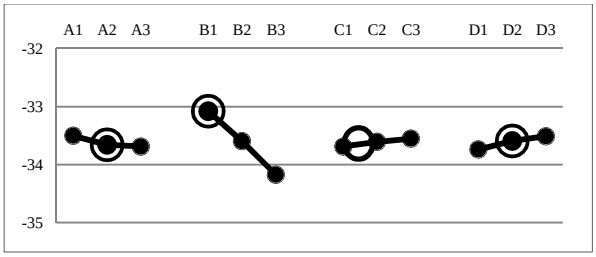
(b) Nkm



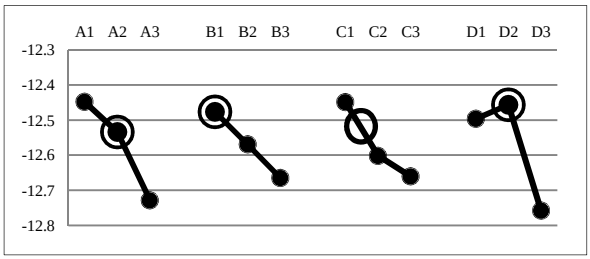
(c) Neck Fx



(d) Neck Fz



(e) Head Contact Time



(f) Head Rebound Velocity

Figure7. Response plot between control factor and parameter levels

Table.3
P-value and contribution of control factors

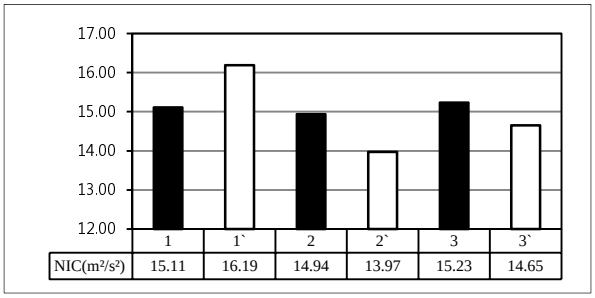
Output Response	Control factor	P-value	Percent Contribution
Nkm	Foam Depth	0.084	19
	Backset	0.576	3
	Height	0.259	9
	H/R Angle	0.014	42
NIC	Foam Depth	0.037	11
	Backset	0	67
	Height	0.145	6
	H/R Angle	0.152	6
Neck Fz	Foam Depth	0.249	5
	Backset	0.005	35
	Height	0.004	38
	H/R Angle	0.17	7
Neck Fx	Foam Depth	0.342	15
	Backset	0.708	4
	Height	0.321	16
	H/R Angle	0.543	8
Head Rebound Velocity	Foam Depth	0.065	22
	Backset	0.245	10
	Height	0.171	13
	H/R Angle	0.034	29
Head Contact Time	Foam Depth	0.213	3
	Backset	0	84
	Height	0.473	1
	H/R Angle	0.151	4

Table 3 shows the result of the significance percent contribution of each control factor through the analysis of variance on the output responses. ANOVA can determine influence of control factors from a series of sled test results by using design of experiment.[5] Percent contribution is based on the estimates of the variance components. Also, the percentage contribution of each factor can be used to evaluate the importance of the factor on the performance characteristic. The reliable correlation factors were satisfied with 5% significance level and contribution limit over 20%. NIC has 67% contribution and zero p value with regard to backset. Nkm has 42% contribution and 0.014 of p value with regard to head restraints angle. Neck Fz has 35% contribution and 0.005 of p value with regard to backset. It has 38% contribution and 0.004 of p value with regard to height. Neck Fx has more than 0.05 of p value with regard to all of control factors. Head rebound velocity has 0.034 of p value with regard to head restraints angle. Head contact time has 84% contribution and zero p value with regard to backset. In this paper, we selected correlation factor based on two way analysis which are significance level and percent contribution limit. As a result, Nkm had a significant correlation to head restraints angle. And Neck Fz had a correlation to backset and height. Head rebound velocity had a correlation to head restraints angle. Finally, Head contact time showed a correlation to backset. Table 4 shows optimal combination of control factor and parameter level.

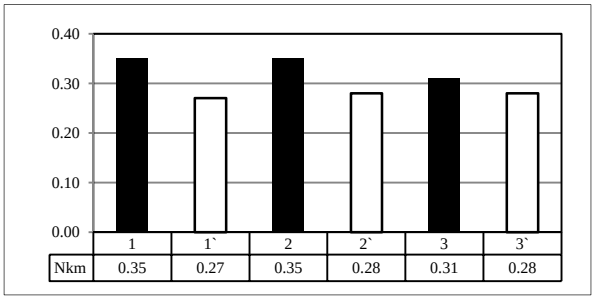
Table.4
Optimal combination of control factors

Control factor	Baseline	Opt. 1	Opt. 2
Foam Depth	Normal	Normal	Normal
Backset	Normal	-10mm	-10mm
Height	Normal	Normal	-10mm
H/R Angle	Normal	Normal	Normal

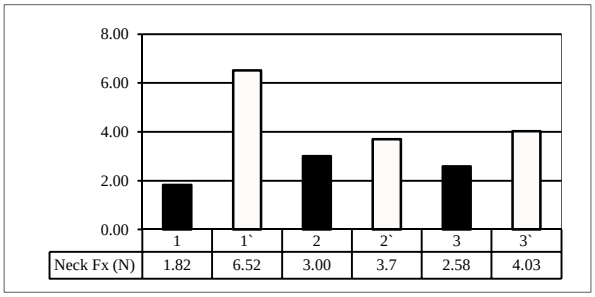
RESULT



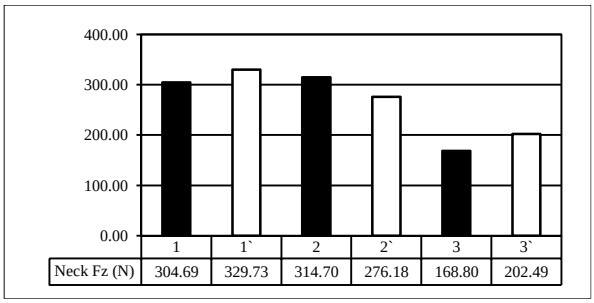
(a) NIC



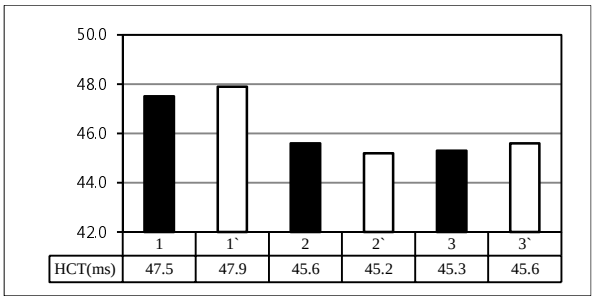
(b) Nkm



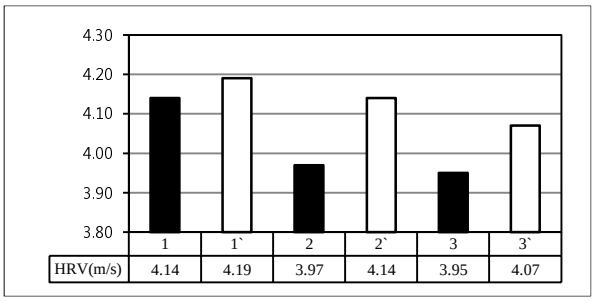
(c) Neck Fx



(d) Neck Fz



(e) Head contact time



(f) Head rebound velocity

Figure8. Comparison of predicted value and verification value

Figure8 shows comparison of dummy injury in the predicted versus verification value of sled tests. Black bar shows actual sled test value and white bar shows predicted value of control factors. Arabica numerals on the horizontal axis indicate value of baseline (1/1`), Opt.1 (2/2`) and Opt.2 (3/3`). In this paper, we judged that the valid control factors were subject to correspond the tendency of output characteristic in S/N ratio response graph and to confirm the difference between predicted values and actual sled test values within 30%. As a result, the output response of the S/N ratio and the ANOVA analysis for control factors shows a very strong influence of selected (b) Nkm, (d) Neck Fz, (e) HCT and (f) HRV and no or little influence of (a) NIC, (c) Neck Fx. Nkm was decreased by reward tilting angle of head restraints. And, Neck Fz was decreased by decreasing backset and increasing height. HCT was reduced by decreasing backset. And HRV decrease by forward tilting angle of head restraints.

Table 5 Prediction and Actual sled score

Parameters	Baseline	Opt. 1	Opt. 2
Prediction Score	7.0	7.3	7.3
Actual Score	6.9	7.1	7.2

Table 5 shows comparison of prediction score and actual score of sled testing. KNCAP whiplash assessment is composed of seven criterias - head restraints contact time, T1 x-acceleration, upper neck shear force, upper neck tension, head rebound velocity, NIC, Nkm. Test total score is maximum 9 point. We have improved result more than baseline. Also, Opt2. is highest score. It means DFSS has been applied effectively.

CONCLUSION

DFSS principals were used In the analysis of influence factor of head restraints on the whiplash performance. As a result, Nkm was decreased by rearward tilting the angle of the head restraints. And, Neck Fz was decreased by decreasing backset and increasing height. HCT was reduced by decreasing backset. And HRV decreased by forward tilting angle of head restraints. We intend to apply this DFSS as a tool in parameter studies to analyze optimum seat characteristics for effective seat design considering the occupant safety.

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GIDAS-AIDED QUANTIFICATION OF THE EFFECTIVENESS OF TRAFFIC SAFETY MEASURES IN EU 27

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ABSTRACT

The paper describes a sound methodology, which leads to a GIDAS-aided quantification of the effectiveness of traffic safety measures for passenger vehicles for countries in EU 27.
Even based on rather limited accident information from national statistics and under the assumption that comparable accidents in different countries lead to comparable accident outcomes, the described procedure allows defining so-called weighting factors. By weighting each single accident of GIDAS a modified GIDAS database can be established which imitates the accident situation in the region or country of interest to some extend. The main ingredients of the proposal are a proper clustering of European countries according to their accident occurence and a statistical procedure (Iterated Proportional Fitting) which allows the prediction of the common distribution (high dimensional) of accident data of the region or country of interest based on available lower dimensional marginal distributions (even one-dimensional). Since the effectiveness of safety systems reliably can be predicted on the detailed GIDAS accident database our procedure allows a prediction of the effectiveness of such systems for other regions or countries. The method is confirmed by real accident data examples, which shed light on the strengths and weaknesses of the proposed procedure.

INTRODUCTION

A reliable quantification of the effectiveness of driver assistant systems and/or traffic safety infrastructure measures is an important task in accident research. For this task police recorded accident data has successfully been used in the literature, e.g. for the effectiveness of electronic stability control (ESC) in passenger cars. See for example Lie et al. (2004), Kreiss et al. (2005), Sugimoto and Sauer (2005), Lie et al. (2006), Zangmeister et al. (2009) or Kreiss et al. (2011).

Dealing with general traffic safety measures, especially recent driver assistant systems or systems which have not been introduced into the market, quantification is a much more delicate problem. An assessment of many safety systems requires much more detailed accident material as available from national statistics. Beside the availability the frame of survey varies significantly, so comparison between different countries is not straightforward. Therefore it is difficult to transfer developed method from one country to another. For recently introduced safety systems the additional problem arises that vehicles equipped with such systems hardly show up in police recorded accident databases as the market penetration of new systems needs time.

One of the most suitable and internationally accepted accident data sets is the German In-Depth Accident Study (GIDAS). GIDAS contains one of the largest in-depth accident data sets ever collected. The GIDAS teams operate in the two German regions Hanover and Dresden and their surrounding areas. Currently accidents are reported to GIDAS teams by police, if and only if injured participants are to be expected. This consequently leads to a substantial bias in the injury severity. It is well known that within GIDAS accidents with severe injury outcomes are overrepresented.

The GIDAS data contains hundreds of categories which carefully have to be reported for every single accident. A deeper insight into the detailed work of the GIDAS teams can be found in Otte et al. (2003). One advantage of GIDAS accident data is that it contains detailed information on the pre-crash phase and on this basis predictions of the possible benefits are possible even for future driver assistant systems.

Motivated by the wish to take advantage of this enormous mass of detailed accident information for regions and countries beyond these restricted German regions of Hannover and Dresden, a proposal for using GIDAS accident data in order to imitate the accident structure in other European countries, or more specifically within EU27, will be presented in this paper. Of course one main problem is that results obtained from GIDAS

cannot be transferred to either Germany or other countries within EU 27 immediately.

A typical approach for transferring GIDAS to other regions, e.g. the whole of Germany or EU 27, is the method of projection factors. The main objective of this projection method is to obtain country specific weights for the GIDAS data such that the modified accident database imitates the accident occurrence of the region or country of interest. Knowing the effectiveness of a specific safety system on the basis of the original GIDAS data the effectiveness can be transferred to the target region easily. In principle this approach could be carried through for all European countries. The main assumption underlying this approach is that comparable accidents in two different countries result in comparable injury outcomes, at least on the level of accident severity distribution. Comparable accident situations can be interpreted as nearly constant intrinsic accident configurations. As a consequence hidden relations of categories or missing information in different countries are assumed to coincide. However, it should explicitly be mentioned that such an approach transfers intrinsic accident relations of German accident data to other countries within EU 27.

The application of the method to all single European countries is rather time-consuming and difficult to handle in a reasonable way. To avoid an enormous computational expenditure on the one hand and to avoid small sample problems of small countries on the other hand a division of European countries into groups of similar accident occurrence will be favourable. A proposal for such an clustering procedure will be developed and obviously this clustering will lead to an essential reduction of the expenditure on computation. The countries of each resulting cluster have comparable accident occurrences to a sufficient. Thus the effectiveness of driver assistance systems can be quantified cluster by cluster.

For this reasons one of the most important issues is the development of an appropriate clustering procedure resulting in as dissimilar as possible clusters of as similar as possible countries regarding accident occurrence and traffic. In other words, the developed procedure should lead to a heterogeneous classification of homogeneous groups of countries.

For some European countries we have to face the situation that only one dimensional distributions of a small number of accident related factors are available. Think for example of the distribution of accident location (*rural* and *urban*), the distribution of accident type or accident severity. In order to obtain country specific weights (actually cluster specific) we need the common multidimensional distribution concerning the mentioned factors. In case of these higher dimensional distributions not being available for the region of interest we make use of a method called Iterative Proportional Fitting (see Deming and Stephan (1940)). This procedure – on the assumption that main intrinsic accident relations stay nearly constant – allows the transfer of multidimensional distributions from GIDAS to these clusters on the basis of original marginal distributions. Therefore a cluster-wise accident database can be constructed and this eventually leads to a possibility for the evaluation of the effectiveness of safety systems for the whole of the EU27.

Our results show that a reliable assessment of the effectiveness of safety measures can be obtained via the described GIDAS-aided quantification procedure. Relevant real world examples will be presented and the similarity of recorded accident data to projection results from GIDAS will be investigated.

Of course, following the suggested proposal, one could not expect absolutely precise evaluations of the effectiveness of all safety measures for the whole of EU 27. It turns out that based on the obtained clusters of accident-similar countries it would be advantageous to have multidimensional distributions of the considered accident parameters of at least one representative region within the cluster in order to be able to calibrate the procedure of projection of GIDAS accident data onto the cluster. Moreover it would be extremely advantageous to have detailed accident data of at least one representative region within every cluster so the projection could be done from this (new) detailed accident database onto the cluster.

Data

Case studies in all sciences require reliable data. Especially the evaluation of traffic safety measures should be based on very detailed accident material. Otherwise it is nearly impossible to secure an assessment of only the considered safety system. As the frame of survey varies for different European countries, national reports are hard to handle in Europe-wide investigations. Relevant accident categories have to coincide for all countries especially if a clustering procedure shall be installed. While there is no in-depth European data base, the International Road Traffic and Accident Database (IRTAD) will be used. The IRTAD database includes accident and traffic data along with other safety indicators for 29 countries (see www.internationaltransportforum.org). The data base is a collection of national statistics and thus, there is no unique coding for accident

categories. To assure the reliability of later investigations and to avoid different country-specific coding (especially for the injury severity) all following investigations are restricted to fatally injured road users.

Further the distribution of traffic participation for these fatally injured road users of the years 2006 to 2009 is used. In detail the distribution of the traffic participation is limited to the categories *bicycle*, *moped*, *motorcycle*, *passenger car* and *pedestrian*. Additionally the location of accidents divided into the categories *urban* and *rural* will be used. Altogether distributions for Austria (A), Belgium (B), Czech Republic (CZ), Denmark (DK), Finland (FIN), France (F), Germany (D), Hungary (H), Italy (I), Netherlands (NL), Norway (N), Poland (PL), Portugal (P), Slovenia (SLO), Spain (E), Sweden (S) and Switzerland (CH) can be obtained for the ensuing exemplary studies. This is close to EU17.

It should be noted that the method is not limited to the EU17. If there is a wider database for the whole of EU27, the procedure will work as well.

The four years (from 2006 to 2009) will be treated separately and the partial results will be combined afterwards. Using this yearly approach one will obtain the possibility to identify trends and randomly occurring clusters. Furthermore, stability of clusters will be shown if clusters consist of the same countries for several years.

In addition to the IRTAD and GIDAS databases a national accident report of Hungary from 2008 will be used for exemplary applications. The example will use a three-dimensional table containing the injury severity in categories *killed*, *seriously injured*, *slightly injured*; the location in categories *rural*, *urban*; and the type of collision in categories *head on*, *rear-end*, *due to crossing*, *with parked*, *skidding*, *with pedestrians.*

GIDAS-AIDED PROJECTION TO CLUSTERS OF EUROPEAN COUNTRIES

Quantification of the effectiveness of traffic safety measures is of essential interest in accident research and for car manufacturers. While case-specific proposals exist for several regions and countries, a Europe-wide evaluation is much more challenging. On the one hand a single Europe-wide evaluation may not be able to point out local differences of the intrinsic accident structure. On the other hand a partition into too many and too narrow European regions often causes small sample difficulties or the problem that data of sufficient detail is not available for each region. Furthermore, such a big amount of regions results in a lot of expenditure in computations as they have to be carried out for every region separately. Thus, the motivation for a classification of Europe into so-called clusters arises quite naturally. Ideally, every cluster will consist of countries containing equal or at least strongly comparable, say similar intrinsic accident structure.

It should be emphasized that the focus is on the development of a general and flexible evaluation method instead of concrete quantifications of the effectiveness of specific driver assistant systems. However, examples will be given later on.

Step 0: How to process accident data (if necessary)?
Step 1: How to obtain high- dimensional data using the IPF?
Step 2: How to decide distributions to be similar or dissimilar?
Step 3: How to cluster countries using the test for similarity of distributions?
Step 4: How to quantify the effectiveness of driver assistance systems in given clusters?

Figure 1. Working packages.

The development of the procedure briefly is divided in step-wise working packages. The first-of-all working package, namely Step 0, is about the processing of data. This step is optional in terms of leaving out if data of sufficient detail and same form is available for every country. Otherwise the data will have to be processed (e.g. consider two countries with different coding of injury severity). Usually this working package contains the screening of the reliability of data and/or the coding of categories of accident parameters. In the following no further comments on this step will be given because there is no general method for data editing. Step 1 will describe how the Iterative Proportional Fitting Procedure (IPF) can be used to generate (approximated) country-specific multi-dimensional distributions of accident parameters. Probably step 2 is the most innovative and essential working package for the quantification approach in its total. It deals with the development of an approach for testing for similarity of distributions. While mathematical standard tests for equality often fail in application cases, a generalization to testing for similarity will briefly be pointed out. This theoretical result creates a basis for the ensuing clustering procedure, namely step 3. The clustering method will be given as a pseudo-algorithm wherein the test for similarity plays a pivotal role. The clustering procedure will lead to a classification in terms of the countries within each group being as similar as possible and the groups being as dissimilar as possible. Further on, Step 4 is the projection approach. Depending on a given

cluster configuration the projection method can be applied to each cluster. Thus one will obtain cluster-wise evaluations of the effectiveness of the driver assistance system of interest which can be aggregated in a final step if liked. Another possibility for evaluation is to aggregate the received weighting factors to projection factors for the whole of Europe. Based on this projection the effectiveness of driver assistance systems can be determined for the whole of Europe. Each Step of the presented method will be discussed using elementary examples.

Step 1: Iterative proportional fitting

Any clustering requires distributions of the same form for every country. As one could expect, the higher dimensional the distributions are the better the classification is (assuming that we consider essential parameters). However, for some countries only low-dimensional data is available. A review of the Iterative Proportional Fitting Procedure (IPF) will be given to show how higher dimensional data can be computed using low-dimensional statistics. In-depth data bases like e.g. GIDAS will be a helpful tool to generate initialization tables during the IPF algorithm. Using IPF, based on several one-dimensional distributions (e.g. the three distributions of the type of collision, the injury severity and the accident location) one will obtain one higher dimensional objective distribution (e.g. the corresponding three-dimensional distribution). This obejctive distribution is required for each country with respect to ensuing country-wise comparisons.

It should explicitly be pointed out that Step 1 is required if and only if the multidimensional objective distribution is not available for all countries of interest. In this instance the IPF defined by Deming and Stephan (1940) takes country-specific marginal distributions of lower dimension and computes a higher dimensional distribution which fulfills the marginal restrictions. The procedure depends on the initialization table. While computing, the procedure keeps the inner dependence structure of the initialization table as much as possible. Obviously the solution will depend on the used initialization table. Assuming that all countries of the European Union have an equal intrinsic accident structure the GIDAS data base can be used for initialization. As a consequence all inner dependencies of GIDAS which have not been controlled by the used parameters throughout the IPF are assumed for Europe in its total.

The IPF algorithm of Deming and Stephan (1940) operates as follows. For reasons of simplicity the review is restricted to the two-dimensional case. Nevertheless, higher dimensional cases can be treated in an analogous way.
Let

$$(m_{i\#}\,; i = 1, \dots, I) \tag{1}$$

and

$$(m_{\#j}\,; j = 1, \dots, J) \tag{2}$$

be two one-dimensional country-specific marginal distributions (e.g. the accident location (*urban, rural; I=2*) or the injury severity (*fatally, severely, slightly injured; J=3*)). The actual underlying two-dimensional distribution

$$(m_{ij}\,; i = 1, \dots, I\,; j = 1, \dots, J) \tag{3}$$

may be unknown. Further an initialization table is required. With the help of GIDAS one can extract a sample

$$(n_{ij}\,; i = 1, \dots, I\,; j = 1, \dots, J) \tag{4}$$

imitating the true two-dimensional distribution. Of course, the total number of absolute frequencies usually differs. However, the algorithm only relies on the inner relation of the accident configurations. Now the IPF algorithm adjusts the initialization table iteratively by the use of alternating row-wise

$$n_{ij}^{*} = n_{ij}\left(\frac{m_{i\#}}{n_{i\#}}\right) \tag{5}$$

and column-wise fittings

$$n_{ij}^{*} = n_{ij}\left(\frac{m_{\#j}}{n_{\#j}}\right). \tag{6}$$

The convergence of the procedure to a stable limit distribution was discussed by Stephan (1942) and Rüschendorf (1995). It should be emphasized that the IPF limit is an approximated version of the true two-dimensional distribution depending on the assumption that the country-specific and the GIDAS-specific intrinsic accident relations are equal. Thus, sample problems in GIDAS will be transferred implicitly to the approximated distribution. In other words the IPF is an approximating procedure which contains coincidence by the use of data sets like e.g. GIDAS. Thus, exact results cannot be expected. Nevertheless, the IPF is a helpful tool and gives a possibility to handle dimension problems of the data.

Additional results and discussions on the IPF can be found in e.g. Fienberg (1970), Wong (1992) and Norman (1999). Latter ones especially give advice

how to handle the difficulties of occurring zeros in initialization tables.
At this point, it should be mentioned that the IPF is necessary if and only if the required high-dimensional distributions are not available for each country. Using IPF one obtains for every country higher-dimensional distributions of the concerned accident parameters which are the basis for further investigations.

Example 1: An exemplary enumeration is given by applying the IPF to Hungarian data of the year 2008 taken from the official national report (see Hungarian Central Statistical Office (2009)). Using the marginal distributions given in the Tables 1 to 3 a three dimensional case study is computed. The GIDAS data is used for initialization. The resulting IPF limit and thus approximately proposed three-dimensional Hungarian distribution is given in Table 4. A comparison to the actual higher-dimensional Hungarian distribution is possible using Table 5 obtained by the national report.

Step 2: Testing for similarity of distributions

The most usual way to decide whether two distributions are equal is the χ^2-test. However, in application cases using accident data the test rejects the hypothesis of equal distributions in nearly every situation. This is due to noisy data and coding problems along with several other reasons. If distributions (countries) shall be clustered, they do not necessarily have to be equal though in detail equality would represent the optimum. In the context of clustering procedures it is mainly sufficient to have the possibility to decide whether or not distributions are similar. This directly motivates the task to find a method indicating similar distributions.

Table 1.
Hungarian marginal distribution for the type of collision in 2008.

type of collision					
head-on	rear-end	due to crossing	with parked	skidding etc.	with pedes-trians
3533	3886	7564	4048	2958	3539

Table 2.
Hungarian marginal distribution for the injury severity in 2008.

injury severity		
fatal	severe	slight
962	6001	11892

Table 3.
Hungarian marginal distribution for the location of the collision in 2008.

accident location	
urban	rural
15927	9601

Table 4.
Resulting IPF-limit for the three-dimensional Hungarian distribution of the year 2008 using GIDAS as initialization table.

	urban			rural		
	fatal	severe	slight	fatal	severe	slight
head-on	22.4	362.6	1053.3	162.1	724.9	1207.9
rear-end	10.7	149.7	1369.0	59.2	450.5	1846.9
crossing	64.6	1339.0	4445.4	52.5	420.2	1242.3
parked	54.4	676.3	2545.1	54.6	211.0	506.6
skidding	37.7	212.8	325.3	166.7	869.4	1346.2
pedestrian	204.6	1471.5	1626.9	60.9	81.4	83.7

Table 5.
Actual three-dimensional Hungarian distribution of the year 2008 obtained of the national report.

	urban			rural		
	fatal	severe	slight	fatal	severe	slight
head-on	33	387	971	181	723	1238
rear-end	27	393	1710	65	428	1263
crossing	82	1420	4714	57	359	932
parked	64	548	1458	118	587	1273
skidding	22	313	595	52	556	1420
pedestrian	160	1138	1892	83	140	126

While the little difference between equality and similarity is clear in interpretation, from a mathematical point of view it is of essential effect. The testing problem, whether distributions are equal, is well-studied (see Hartung (2005) for a review and detailed examples). Especially the χ^2-test and the Kolmogorov-Smirnov-test are well understood. However, only less satisfying results dealing with the similarity of distributions exist.

One recent analysis on similarity of distributions is given in the work of Niebuhr et al. (2011). Their main results are shortly reviewed below. For reasons of simplicity technical details are neglected in here.

Transferring the idea of the standard χ^2-test to the more general non-central χ^2-pattern their approach introduces a correction term representing additional tolerance to the standard test hypothesis of strict identity of two distributions. From a less statistical point of view one could interpret this approach as a modification of the test of equality. The modification itself, represented by a so-called term of tolerance (see equation (11)), weakens the claim of equal distributions to at least similar ones.
In consequence also the test statistic has to be changed in comparison to the standard test, see (9). The additional term represents tolerated deviation. Vividly, this tolerance is interpreted as an overlaying jittering to the original distribution. From another point of view, instead of comparing a sample to one specific distribution, the sample is compared to all possible distributions close to the specific distribution or in other words to a class of similar distributions.

The mathematical construction of the correction term includes both small overall deviations and larger deviation in few cells of the distribution. The resulting test for similarity is reviewed below. It should explicitly be emphasized that the developed test statistic is consistent to the one of the standard χ^2-test for equality if the additional tolerance level is set to zero. Thus, similarity without tolerance clearly becomes equality. The test is as follows. Let

$$(n_{ij}\,; i = 1, \dots, I\,; j = 1, \dots, J) \tag{7}$$

be the assumed original distribution (e.g. yearly national accident distributions of Hungary, see Table 5, containing the type of collision, the accident location and the injury severity) and let

$$(n^*_{ij}\,; i = 1, \dots, I\,; j = 1, \dots, J) \tag{8}$$

denote the assumed sample of (7) (e.g. a GIDAS-aided imitation of the national statistic or a computed IPF approximation, see Table 4). Further, n may describe the total number of cases, which is the sum of the n_{ij}. As already mentioned, the test statistic χ^2 from the test for equality plays an important role in this generalization. It is defined via

$$\chi^2 = \sum_{i,j} \frac{\left(n^*_{ij} - n_{ij}\right)^2}{n_{ij}}. \tag{9}$$

The null hypothesis H_0 and alternative H_1 are given as expected:

H_0: The distributions are similar.
H_1: The distributions are not similar.

The accompanying test decision is as follows. The null hypothesis H_0 will be rejected if

$$\frac{\chi^2 - \lambda - IJ}{\sqrt{\frac{2IJ + 4\lambda}{2IJ}}} - IJ \;>\; \chi^2_{IJ,1-\alpha}, \tag{10}$$

where

$$\lambda = u^2_{0.5+\beta} \sum_{i,j} n_{ij} \left(1 - \frac{n_{ij}}{n}\right) \tag{11}$$

and u_δ describes the δ-percentile of the standard normal distribution. The additional tolerance is introduced by β which implicitly scales λ and thus, at least has a decreasing effect on the test statistic value. If β is set to zero, the test will simplify to standard χ^2 -test.

Careful analysis gives the fact that any two distributions are decided to be similar if the tolerance β is generously increased. More detailed, there is a specific tolerance value where the test decision switches from rejection to non-rejection. This specific and also unique value may be denoted as the *p*-value of β in the following. Depending on a fixed level of significance α, one is able to obtain the *p*-value β^* by solving the implicit equation

$$\chi^2 - u^2_{0.5+\beta} \sum_{i,j} n_{ij} \left(1 - \frac{n_{ij}}{n}\right) - \chi^2_{\alpha,IJ} = 0. \tag{12}$$

However, this *p*-value of β represents a kind of dissimilarity measure which will be of essential importance for the ensuing clustering procedure.

Example 2: Besides using the *p*-value as a measure of dissimilarity (see Example 3 for its application in the clustering method), the test for similarity of distributions is a helpful tool in the evaluation of the quality of projections. Returning to the situation of Example 1, the *p*-value gives advice about the quality of the IPF approximation of the Hungarian

statistic. A direct application using Table 4 as the sample and Table 5 as the original distribution leads to

$$\beta^* = 0.133 \tag{13}$$

what corresponds to an required additional tolerance of 13.3 %. It has to be individually decided if this value is acceptable or not. However, empirical investigations of the IPF done by the authors let them conclude that tolerance levels up to 15 % seem appropriate.

Step 3: Clustering procedure

The test for similarity of distributions and especially the corresponding p-value β^* allows evaluating the degree of similarity of country-specific accident data. Using β^* as a measure of dissimilarity one is able to identify the two countries with the most similar distributions out of a pool of countries. Based on this thought a clustering procedure is presented in the following. The procedure can be described as an Iterative Nearest-Neighbor-Centroid-Procedure. In terms of a greedy heuristic the most similar distributions are clustered (nearest-neighbor) and their absolute frequencies are summarized. Therefore, the distribution of the resulting cluster is a weighted interpolation of the two used original distributions (centroid). Finally iterative application leads to one single cluster containing all countries. Further investigations on nearest-neighbor clustering procedures can be found in Wong and Lane (1983).

It should explicitly be pointed out that the test presented in Step 2 compares a given sample with an actual distribution. The clustering procedure instead measures the dissimilarity of samples of two countries in each step. Formally, the statistic of country A is seen as a sample of the distribution of country B and vice versa. Afterwards the mean of both computations is obtained as an approximated p-value. Thus an underlying mutual distribution is assumed that is located between the distributions of the two country-specific samples. The step-wise clustering procedure is as follows:

Step 0:	Start with the distributions of m countries/clusters. Stop if m is equal to 1.
Step 1:	Compute the p-values β^*_{AB} for all possible pairs of countries/clusters A and B.
Step 2:	Compute the mean of β^*_{AB} and β^*_{BA} for all pairs of countries/clusters A and B.
Step 3:	Note the minimum mean of p-values and the corresponding countries/countries.
Step 4:	Aggregate the raw data of the two countries with minimal dissimilarity.
Step 5:	Go back to Step 0 with m replaced by m-1.

Figure 2: Clustering algorithm.

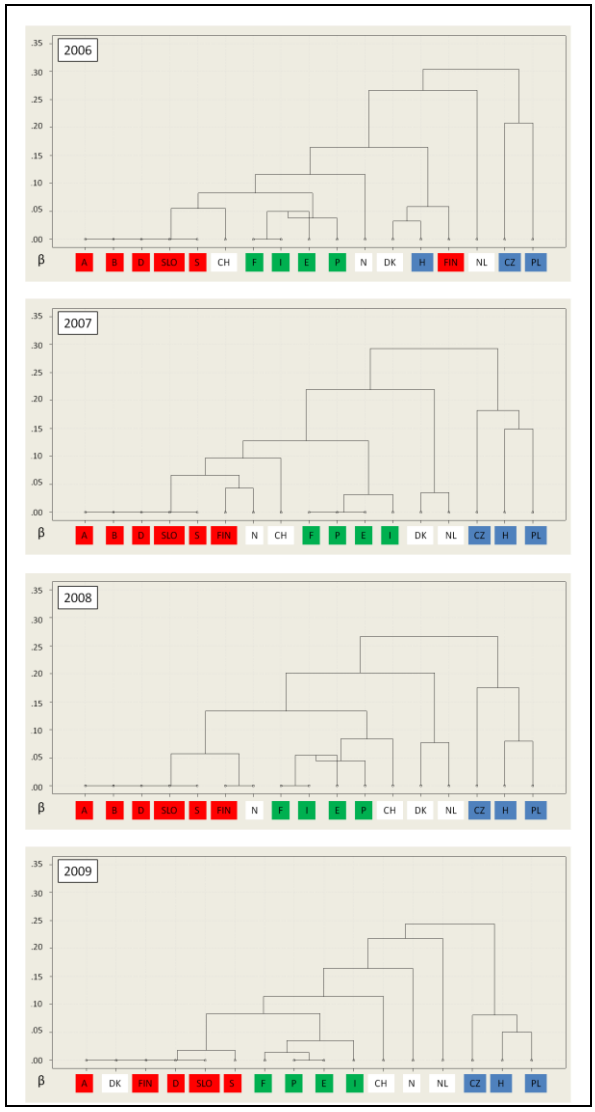

Figure 3. Development of the EU17 clusters from 2006 to 2009 for fatal injuries in dependence on the traffic participation. (Remark: There is no data available for Belgium in 2009).

A visualization of the clustering procedure can be done by a so-called dendrogram (see the plots in Figure 3). The dendrogram has to be read bottom-up. Starting with all countries the development of the clustering is visualized step by step. Each dissimilarity value is represented by the height of the horizontal lines and can be interpreted as the clustering level.

Because the p-value β^* gives no indication about a potential test decision, one has to fix the maximum level of tolerance. This corresponds to a level of significance of the test. The level can individually be chosen and it can easily be integrated into the dendrogram plot as a horizontal line. All clusters below this horizontal line are accepted to be similar; all clusters above the level are rejected. Imagine deleting the graph above this horizontal

line. All still connected countries are accepted to be similar and to define clusters.

As already discussed in the introduction, there is no advantage of too many or too few clusters. To obtain a satisfying number of clusters, a more useful approach is to fix the accepted level of tolerance afterwards. This alternative proposal is used in Example 3 to determine Figure 4 in dependence of Figure 3.

Example 3: An exemplary clustering is given. To assure the reliability of this example, the investigation is restricted to fatally injured road users. The distributions of the traffic use of these fatally injured road users for the years 2006 to 2009 were extracted of the IRTAD data base. In detail the categories *bicycle*, *moped*, *motorcycle*, *passenger car* and *pedestrian are used for traffic use*. Using the aforementioned clustering procedure the development of the similarities (2006-2009) can be seen in Figure 3. All computations were implemented using the free software *R*.

The year-wise separated investigation allows to identify stable clusters and trends in the data. Figure 3 shows two very stable clusters (red and green) and a group of countries coming closer to each other (blue). White countries cannot be classified to one specific cluster. One reason may be the small total numbers of accidents and especially fatalities of these countries. In these countries, small fluctuation in the data causes significant changes in the distributions.
It should be emphasized that this example doesn't use an a priori fixed level of tolerance. The alternative proposal is used to determine a satisfying number of clusters.

This four year analysis of fatal traffic participation ends up in Figure 4. It seems that the localization of the countries is essential for the distribution of the traffic use of fatally injured people.

Figure 5 is developed using exactly the same approach based on the distribution of the accident location (*urban* and *rural*) of the fatalities instead of the distribution of road use. Again the IRTAD database was used. It should be mentioned that these two-point-distributions of the location are very sensitive. However, certain clusters can be indicated (see Figure 5).

Both examples give the impression that the country localization is essential for several accident categories. Further, especially small countries with few accident samples fluctuate a lot and cannot be classified to one specific cluster.

It should be mentioned that at this point of research it is not clear if aggregation is possible and if yes how to aggregate several results like Figure 4 and Figure 5 to one final solution. One would expect that equal clusters would be kept but differences in the clusters are hard to handle and at this point of research there are no specific results.

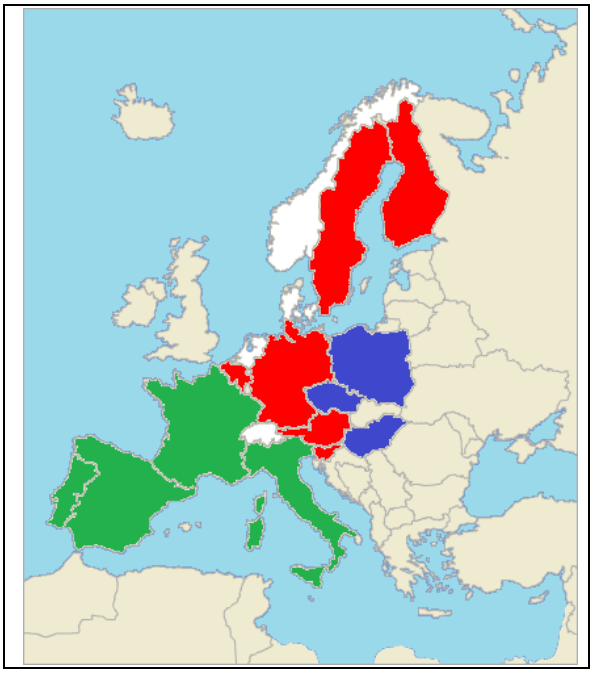

Figure 4. EU17 clusters for fatalities in dependence on the traffic participation as consequence of Figure 3. (white: non-allocated countries).

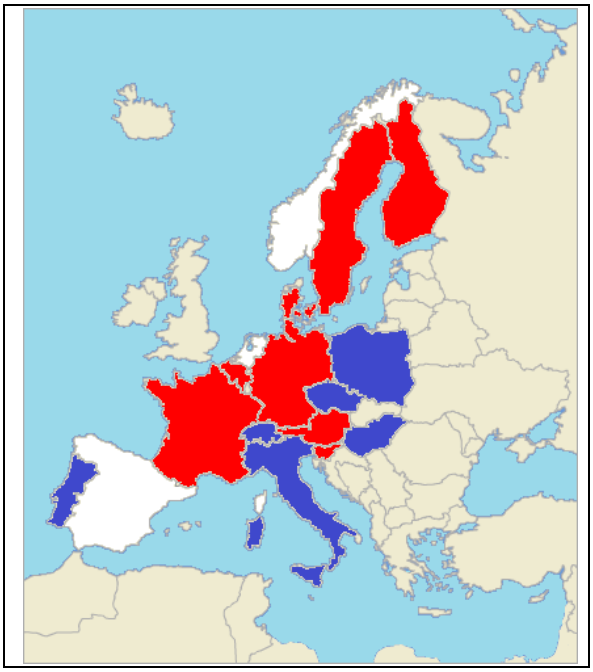

Figure 5. EU17 clusters for fatal injured participants in dependence on the accident location. (white: non-allocated countries).

Step 4: Method of projection

A common way to evaluate driver assistance systems within Germany is to imitate the distribution of interest on the basis of the GIDAS data set. Thus, one has the original distribution (e.g. a two-dimensional distribution containing information on the accident location (*rural*, *urban*) and the injury severity (*fatal*, *severe*, *slight*)) and one distribution mimicked by GIDAS. Obviously, the mimicked one will differ from the original distribution. To solve this differing so-called projection factors can be computed in a cell-by-cell device by dividing the actual number of cases through the number of cases in the mimicked GIDAS table (in the hypothetical two-dimensional example six factors have to be computed, i.e. [*urban,rural] x [fatal,severe,slight]*). Further, using these projection factors the GIDAS-based imitation is weighted in terms of weighting each involved person by the projection factor instead of the weight one. The result is a weighted GIDAS data set that fulfills the correct original distributions. The evaluation of a driver assistance system can be done by using the weighted GIDAS version.

Justification of this procedure is given if inner relations of GIDAS are assumed to represent relations in other regions as well. This is based on the fact that weighting regarding certain parameters (e.g. injury severity, accident location, road use) implicitly influences further parameters (e.g. type of accident). Obviously, positive correlated variables are influenced in the right direction. Nevertheless, misjudgment may occur in few cases and has to be taken into account. However, this straightforward approach is reasonable for empirical investigations.

Furthermore smoothing effects within Europe-wide investigations may hush up local characteristics. The wish to avoid such possibly conflicting regional effects of the weighting a posteriori leads to another motivation for an appropriate clustering procedure.

As a consequence, the projection idea can be applied to each cluster identified in Step 3. While the clustering procedure separates groups with similar distributions one assumes similar intrinsic relations in each group, and thus the projection can directly be applied. The evaluation of a driver assistance system can be evaluated in each cluster separately and possibly be combined to an all-European result afterwards. Another possibility to obtain Europe-wide results would be the aggregation of cluster-specific projection factors to all-European projection factors. Thus evaluations could base on a GIDAS data set adapted to Europe in its total.

It should explicitly be pointed out that the worth of this approach extensively depends on type and scope of the original distribution. Obviously, higher-dimensional distributions result in much better projections than lower-dimensional ones. Thus, the IPF procedure computing higher-dimensional distributions is of far use for this approach. The combination of the technical IPF, the in-depth GIDAS data base and the cell-by-cell projection creates a powerful tool for the evaluation of traffic safety measures, especially for the whole of Europe. Some countries may not offer such detailed data than others do. However, the IPF can be applied and thus the quality of the projection may increase. The only theoretical limit for this approach is given by the dimension of the GIDAS data set and the availability of national statistics.

<u>Example 4:</u> While the presented procedure works for any dimension of data, for reasons of simplicity this example is restricted to one single dimension. Nevertheless, the proposal can be directly transferred to higher dimensional data. The situation of Example 1 is shortly reviewed. The Hungarian distribution of the injury severity is given in Table 2. It is divided into three categories, namely *fatally*, *severely* and *slightly injured* traffic users, with frequencies

$$(962, 6001, 11892) = (5.1\%, 31.8\%, 63.1\%). \tag{14}$$

The corresponding GIDAS distribution is given by

$$(775, 8590, 24349) = (2.3\%, 25.5\%, 72.2\%). \tag{15}$$

Obviously, the Hungarian national statistic differs from the GIDAS one. In consequence, the GIDAS sample has to be weighted. Every case (person) of the data set is valued depending on its injury severity category. Thus, every *fatal* case in GIDAS obtains the weighting factor

$$962/\,775 = 1.24, \tag{16}$$

every *severe* case obtains the weighting factor

$$6001/8590 = 0.70 \tag{17}$$

and every *slightly injured person* the weighting factor

$$11892/24349 = 0.49. \tag{18}$$

Equations (16)-(18) represent the cell-by-cell projection factors. Again it is commented that in this example the weighting is restricted to only one accident property with three categories, namely the injury severity. However, projections containing

any number of properties with any number of categories would follow an analogous approach.

Assuming a hypothetical driver assistance system which is able to prevent 25% of all urban fatalities an exemplary evaluation is computed. Using the weighted GIDAS version as described before a two-dimensional table is build, see Table 6. The effect of the hypothetical system is restricted to one single cell in Table 6. It causes a reduction of 25% of all urban fatalities, thus

$$341.1 * 0.25 = 85.3 \qquad (19)$$

fatalities will be avoided. The total number of fatalities decreases from 962 to at least 876.7 that is a percentage decreasing of

$$1 - 876.7/962 = 0.089, \qquad (20)$$

respectively 8.9%. Note that the described projection approach can directly be transferred to other driver assistance systems and thus one has the possibility to quantify the effectiveness of systems in an appropriate way.

Table 6.
Two-dimensional table from GIDAS with Hungarian weights containing accident location and injury severity.

	fatal	severe	slight	total
urban	341.1	3613.9	8693.0	12648.2
rural	620.6	2387.1	3199.0	6206.8
total	962	6001	11892	18855

CONCLUSION & DISCUSSION

A method of the evaluation of the effectiveness of driver assistance systems was presented. Using a step-wise approach it was pointed out how data can be processed to mutual form by the use of the IPF. Though case studies result in very satisfying results, the quality and sensitivity has to be quantified. Further, based on a developed testing procedure for the similarity of distributions, a powerful clustering algorithm was described. The intrinsic relations of higher-dimensional distributions within the obtained clusters result in similar characteristics. Nevertheless, it is not clear in detail how to combine several partial solutions to an overall result.

The method should be expanded to higher-dimensional distributions and all countries within EU 27. The probably largest difficulty will be the common database. However, the combination of the IPF, the GIDAS data base and the projection procedure creates a trustworthy method that seems appropriate for European-wide investigations.

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MATHEMATICAL ANALYSIS OF BRAKING IN REAR-END CRASH SCENARIOS

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ABSTRACT

Recently, a test-based assessment method for forward-looking crash avoidance and mitigation systems (pre-crash systems) was developed within the EU project ASSESS. In this method, injury outcome is correlated with the change of velocity (Delta-V) during the crash and the effect of the pre-crash system on this quantity is investigated. Delta-V may be related to relative impact speed (i.e., the speed difference between the vehicles at the moment of collision) by certain assumptions. It is therefore a central question in the ASSESS assessment method to determine the relative impact speed in all rear-end test scenarios in the test protocol. This is most challenging in the scenario when the vehicle under test (striking vehicle) is approaching a braking lead vehicle.

In this paper, the corresponding question is addressed in a much more general setting. In particular, instead of the fixed values used in the test protocol for the ASSESS method, all possible values for the initial speeds and decelerations of the vehicles and the initial headway of the lead vehicle are considered in the important case when the two vehicles have equal initial speeds and decelerations. The question addressed here is the following: given arbitrary values of all these parameters, is it possible to determine the speed difference between the two vehicles at the time of collision from the impact speed of the vehicle under test using mathematically rigorous methods?

The results show that under simplifying assumptions, the relative impact speed may be expressed as a function of the impact speed of the vehicle under test. The set of valid test results is characterized for all possible parameter values together with the requirements on how early braking needs to be performed in order to avoid the crash.

Possible generalizations of the method (including the feasibility of removing some of the theoretical assumptions) are also discussed. The results may be of use in the design of future test protocols for radar-based braking systems as well as in the development of such systems.

INTRODUCTION

Forward-looking crash avoidance and mitigation systems (pre-crash systems) constitute an important family of active safety systems. The safety effects of such systems – forward collision warning (FCW), pre-crash brake assist (PBA) and autonomous pre-crash braking (PB) in particular – in real-world rear-end crashes have been assessed in e.g. [3,4,5]. The results showed tangible benefits in terms of a reduced number of injuries in both vehicles involved in a rear-end crash.

It is a common feature of pre-crash systems that radar technologies of high accuracy are used to scan the road in front of the equipped vehicle to detect any object or vehicle that poses a potential safety risk. This way the system can intervene if necessary by issuing warning, providing brake enforcement or performing autonomous emergency braking. Therefore, a proper understanding of vehicle dynamics in rear-end scenarios is essential for the development and testing of pre-crash systems. The mathematical analysis described in this paper will give an exact description of the corresponding motions under certain simplifying assumptions.

Recently, a test-based assessment method for pre-crash systems was developed within the EU project ASSESS, see [1,2]. In this method, the injury-reducing capacity of a pre-crash system is assessed based on test results in three rear-end scenarios in which the vehicle under test (which is the striking vehicle) is approaching a slower lead vehicle, a stationary lead vehicle and a braking lead vehicle, respectively. In the current paper, the same classification of rear-end scenarios is considered and the braking lead vehicle scenario will be analysed in detail.

It is convenient for the implementation of the ASSESS method to determine the relative impact speed (i.e., the speed difference between the vehicles at the moment of collision) from the impact speed of the subject vehicle in all rear-end

test scenarios in the test protocol. This is easily done in the scenarios when the lead vehicle is stationary or travelling at a constant speed but it is much more challenging when the lead vehicle is braking. With the help of the mathematical analysis of the braking lead vehicle scenario described here, it will be possible to find a solution to this problem for a multitude of parameter values.

In this paper the following basic model of the braking lead vehicle scenario is analyzed. A target vehicle (TV) and a subject vehicle (SV) move along a straight line in a given direction, with TV having an initial headway of $h > 0$. TV has initial speed $v_T > 0$ and is braking at deceleration $b_T > 0$ from time 0 on as long as it has positive velocity. SV, having initial speed $v_S > 0$, is driving at constant speed v_S until a time $T_b \geq 0$ after which it is braking at deceleration $b_S > 0$ as long as it has positive velocity. In both cases the deceleration associated with braking is immediately reached (i.e. no ramp-up period is taken into account).

The rest of this paper is concerned with the case of $v_S = v_T = v_0$ and $b_S = b_T = b$, i.e., when the two vehicles have equal initial speeds and decelerations. The importance of this special case is due to the fact that it represents the real-life situation when both vehicles drive at the speed limit of the road that they are driving on and their emergency brakings result in similar decelerations.

METHODS

All results in this paper are obtained via mathematically rigorous methods. The main step in the analysis is the reduction of the problem to the case of $T_b = 0$ by determining the velocities of the vehicles and the distance between them at time T_b, and substituting the corresponding parameters in the solutions for the case $T_b = 0$. However, the description of the detailed computations involved is out of the scope of this paper and will therefore be published separately.

RESULTS

First, it is important to note that there is an upper bound for the value of T_b, namely the time when SV reaches TV without braking, since the possibility of braking after the two vehicles have crashed is excluded in the current analysis. The resulting upper bounds are the following:

$$T_b \leq \sqrt{2h/b} \qquad (1)$$

if $h \leq v_0^2/(2b)$ (see curve C in Figure 1), and

$$T_b \leq h/v_0 + v_0/(2b) \qquad (2)$$

if $h > v_0^2/(2b)$ (see curve D in Figure 1). Note that the expressions on the right hand sides of (1) and (2) take the same value (namely v_0/b) in $h = v_0^2/(2b)$, hence their concatenation determines a region above these curves (marked as region IV in Figure 1). This parameter region is disregarded in the current analysis.

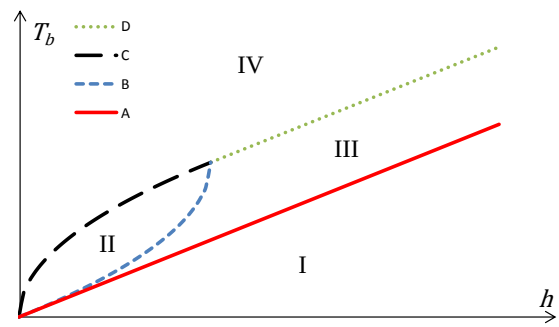

Figure 1. Illustration of the functions and regions that are relevant to the analysis in the case of $v_0 = 1$ and $b = 1$.

It is of special interest to determine which values of T_b allow the avoidance of the crash. The corresponding parameter region in Figure 1 is region I (with curve A as a non-inclusive upper bound), which is determined by the equation

$$T_b < h/v_0 \qquad (3).$$

In other words, the crash is avoided if and only if (3) holds.

A crash may occur before or after the target vehicle has stopped. It turns out that a crash while both vehicles are in motion may occur only for the following values: $h < v_0^2/(2b)$ and

$$(v_0 - \sqrt{v_0^2 - 2bh})/b < T_b \leq \sqrt{2h/b} \qquad (4).$$

In Figure 1, the corresponding region is II. It is important to note that $(v_0 - \sqrt{v_0^2 - 2bh})/b$ and $\sqrt{2h/b}$ indeed take the same values for $h = 0$ as well as for $h = v_0^2/(2b)$ while for $0 < h < v_0^2/(2b)$, it holds that

$$h/v_0 < (v_0 - \sqrt{v_0^2 - 2bh})/b < \sqrt{2h/b} \qquad (5).$$

This shows that II is indeed a well-defined parameter region which is situated between h/v_0 and $\sqrt{2h/b}$ as shown in Figure 1.

Finally, for $h < v_0^2/(2b)$ and

$$h/v_0 \leq \mathrm{T_b} \leq (v_0 - \sqrt{\mathrm{v_0^2 - 2bh}})/\mathrm{b} \qquad (6)$$

or for $h \geq \mathrm{v_0^2}/(2b)$ and

$$h/v_0 \leq \mathrm{T_b} \leq h/v_0 + v_0/(2b) \qquad (7)$$

it holds that a crash occurs when the target vehicle has already stopped. The corresponding parameter region in Figure 1 is region III.

In the parameter regions where the two vehicles crash, the speeds of the vehicles at impact are computed as follows. In region III, the impact speed of the subject vehicle is

$$\mathrm{v_S^{impact}} = \sqrt{2\mathrm{b}}\sqrt{v_0\mathrm{T_b} - \mathrm{h}} \qquad (8).$$

Since the target vehicle is standing still at the time of impact in this parameter region, the relative impact speed $R = \mathrm{v_S^{impact}} - \mathrm{v_T^{impact}}$ equals $R = \mathrm{v_S^{impact}}$ whose value is determined in equation (8). In region II, the subject vehicle has an impact speed of

$$\mathrm{v_S^{impact}} = (\mathrm{bT_b^2} + 2\mathrm{v_0T_b} - 2\mathrm{h})/(2\mathrm{T_b}) \qquad (9)$$

while the target vehicle has impact speed

$$\mathrm{v_T^{impact}} = \mathrm{v_S^{impact}} - \mathrm{bT_b} \qquad (10)$$

hence the relative impact speed in region II is $R = \mathrm{bT_b}$.

It may be noted that the right hand sides of both (8) and (9) are strictly increasing and continuous functions of $\mathrm{T_b}$ (in the relevant intervals of h), and the limit of (9) as $\mathrm{T_b}$ tends to $(v_0 - \sqrt{\mathrm{v_0^2 - 2bh}})/\mathrm{b}$ from above equals the value of (8) at braking time $T_b = (v_0 - \sqrt{\mathrm{v_0^2 - 2bh}})/\mathrm{b}$ (with the value in question being $v_0 - \sqrt{\mathrm{v_0^2 - 2bh}}$). This implies that for all initial parameters $\mathrm{v_0}$, b and h, $\mathrm{v_S^{impact}}$ is a strictly increasing and continuous function of $\mathrm{T_b}$ in the regions where a crash occurs. This function has a minimal value of 0 (which is taken at $\mathrm{T_b} = h/v_0$) and a maximal value of v_0 (at $\mathrm{T_b} = \sqrt{2\mathrm{h/b}}$ if $h \leq \mathrm{v_0^2}/(2b)$ and at $\mathrm{T_b} = h/v_0 + v_0/(2b)$ if $h > v_0^2/(2b)$). According to Bolzano's theorem about continuous functions on closed intervals, all values between the minimum and maximum are taken at respective values of $\mathrm{T_b}$. In other words, any impact speed between 0 and v_0 is a possible impact speed for the subject vehicle.

It is now possible for each $0 \leq \mathrm{v_S^{test}} \leq \mathrm{v_0}$ to determine the corresponding value of $\mathrm{T_b}$ (i.e. the value which results in $\mathrm{v_S^{impact}} = \mathrm{v_S^{test}}$) and the relative impact speed as follows. If $h \geq v_0^2/(2b)$, then

$$\mathrm{T_b} = ((\mathrm{v_S^{test}})^2 + 2bh)/(2bv_0) \qquad (11),$$

and the relative impact speed R is determined by

$$R = \mathrm{v_S^{test}} \qquad (12).$$

If $h < v_0^2/(2b)$ and $0 \leq \mathrm{v_S^{test}} \leq v_0 - \sqrt{\mathrm{v_0^2 - 2bh}}$, then $\mathrm{T_b}$ and the relative impact speed are again given by the equations (11) and (12), respectively. On the other hand, if it holds that $h < v_0^2/(2b)$ and $v_0 - \sqrt{\mathrm{v_0^2 - 2bh}} \leq \mathrm{v_S^{test}} \leq v_0$, then the subject vehicle started braking at time

$$\mathrm{T_b} = \frac{\mathrm{v_S^{test}} - v_0 + \sqrt{(\mathrm{v_S^{test}} - v_0)^2 + 2\mathrm{bh}}}{\boldsymbol{b}} \qquad (13),$$

and the relative impact speed is

$$R = \mathrm{v_S^{test}} - v_0 + \sqrt{(\mathrm{v_S^{test}} - v_0)^2 + 2\mathrm{bh}} \qquad (14).$$

These results show that the relative impact speed may indeed be expressed as a function of the impact speed of the striking vehicle and the initial parameters.

DISCUSSION

The results in the previous section address all relevant aspects of rear-end scenarios with a braking lead vehicle that were considered in the Introduction. Since the results are derived using mathematical computations, they yield definite answers to the underlying questions under the theoretical assumptions that describe the dynamics of the two vehicles. Therefore, it is important to discuss the relevance of these assumptions to real-world rear-end crashes and the possibility of weakening some of the assumptions.

The first limitation of this study is that only the special case of equal initial speeds and decelerations is considered. It would also be important to consider $\mathrm{v_S} = \mathrm{v_T} = \mathrm{v_0}$ and $\mathrm{b_S} < b_\mathrm{T}$ since this case determines whether the crash can be avoided by moderate braking or rather emergency braking is necessary. Even $\mathrm{v_S} = \mathrm{v_T} = \mathrm{v_0}$ and $\mathrm{b_S} > b_\mathrm{T}$ is relevant due to the fact that the vehicle under test is typically a new vehicle and hence may be able to achieve greater deceleration by emergency braking than an average vehicle on the road does.

Furthermore, $v_S \neq v_T$ should also be analysed at various deceleration values. These more general cases will be addressed in future work.

However, even the most general case with fully arbitrary values of the initial speeds and decelerations of the vehicles is rather idealistic. In fact, each one of the assumptions of the underlying model could be criticized for incomplete practical relevance. For example, there will always be some delay in real-world vehicles after the application of the brakes until the deceleration associated to the braking is attained. Therefore, the model could be made more realistic by considering a ramp-up period; for instance, it may be assumed that the deceleration increases from 0 to the desired level linearly with a certain slope.

It is also reasonable to allow the subject vehicle to increase its deceleration at a time point after T_b. This is especially relevant for those values of T_b that are too large for avoiding the crash. Another generalization of the current model is to allow the target vehicle to stop braking at a certain time or even allow re-acceleration. Note that both of these changes would enable collision avoidance at larger values of T_b than those in the present study.

CONCLUSIONS

In this paper, a mathematical analysis of rear-end scenarios with a braking lead vehicle under simplifying theoretical assumptions is presented. In particular, it is shown that the relative impact speed may be expressed as a function of the impact speed of the striking vehicle, and it is determined how early the striking vehicle needs to start braking in order to avoid the crash. The results are obtained by mathematically rigorous methods hence their only limitations are the underlying theoretical assumptions regarding the dynamics of the vehicles. However, these assumptions capture only a fraction of the complexity of real-world rear-end scenarios; therefore, the results presented here may be used as a first approximation, as well as a stepping stone for the analysis of more advanced models.

Nevertheless, the current simple model is fully solvable. Although this model (as well as its proposed generalizations) may easily be simulated, having exact solutions has numerous advanages; for example, the formulas derived in the previous section instantly provide solutions that are perfectly accurate and do not suffer from rounding errors. Although the simulations are very fast themselves, using exact solutions can save substantial time in those applications that would otherwise require multiple simulations. Also, exact solutions may be used in other studies; see e.g. [4] where mathematical formulas were applied in a creative way to evaluate potential outcomes of rear-end crashes had the involved vehicles been equipped with certain pre-crash systems. Therefore, depending on the desired application, the theoretical assumptions in this study may be a reasonable compromise in order to ensure solvability. Finally, solutions of the current simple model may pave the way for finding exact solutions in more advanced models.

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DEVELOPMENT OF A METHODOLOGY AND THE TEST TOOLS FOR THE EVALUATION OF PEDESTRIAN DETECTION SYSTEMS

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ABSTRACT

Pedestrian detection systems are expected to provide a relevant impact in the decrease of vulnerable road user casualties and injuries. Currently, different safety functions are under development and some of them have reached the market. In order to promote the wide spread of these functions and to standardize as much as possible the performance requirements, consumer organizations are also working in the development of test and assessment protocols

As a contribution to the current activities done by car manufacturers, research centers and consumer testing organizations, the research described in this paper will address some specific questions, including:

- The development of a crashable representative pedestrian test target, in terms of sensor detection
- The definition of the walking movement characteristics of pedestrians and implementation of these characteristics in the test target
- The development of a complete test facility for pedestrian detection tests
- The validation of the test target as a test tool for pedestrian detection systems
- The evaluation of representative test scenarios for pedestrian detection systems
- The estimation of the benefits of using test targets with walking movement capabilities for the better pedestrian recognition

As a result, the paper will present the developed pedestrian test target and further indications for the implementation of pedestrian detection tests.

All these questions are currently a challenge for the definition of new test procedures in the field of pedestrian detection systems.

The results of this paper will be useful for the current development of pedestrian detection systems and further development of test targets suitable for ADAS testing.

INTRODUCTION

Most accidents with pedestrians are caused by the driver being in-alert or misinterpreting the situation. Vulnerable road users, pedestrians and cyclists, have a greater risk of injury in any collision with a vehicle. For this reason pedestrian detection systems coupled with driver warnings and/or autonomous emergency braking actions are recommended to facilitate accident avoidance or reduction of the impact speed.

As described in [1], some OEMs have started to provide autonomous emergency braking systems (AEBs), which provide longitudinal assistance. In parallel to the appearance of these systems into the market, consumer testing organizations, manufacturers, engineering companies and research centers are interested in the development of test and assessment methodologies allowing the evaluation of the safety level that these systems. It is accepted that a key aspect for the success of these systems and the associated safety benefit is the information to the consumer. In order to develop a test and assessment procedure for the evaluation of Autonomous Emergency Braking systems, several initiatives have been set up: ASSESS [2], AsPeCSS [3], AEB Group [4], vFSS [5], ADAC [6]. Some of these initiatives are supported by public authorities while others are independent.

Each of these initiatives is proposing a methodology for the evaluation of autonomous emergency braking systems, including:

- The identification of relevant test scenarios and test cases

- The standardization of a representative test target representing a real pedestrian
- The definition of evaluation criteria for the performance of AEBs

This paper focusses in the development of the tools for evaluating pedestrian detection systems. Therefore, first step was to identify the most relevant accident scenarios and their derived test scenarios for pedestrian detection systems. According to [7], the most representative situation in pedestrian accidents is the crossing scenario, where a vehicle is driving in straight road while a pedestrian is crossing the road in front. Examples of these scenarios are shown in Figure 1. Different parameters can modify the configuration of these scenarios, such as obstructions and approaching direction of the vehicle.

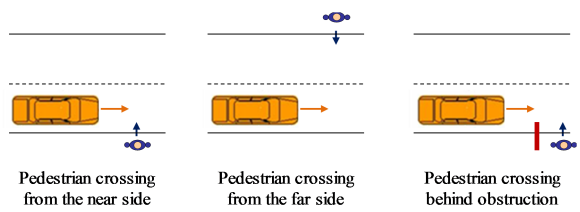


Figure1. Most typical test scenarios representing pedestrian accidents

The tools proposed in this paper should, at least, be able to reproduce these situations in a controlled environment. Additional situations might include pedestrian walking along the road and vehicles turning in a crossing.

Pedestrian test target geometry

Once the test scenarios were been identified, a test target representing pedestrian was developed. Most of the pedestrian detection systems use camera sensors to determine that the obstacle in front of the vehicle is a pedestrian. For this reason, the geometry of the pedestrian test target should match in shape and size of real humans.

The two sizes chosen in this particular case are:
- 50%ile adult male, total height 1800 mm
- 6 years old child, total height 1200 mm

A lot of activities have been addressing these issues: [3], [4] and [5]. These two sizes were chosen in order to match the decisions in other activities.

The CAD data for these 2 sizes was obtained from:
- ATD Hybrid III 50th Male Dummy, FEM model for LS-Dyna
- ATD Hybrid III 6 yo Child Dummy, FEM model for LS-Dyna

This CAD data was modified in order to match other criteria, such as walking posture and hanging mechanisms.

Walking posture

However, shape and size are not the only parameters required by camera sensors to classify the test target as a real human. Walking posture is a key attribute. Figure 2 shows the postures along the whole walking cycle. [8] has been working a lot in this aspect and the proposal is to use the posture between the MSw and TSw steps.

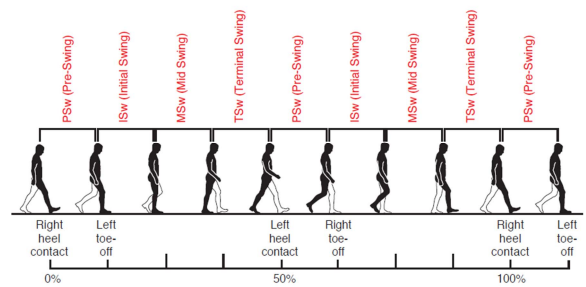


Figure2. Human postures in different walking steps, as proposed in [8]

Walking movement

The CAD data for the pedestrian test targets should have been modified in order to represent the proposed walking posture. In this particular case, it was decided to develop a test target with moving articulations able to reproduce the whole walking cycle.

Discussions with some sensor suppliers, suggested that a test target with moving articulations would better represent a real human during its walking activity. This would result in a better system performance. According to their input, the movement of the lower extremities allows a better classification of the test target as a real human. By this:

1. Algorithms can be developed to detect and classify objects which are more representative to real humans.
2. Algorithms can be developed to distinguish static objects which are not representing real humans.

Sensor and algorithm suppliers also indicated that, while current systems do not require test targets with moving articulations in order to classify the target as a pedestrian, they would allow the development of a new generation of systems.

In order to address this possibility, the walking movement of real pedestrians was analyzed. As an example, Figure 3 provides the flexion of hip and knee during the whole walking cycle.

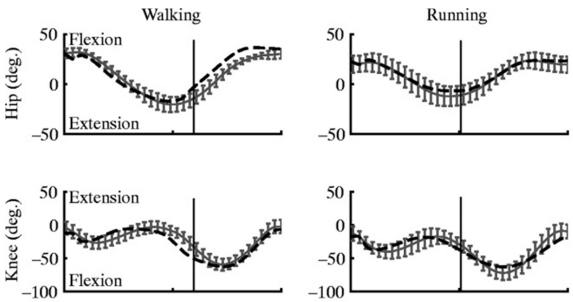


Figure3. Hip and knee flexion during walking and running [9]

In order to implement these flexion angles, the pedestrian test target was fitted with articulated knees and hips, which could be commanded mechanically by wires. An external 4-cam mechanism was designed to reproduce the movement shown in Figure 3.

Crashability of the test target

Pedestrian test targets are intended to reproduce real humans in test scenarios which should be detected by the AEB systems under test. In case of system failure, the test target will be overrun by the vehicle. In order to allow continued testing, the test targets must be crash-forgiving and do not damage the vehicle under test.

For this reason, most of the test targets are built with light materials, which should provide a low density combined with some compressibility capabilities. In this particular case, a low density polyethylene foam was used to reproduce the body of the pedestrian, which covered the aluminum structure used to reproduce the walking movement.

As in some of the test scenarios under proposal, the driving speed of the vehicle reaches up to 60 km/h, the objective was to allow impacts at 60 km/h with no damage for the vehicle under test and the pedestrian test target. FEM simulations where used to assess the crashworthiness of the adult and child pedestrian test targets. Figure 4 shows 3 time steps of these simulations.

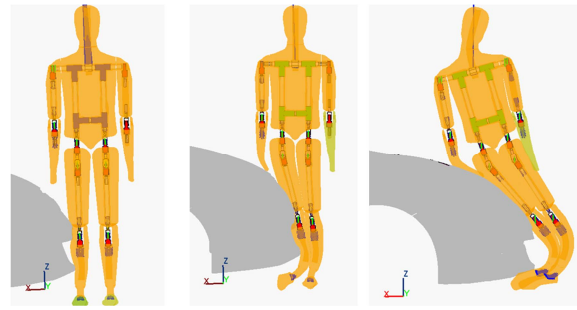
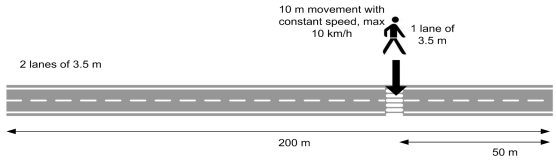


Figure4. Simulation of the 50%ile pedestrian test target during impact

The initial simulations suggested that in order to ensure no damage in crashes at a high speed, the mass of the test target should be limited to 15 kg maximum. Additionally, strong effort was made in order to ensure the crash performance of the articulations during the impact. Initially, rotational joints in Y-axis of the test target where used to allow the articulation of the extremities. Additional joints in X-axis where included to allow deformation of the articulations during the impact. This allowed some deformation of the articulation during the impact with no breakage.

Validation of the test targets

The test targets were tested at Applus IDIADA premises located in Santa Oliva, Spain. The crossing pedestrian facility consists in a 2 lanes straight road with an acceleration length of 200 m and a braking length of 50 m. A portal test rig is installed, with a total crossing distance of 25 m. A controlled trolley slides through the cross beam of the portal and pedestrian test targets can be hung from this trolley. Figures 5 and 6 provide a view of the facility.



Figures5 and 6. Pedestrian crossing facility available at Applus IDIADA premises

With this facility, tests can be executed in controlled conditions. The position of the pedestrian can be controlled with ± 1 cm accuracy. The movement can be real-time synchronized with the movement of the oncoming car via a D-GPS with ± 2 cm accuracy.

This test setup was used to validate some of the characteristics of the pedestrian.

Test target geometry and walking movement - The cam mechanism for commanding the articulations of the pedestrian was installed in the trolley. The walking movement of the adult male and the child were tested with different vehicles. The test targets were correctly recognized as pedestrians. Figure 7 provides a view of the walking movement of the test target.

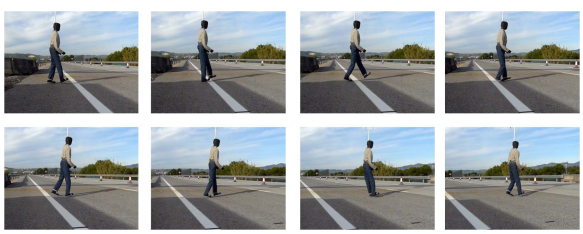


Figure7. Walking movement of the adult pedestrian test target

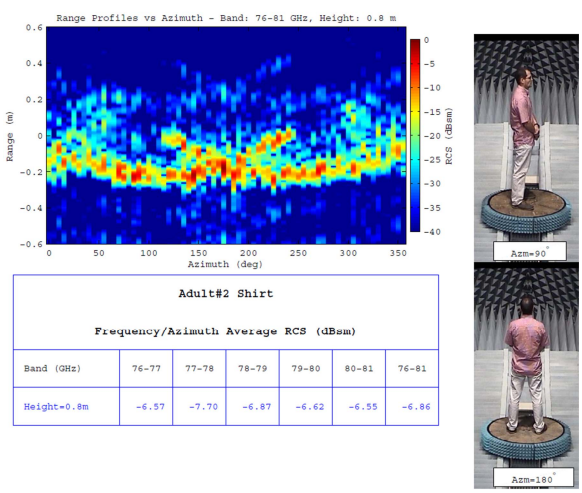
Crashworthiness – During the tests, the test targets were impacted at different speeds, up to 50 km/h. Impacts at high speeds resulted in minor damages to the vehicle under test. The test targets withstood the impacts correctly. The X-axis joints allowed the deformation of the extremities with no damage. After some impacts, the test targets had to be re-adjusted, due to degradation of the mechanism.

RADAR signature – Within this paper, shape, size and posture of the pedestrian test target have been discussed in order to ensure the correct classification of the target by camera sensors. State of the art systems use data fusion of the camera sensors combined with other sensors such as radar or lidar in order to better perform. Both radar and lidar issues have been identified by [8].

According to them, the performance of the target for lidar sensors can be mainly controlled by the clothes used. For this reason, during all the test activities, the clothes proposed by [8] were used.

Additional activities were implemented for radar sensors, under the frame of the AsPeCSS project. An object reflects a limited amount of radar energy. In order to quantify this phenomenon, several pedestrian test targets were delivered to [10], in order to measure radar signature. Radar cross section (RCS) is a measure of how detectable an object is with a radar. A larger RCS indicates that an object is more easily detected. Real humans and test targets were measured in different conditions. This paper includes only the measurement results relevant for the developed target.

Figures 8 and 9 show the RCS measurements of a standing adult and the test target in the 76 – 81 GHz band. Additional measurements in the 23 – 28 GHz band were also implemented and available in [10].

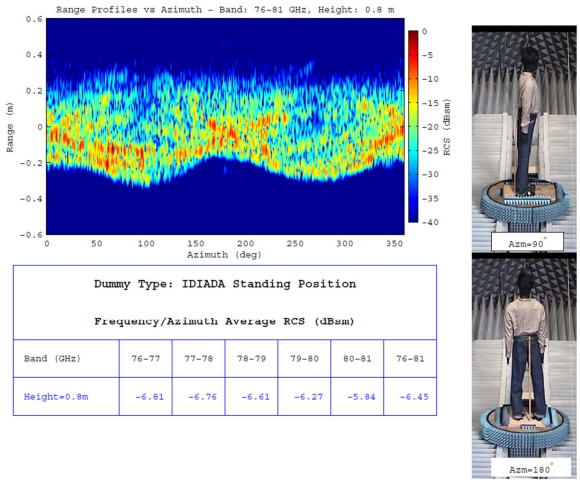


Adult#2 Shirt

Frequency/Azimuth Average RCS (dBsm)

Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-6.57	-7.70	-6.87	-6.62	-6.55	-6.86

Figure8. Real standing human RCS signature in the 76 – 81 GHz band [10]



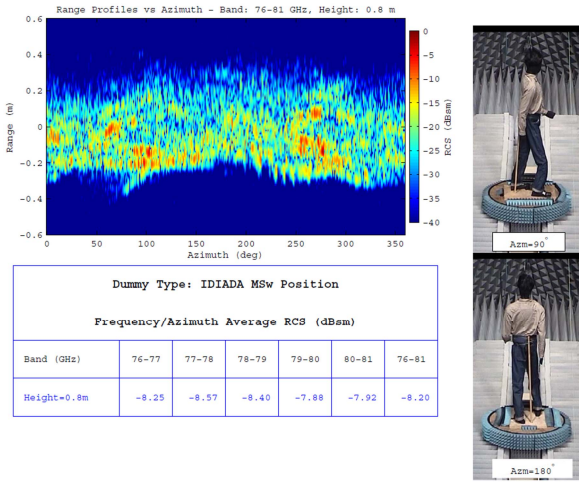
Dummy Type: IDIADA Standing Position Frequency/Azimuth Average RCS (dBsm)						
Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-6.81	-6.76	-6.61	-6.27	-5.84	-6.45

Figure9. Standing pedestrian test target RCS signature in the 76 – 81 GHz band [10]

Before the measurements were implemented, initial thoughts suggested that the test target might provide an excessive RCS, as it had a metal structure inside. However, the measurements showed that the RCS of the test target is slightly lower when compared to real humans.

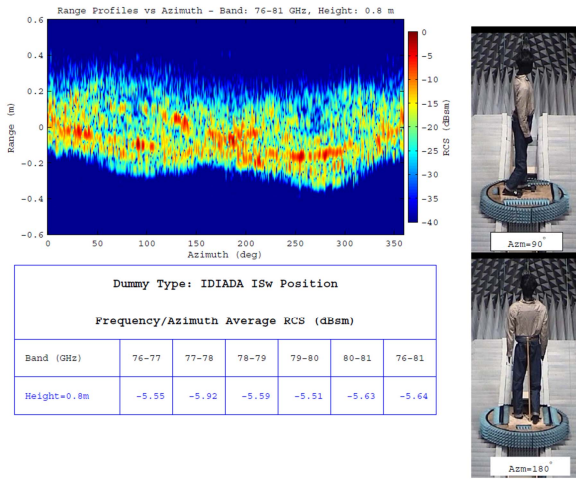
After this result, additional efforts were required in order to better match RCS of real humans. Fortunately, this was a relatively easy task, as RCS can be easily increased by adding reflective material. If RCS had been excessively high, the task would have been more complex, as shielding strategies with radar absorbers are not very efficient.

<u>Effect of RCS signature in walking posture</u> - Taking the opportunity brought by [10], the effect of the walking posture in the RCS signature was investigated. Figures 10 and 11 show the differences in the MSw and ISw positions of the walking cycle. It can be noted that RCS strongly depended on the posture of the pedestrian. Therefore, it could be stated that walking movement should be considered when implementing pedestrian detection tests in vehicles fitted with RADAR sensors.



Dummy Type: IDIADA MSw Position Frequency/Azimuth Average RCS (dBsm)						
Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-8.25	-8.57	-8.40	-7.88	-7.92	-8.20

Figure10. Articulated pedestrian test target RCS signature in the 76 – 81 GHz band, MSw position [10]



Dummy Type: IDIADA ISw Position Frequency/Azimuth Average RCS (dBsm)						
Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-5.55	-5.92	-5.59	-5.51	-5.63	-5.64

Figure11. Articulated pedestrian test target RCS signature in the 76 – 81 GHz band, ISw position [10]

This result also confirmed the indications of sensor and algorithm suppliers regarding the necessity of reproducing the walking movement of the pedestrians for more realistic test implementation.

Discussion and limitations

This research was implemented as collaboration between Applus IDIADA and other OEMs. The activities described in this paper are complementary to other research activities in this field, such as the AsPeCSS project (EC funded) and the vFSS project (supported by major German OEMs).

The issues addressed in this research do not overlap the results provided by these other projects; this has a more specific focus in the development of the test target and the definition of a standard methodology for radar signature measurement.

CONCLUSIONS

This paper has discussed the most relevant aspects to be considered for the development of a test methodology and the suitable test tools for testing pedestrian detection systems. As a particular case, the paper has also presented some of the activities implemented for the development of an articulated pedestrian test target with moving extremities and the validation results.

The most relevant aspects to be considered are:

- **Geometry**, including shape and size. The size of an 50% adult male and a 6 years old child was proposed by several sources and used in the developed test target.
- **Walking posture**. As proposed by several sources, the test target should represent a walking posture. Postures between MSw and TSw are the most representative for camera sensors.
- **Walking movement**. As an addition to the walking posture, the complete walking cycle provides a more realistic behavior and would allow better sensor performance. The relative movement of the extremities can be reproduced by different mechanisms. The developed test target was able to correctly reproduce the walking cycle.
- **Crashability**. The pedestrian test target should withstand impacts up to 60 km/h with no damage for the vehicle under test and the test target. In case the target has an internal structure, some mechanical fuses or joints might be required in order to allow some deformation with no damage during the tests.
- **RADAR signature**. The RCS signature of the developed test target was compared to real humans. The metal structure of the test target does not disturb the signal and additional reflectivity might be requested. RCS signature of pedestrians is heavily influenced by the position of the extremities. Therefore, walking movement capabilities should be considered when designing a representative test target.

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EVALUATION OF THE VISION BASED BLIND SPOT DETECTION SYSTEM MISJUDGMENT PERFORMANCE BASED ON ROADWAY CURVATURE

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Paper Number 13-0331

ABSTRACT

Even though state of the art technologies in assisting drivers to prevent accident or to minimize damages are currently adopted in most vehicles, few methodologies have been proposed in terms of evaluating the effectiveness and performance of those systems being operated in local roadway environment.
Those assistance systems would warn drivers' lack of awareness or carelessness through proper warning signal but fault or misjudgment in detecting an incidence often discourage customers and drive them away from relying on relevant systems.
The blind spot detection (BSD) system has been designed to warn drivers when adjacent vehicles are out of driver visible sight with close proximity.
At a certain curvature lane, even though a vehicle follows preceding one in the same lane, it would be located in the warning zone and might provoke an alarm.
A study objective is to evaluate the characteristics of BSD system in various curvature roads.
The roadway design standard with flat surface eliminating the effect from elevation is used in introducing curvature road. The vision based BSD system with lane width of 3.5m, lane radius of curvature as 110 and 125m is used. The BSD system detection criteria are applied referring to ISO 17387. The possibilities of system's misjudgment are based on the proportion of current lane area detected by the system within the detection range. The assessment of the area is found from analytical analysis or Monte Carlo method based on the geometry.
The BSD system performance is found to be characterized by lateral and longitudinal detection range, roadway width and curvature. The results show that the possibility of misjudgment increases as the curvature decreases. As the longitudinal detection range increases, erroneous measurement increases gradually and reaches sudden leap. The misjudgment trend with respect to lateral detection range shows similar variation.
The other parameters affecting the system performance might be current and following vehicle orientation, location, lane width, vehicle speed with different inter vehicle gap. Further study is encouraged.
Various calculation methods would be proposed for the assessment of overlapped area composed of lines and arc. Since the combination of geometrical disposition and operating condition would require detailed classification of cases for assessment purposes, more thorough studies are required.
Different roadway design like clothoid curve would require complex evaluation method other than simple analytical approach.
A vision base BSD system might cause malfunction and deteriorate the credibility that the driver assistance system has been accumulating. As for the misjudgment of system, similar analogy can be applied to different type of BSD system like radar based one. Studied results can be used to enhance the system reliability by adjusting the lateral and longitudinal detection range. Proper test procedures considering roadway design criteria and vehicle condition can be proposed for evaluating BSD system performance.

INTRODUCTION

Recently, lots of studies for Advanced Driver Assistant System(ADAS) aiding drivers in order to enhance vehicle safety have been conducted.
As one of many active safety systems, ADAS contributes in preventing accidents and reducing severity of damages. And the numbers of vehicles that adopt ADAS are increasing [1]. The most popular vehicle safety assistance systems that are

currently available are Adaptive Cruise Control (ACC), Automatic Emergency Braking System (AEBS), Lane Departure Warning System (LDWS), Lane Keeping Assistance System (LKAS), Active Head Restraint (AHR), Adaptive Front Lighting System (AFLS), and Blind Spot Detection (BSD)[2]-[7].

The role of BSD is to issue a signal warning a driver against imminent vehicles which are located in the zone where a driver cannot detect. In other words, it prevents an incident caused by a lane change maneuver when a driver cannot recognize adjacent vehicles.

BSD is mostly available to luxurious vehicles. Even though, due to the technological leap of the system, more affordable systems are expected to be available in the near future, tools to evaluate its performance are yet to be developed.

Even though the ADAS is to assist drivers, more studies are needed to be made to solve nuisance problems like frequent warning or false alarm. Most of the problems are caused by misdetection or misjudgment of the system. The misdetection is closely related with environmental elements like climate.

The causes of misjudgment can be related with domestic roadway conditions and sensor detection ranges [8].

At the curved road with minimal radius of curvature, even if an approaching vehicle from the rear is staying in the identical lane with current vehicle, it might be classified as an imminent danger since it is located in the detection zone (Figure 1). A false waning might be issued because of a misjudgment.

Studies for evaluating the characteristics of BSD with respect to various domestic curvature roadway conditions that might cause false alarm due to misjudgment

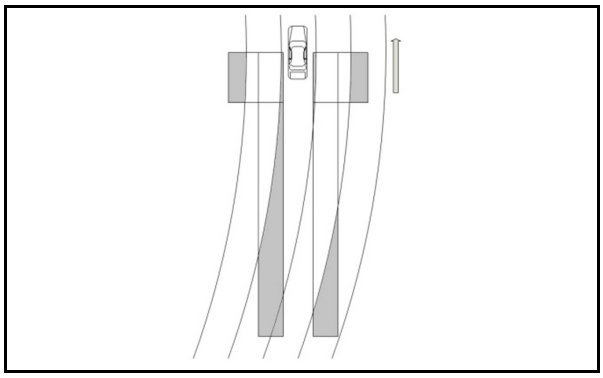


Figure 1. Misjudgment zone of blind spot detection systems

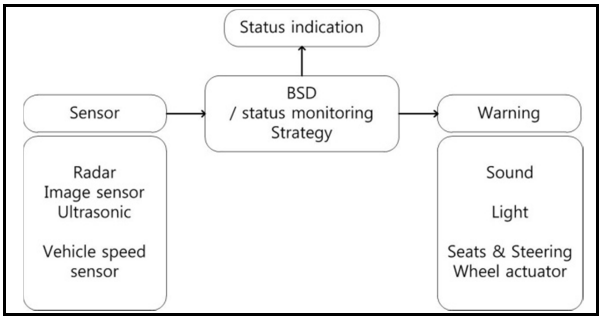
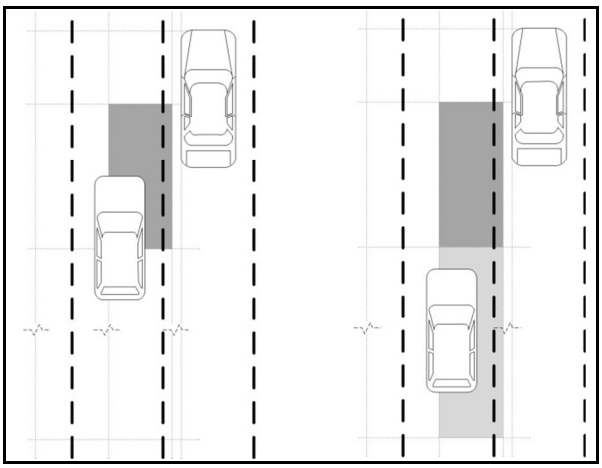


Figure 2. Blind spot detection systems



(a) Adjacent zones **(b) Rear zones**

Figure 3. Coverage zone of blind spot detection

BLIND SPOT DETECTION SYSTEM (BSD)

Typical BSD system has a detector which senses nearby vehicles and a processor which makes a decision based on collected data and issues a warning if necessary (Figure 2). In detecting vehicles, either optical or radar type are most frequent one[9]. The sensor detects closing vehicle speed and its relative distance. The processor monitors the whereabouts and movement of vehicle. If the vehicle is located in the warning zone, the system would decide the imminence of the detected vehicle.

The types of waning could be visual, audio and haptic. The detect zones defined in ISO 17387:2008 are adjacent zones and rear zones[10]. If any vehicle arrives to the predefined adjacent zone, a proper warning signal should be issued.

Contrast to that, a warning might not be followed depending on the BSD system when other vehicle is located in the rear zone.

ROAD ALIGNMENT

The fundamental design rule for roadway structure configuration includes road assortment, design speed and geometry structure.
Elements of roadway geometry structure including radius of lead curve, incline, super elevation, sight distance, rate of vertical curvature are the key factors governing the vehicle safe operation.
Along with the road design factors, roadway combinations along the longitudinal direction as straight line, transition curve and circular curve are properly allocated to accommodate vehicle operation. Vehicle factors affecting the roadway design are vehicle specification and vehicle speed. Typical vehicle data among available specifications are dimension of vehicle width, height, weight and wheel base distance (Table 1 for full size passenger vehicle). Depending on the vehicle speed that the roadway can accommodate, roads are classified as stated in Table 2.
According the roadway design criteria, minimum lane width is defined depending on the vehicle speed allowed in rural and urban area (Table 3).

METHOD OF MISJUDGMENT ZONE

Simulation Factors

The roadway specification is introduced base on ISO 17387 test condition. The vehicle test speed recommended in ISO 17387 is 72km/h. In order to guarantee the proper operation and detection of false warning in the curvature road, lane width of 3.5m is selected. The radius of curvature in ISO 17387 is defined to be 3 types as 125m, 250m and 500m depending on the other vehicle's closing speed. In practice, the actual roadway radius of curvature varies depending on the road sector reflecting nearby environment. In the exit, the minimum radius of curvature is set to be 110m for the speed of 60km/h[11]. Therefore, minimum radius of curvature as 110 and 125m reflecting the practical and ideal design criteria would be applied in the study. The vehicle type for the study is chosen to be the most popular full size passenger car. Driver's observing reference for the study is assumed to be at 3.66m from the vehicle front[12].

Assumption

Following assumptions are introduced for the simulation:

1) No malfunction in BSD device operation
2) Only the horizontal elements are considered in order to observe the characteristics of the BSD detection range with respect to the roadway geometry under the horizontal linear roadway design criteria.
3) The radius of curvature is decided based on the vehicle speed and lane width of the road
4) Vehicles are operated in the midst of the lane.

Selection of factors

Key parameters used for BSD simulation to evaluate its benefit in terms of reducing traffic accident are as follows:

1) Only the curvature factor is introduced among many available elements in horizontal linear roadway design criteria
2) The radius of curvature data are 110 and 125m.
3) Roadway is 3.5m in width and number of lanes are three
4) Vehicle type is full-size passenger car
5) The detection zones are based on ISO 17387 specification.
6) Full-size passenger cars eyellipse is located at 3.66m from the vehicle front

Table 1.
The specification of design vehicle

(m)	Width	Height	Length	Wheel base
Mid-size Passenger cars	1.7	2.0	4.7	2.7
Full-size passenger Cars	2.0	2.8	6.0	3.7
Trucks	2.5	4.0	13.0	6.5
Semitrailers	2.5	4.0	16.7	4.2 / 9.0

Table 2.
The Design speed of road

Road	Design speed (km/h)
Highway	100
Major Arterial	80
Minor Arterial	60
Collector Road	50
Local Road	40

Table 3.
The Design speed and lane width

Road	Design speed (km/h)	Minimum width of the road (m)	
		Province	City
Highway	≥100	3.50	3.50
road	≥80	3.50	3.25
	≥70	3.25	3.25
	≥60	3.25	3.00
	60≥	3.00	3.00

RESULTS

The BSD detection ranges can be stretched toward either longitudinal or lateral direction. With these configurations, there is a possibility that erroneous detection can occur due to the combination of roadway curvature and straightness of BSD range. Also the combination of roadway geometry and vehicle heading would produce different error results depending on either side of the vehicle.
The possible misjudgment zone as in Figure 1 can be defined as the overlapping area between the vehicle operation lane and the BSD system detection range. Therefore, rate of misjudgment can be evaluated by calculating the proportion of the zone with respect to the whole detected area. The area of misjudgment zone can be calculated by using either mathematical formula to be developed or geometrical configurations. In this process, factors like detection range, lane width and vehicle width are considered. Additional roadway design elements like clothoid shape instead of simple circular formula would add complexity to the simulation.
The misjudgment area is calculated using Monte

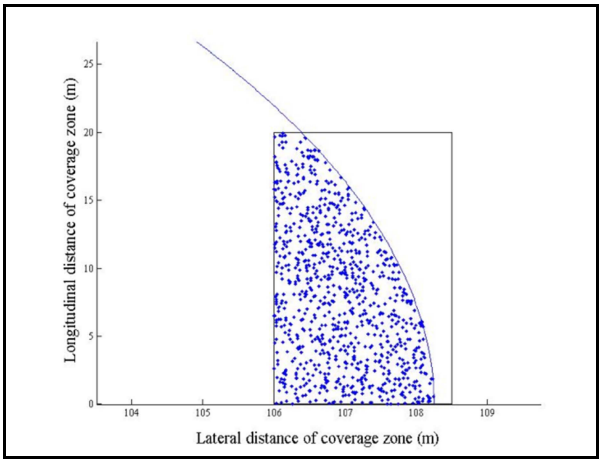


Figure 4. Misjudgment zone calculate by Monte Carlo integral

Carlo integral method as in Figure 4 using random numbers and assessing every counts falling in the designated zone. The BSD lateral detection range is stretched from the vehicle side to the maximum while the longitudinal detection range is extended from the eyellipse. The range increments introduced for the simulation are 0.5 and 1m for lateral and longitudinal direction respectively.
The result of misjudgment area rate towards longitudinal direction is displayed in Figures 5~8 while that towards lateral direction is shown in Figures 9~12 for the radius of curvature as 100 and 125m. Along each direction, at each incremental point unit square areal patch is examined to produce proportion of misjudgment area. Accumulated results are also displayed to evaluate the trend of misjudgment area.

The BSD system misjudgment possibility increases along the longitudinal direction as its range increases. As soon as the BSD system range reaches 25m in the longitudinal direction, all unit areal patch displayed that all detected result are false. As stated earlier, lateral directional characteristics in each side are not identical since the roadway environments on each side with respect to the vehicle are neither identical nor symmetrical.

The rate of misjudgment area on the left had side of the vehicle increases rapidly after the range of 10m (Figs. 5~6) while that on the right happens after 18m (Figs. 7~8). Since the simulation is based on the case where vehicle is driven to bear left, the possibility of misjudgment on the left is greater than that on the right. It would be vice versa. It refers to the result that the rate of misjudgment is naturally related with the roadway geometry.

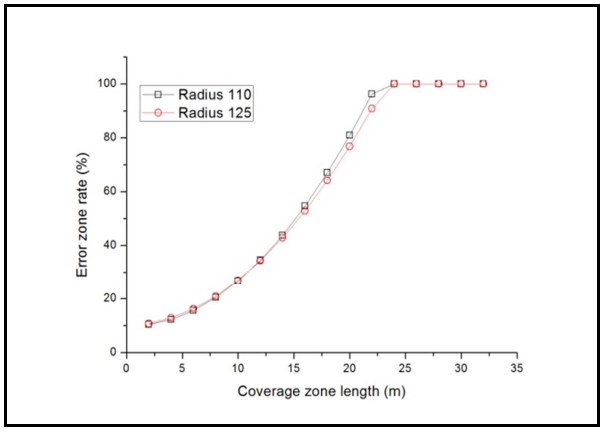


Figure 5. Error area rate of misjudgment zone per meter (longitudinal distance of left side)

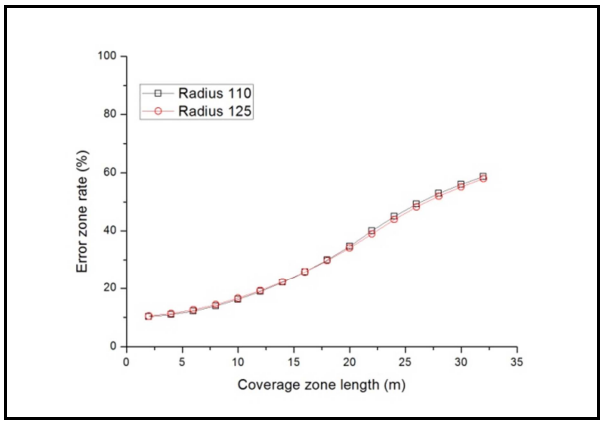


Figure 6. Misjudgment zone error rate for detection range (longitudinal distance of left side)

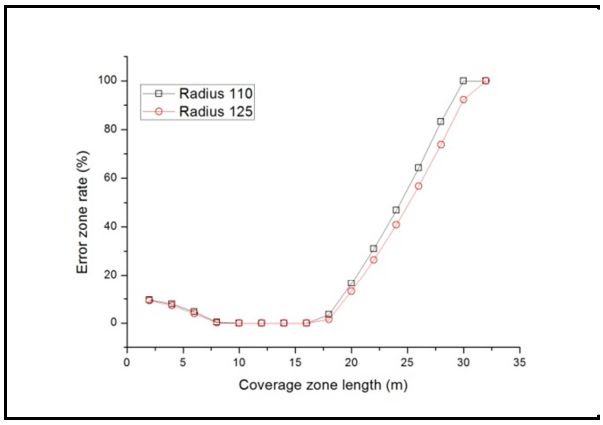


Figure 7. Error area of misjudgment zone per meter (longitudinal distance of right side)

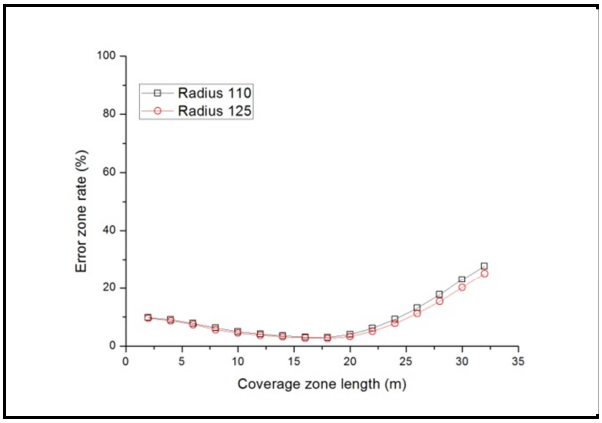


Figure 8. Misjudgment zone error rate for detection range (longitudinal distance of right side)

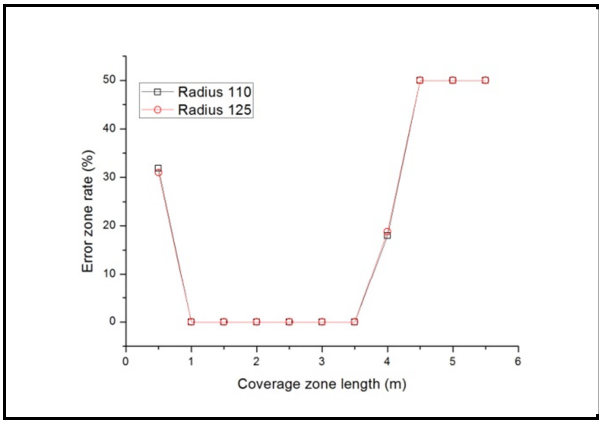


Figure 9. Error area rate of misjudgment zone per meter (lateral distance of left side)

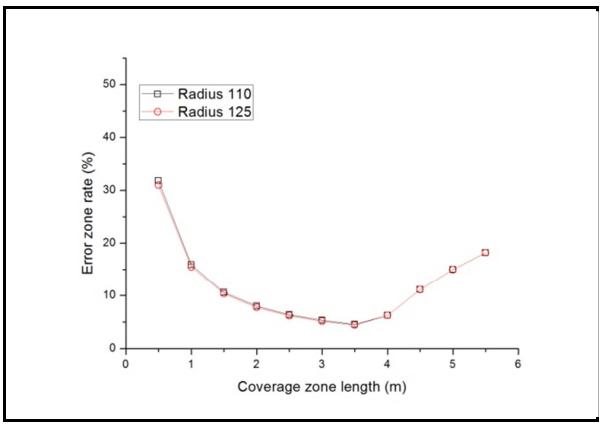


Figure 10. Misjudgment zone error rate for detection range (lateral distance of left side)

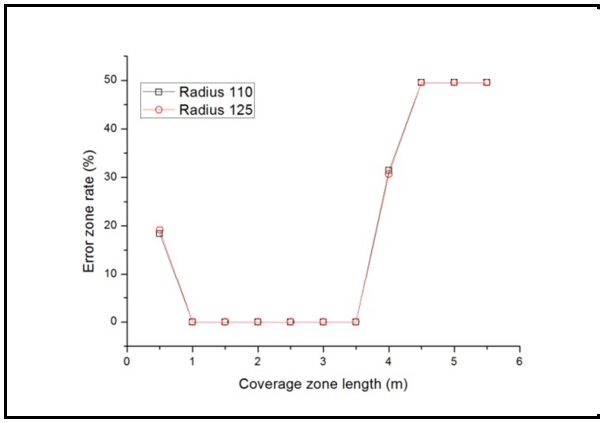


Figure 11. Error area rate of misjudgment zone per meter (lateral distance of right side)

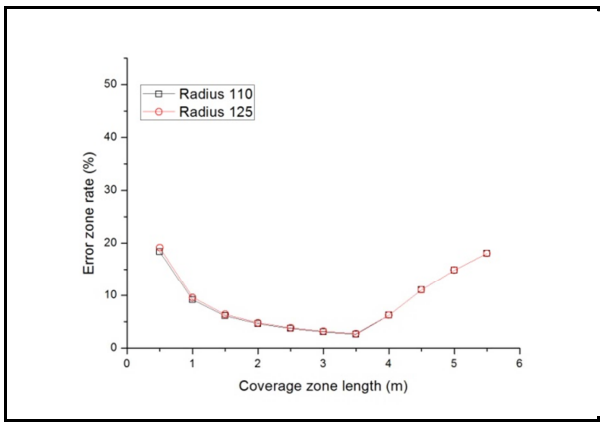


Figure 12. Misjudgment zone error rate for detection range (lateral distance of right side)

The results of lateral direction misjudgment rate are in Figures 9~12. The left side lateral directional results are in Figures 9 and 10 while those of right hand side are in Figures 11 and 12.

The trend of misjudgment rate shows that as the detection range increases the rate drops initially and then increases. The rate on either side varies almost identically with sudden increase after 3.5m detection range. Within the range in between 1m and 3.5m, no misjudgment would be expected since those ranges belong to the lane range next to the current vehicle.

The rate increases rapidly after 3.5m since the range stretches beyond the lane next the current vehicle. All vehicles detected in this range should not provoke a warning.

The accumulated rate trend displays almost identical trend except in the initial range. Actually, the rate observed on the vehicle's left shows minutely higher result compared to that seen on the vehicle's right. This is again the vehicle is driven on the road bearing to the left.

As for the radius of curvature effect between 110m and 125m, higher rate of misjudgment is observed in smaller curvature road.

CONCLUSIONS

The BSD system detection range characteristics have been analyzed for various roadway conditions. Misjudgment zone has been calculated considering linear roadway design factors and BSD system detection ranges. Detailed simulation has been conducted using Monte Carlo method. The major studied results can be summarized as:

1) The major factors affecting misjudgment are radius of curvature and BSD detection range.
2) The level of misjudgment rate could be assessed based on BSD detection range when the vehicle is on the curvature road.
3) Non-symmetric results for longitudinal detector range study results due to the roadway curvature direction would greatly contribute to enhance the system performance.
4) More elaborated implementation of BSD system is recommended in curvature road.
5) The longitudinal direction misjudgment rate results could be applied to set the maximum allowable detector range to prevent false reading.
6) The study results along lateral direction could be applied to limit the range of BSD system detector laterally.
7) More elaborated studies are required to assess the system performance reflecting more practical driving environment with external perturbation while driving.

ACKNOWLEDGEMENTS

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Detection of Driver Distraction Using Vision-Based Algorithms

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ABSTRACT

The risk of drivers engaging in distracting activies is increasing as in-vehicle technology and carried-in devices become increasingly common and complicated. Consequently, distraction and inattention contribute to crash risk and are likely to have an increasing influence on driving safety. Analysis of police-reported crash data from 2008 showed that distractions contributed to an estimated 5,870 fatalities and 515,000 injuries. This paper assesses the extent to which vision-based algorithms can detect different types of driver distraction under different driving conditions.

Data were collected on the National Advanced Driving Simulator from 32 volunteer drivers between the ages of 25 and 50. Participants drove through representative situations on three types of roadways (urban, freeway, and rural) twice: once with and once without distraction tasks. The order of the drives was counterbalanced. The three distraction tasks included a reaching task, a visual-manual task and a cognitive task which were

repeated eight times throughout the drive.

Four different vision-based algorithms were evaluated. All of them performed significantly better than chance (random) performance . There was little difference between the approaches for the visual-manual bug task which required the most eyes-off-road time. The algorithm that estimated level of distraction by combining percent of glances to the road and long glances away from the road performed best for the arrows task, and was also the only algorithm that detected cognitive impairment. Differences across road types were also observed. Trade-offs exist between ensuring distraction detection and avoiding false alarms that complicate determining the most promising algorithm for detecting distraction. The differences in the algorithms' abilities across evaluation criteria, road type, and distraction task type demonstrate critical trade-offs in capabilities that need to be considered. Depending on how feedback is presented to drivers, high false alarm rates may undermine drivers' acceptance of the system. The study shows the importance of designing and testing algorithms with a variety of challenges to assess performance across a range of representative road and task types.

INTRODUCTION

Driver distraction is occurring with greater frequency as in-vehicle technology and carried-in devices become increasingly common and complicated [1]–[3]. Consequently, distraction and inattention contribute to crash risk and are likely to have an increasing influence on driving safety. Analysis of police-reported crash data from 2008 shows that distractions account for 5,870 fatalities and an estimated 515,000 injuries [3]. It should be noted that the challenges of detecting distractions at the crash site and reluctance of drivers to admit to being distracted are a limitation for this method of estimating the linkage between distraction and injuries and fataliites. A naturalistic driving study found that distraction and inattention contribute to approximately 80% of crashes or near crashes [4]. The extent to which this generalizes from the small number of crashes that were observed in this study to the overall population of crashes remains unclear, but there is cause for concern even if the contribution is a fraction of that observed in this study.

Rapid advances in wireless, computer, and sensor technology present drivers with a range of new distractions. Not only are drivers managing their use of cell phones, CD players and navigation systems, they are increasingly engaged in long text message "conversations" and searches through MP3 music catalogs that can extend beyond 30 seconds [5] and involve more than 15 glances [6]. In the coming years, drivers will have the ability to retrieve a broad variety of information not only from the Internet via hand-held phones but also through dedicated connections in the vehicle itself. Rapid changes in vehicle design illustrate this trend: 90% of all new vehicles are compatible with MP3 players [7], all 2009 Chrysler vehicles have a wireless connection to the Internet [7], and several manufacturers introduced sophisticated Internet-enabled computers in vehicle consoles in 2010 [8]. Although these devices may have the potential to make driving more enjoyable, efficient, and potentially even mitigate drowsiness; they also have the potential to distract drivers. Helping drivers benefit from these devices and avoid distraction-affected crashes represents an important challenge.

Although efforts are afoot at state and federal levels in the US to regulate the use

of certain devices, such as hand-held cell phones, or distracting behaviors, such as the federal ban on texting by commercial truck and bus drivers [9], such regulation will likely lag behind the fast pace of technological change that is responsible for many distractions. A complementary approach that uses technology to detect and mitigate dangerous episodes of distraction, such as warnings based on long and/or frequent glances to an in-vehicle device, also has great promise in reducing the frequency and severity of distraction-affected crashes [10]. Such technological mitigations have been hampered by limitations of sensors and algorithms, but the increasing availability of improved sensor and computing technology have made more sophisticated systems possible.

The focus of this study is on the recent trend of using vehicle-based technology to combat distraction. It developed and assessed real-time distraction detection and mitigation systems to (1) guide technology development to enhance driver safety, and (2) identify potential evaluation techniques to characterize and assess this emerging technology. This paper will focus on evaluation of different algorithms for detecting driver distraction.

The overall objectives were to apply this evaluation to compare algorithm performance:

- Across road types
- Across different forms of distraction

METHOD

Participants

Data were collected on the National Advanced Driving Simulator from 32 volunteer drivers between the ages of 25 and 50. Participants drove through representative situations on three types of roadways (urban, freeway, and rural) twice: once with and once without distraction tasks. Additionally, 14 participants enrolled in the study but did not complete for various reasons.

To be eligible, participants were required to:

- Possess a valid US driver's license
- Have been licensed driver for one or more years
- Drive at least 3,000 miles per year
- Have no restrictions on driver's license except for vision
- Not have participated in simulator study in the preceding 12 months
- Have experience engaging in distracting activities while driving, such as talking on a cell phone, sending or receiving text messages, sending or receiving emails, eating, or changing compact discs

Procedure

After providing informed consent, each participant completed a demographic questionnaire that assessed their driving history, habits of interaction with distracting devices, and beliefs in their own capability as safe drivers. They then watched a presentation that described the simulator cab and the tasks they were to perform during their drives. Participants then completed three drives: an eight-minute practice drive, an experimental drive performing distracting tasks, and another experimental drive with no distractions (the latter two in a counterbalanced order) each with a duration of approximately 35-40 minutes. The practice drive acclimated the participant to the simulator and provided practice performing the distraction tasks.

After driving the urban, interstate, and rural segments, participants completed a visual-

analog scale assessing their subjective workload and performance (lateral and longitudinal control) for each distraction type. Standard simulator realism and wellness surveys were also administered after the drives, as was a post-drive survey about potential distraction mitigation strategies. A debriefing statement requesting that participants not discuss their participation with others until the end date for the data collection was provided to encourage participants to not share strategies they may have developed to perform the tasks while driving with other potential participants.

An incentive system (score) was used to encourage the participants to engage in the distracting tasks. The incentive was a function of overall task performance, including the time to initiate the distraction task, continuous attention to the task, and response accuracy. The experimenter provided scores out of 100 points to participants at the end of the three road segments in the drive with distraction tasks. Participants were told the tasks were urgent and instructed to complete as many tasks as possible while driving as they normally would.

Apparatus

The National Advanced Driving Simulator (NADS), shown in Figure 1, made it possible to collect representative driving behavior data from distracted drivers in a safe and controlled manner. The highest fidelity simulator in the United States, the NADS allowed for precise characterization of drivers' control inputs, vehicle state, driving context, and driver state during representative driving situations (see Figure 2). Eye and head tracking data is collected using a faceLAB 5™ eye tracking system.

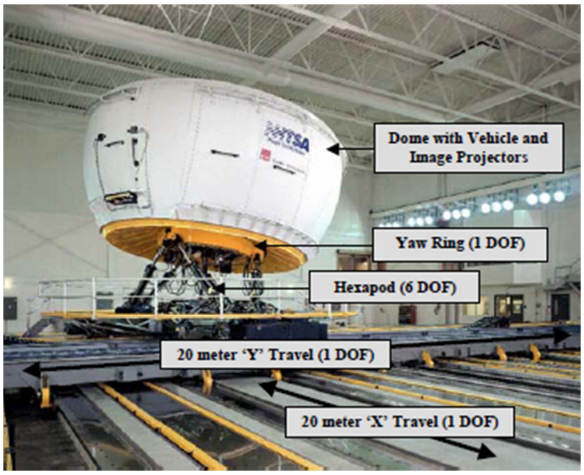

Figure 1. The NADS-1 high-fidelity driving simulator

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

Distraction Tasks

Three secondary tasks were chosen to reflect distracting activities in which drivers currently engage, like reaching toward the backseat or adjusting the radio, as well as future distractions that a distraction detection algorithm should detect. Based on the current trajectory of innovations for in-vehicle internet-based technologies and the proliferation of wireless "carried-in" devices that drivers use in vehicles, the specific activities drivers might engage in are likely to change quickly in the coming years. For this reason, generic tasks were prioritized over specific tasks that are linked to a

particular technology so that the results are more likely to accommodate the rapidly changing array of distractions that will confront drivers.

Three levels of distraction were chosen: a reaching task (bug), a visual/manual task (arrows), and a cognitive task (menu). The reaching task required drivers to reach to the back of the passenger side seat and follow a moving display with their finger similar to that used in the Crash Warning Interface Metrics program [11]. The visual/manual task was based on the arrow task used in the HASTE project [12], and presented drivers with a series of matrices of arrows on a three-inch diameter LCD touch screen located to the right of the steerig wheel. Participants had to review and discern whether or not a target arrow pointed in a particular direction was present in a field of distracter arrows. In the cognitive task, drivers traversed an interactive voice response menu that required them to respond to prompts from the system based upon information they were given concerning a fictional flight to determine if the flight was on time.

A self-paced radio task was also included but did not contribute to the protocol sensitivity analysis or algorithm evaluation except to indicate task engagement throughout the drive

Simulator Scenario

Each drive was composed of three nighttime driving segments previously used in other impairment research being conducted at NADS. 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 (see Figure 3 and Figure 4) with signal-controlled and uncontrolled intersections. An interstate segment followed that consisted of a four-lane divided expressway with a posted speed limit of 70 mph. After following a lead vehicle, drivers encountered several slower-moving trucks (see Figure 5) that prompted frequent lane changes. The drives concluded with a rural segment composed of a two-lane undivided road with curves (see Figure 6). A portion of the rural segment was gravel.

Distraction tasks occurred in counterbalanced blocks of three at eight points during the drive: thrice in the urban portion of the drive, twice on the interstate, and thrice in the rural portion.

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

The Algorithms

The four algorithms evaluated in this study were chosen for their ability to distinguish between distracted and non-distracted states using eye-tracking data. The algorithms increase in complexity, and only one is designed to detect cognitive distraction.

- Eyes off forward roadway (EOFR) estimates distraction based on the cumulative glances away from the road within a 6-second window.(Dingus, Neale, Sudweeks, & Ramsey, 2006).

- Risky visual scanning patterns (RVSP) estimates distraction by combining the current glance and the cumulative glance durations [10].

- AttenD estimates distraction associated with three categories of glances (glances to the forward roadway, glances necessary for safe driving (i.e., at the speedometer or mirrors), and glances not related to driving), and uses a buffer to represent the amount of road information the driver possesses [13], [14].

- Multi distraction detection (MDD) estimates visual distraction using the percent of glances to the road center (PRC) and long glances away from the road, and estimates cognitive distraction by gaze concentration focused on the center of the road. The implemented algorithm was modified from Victor [15] to include additional sensor inputs (head and seat sensors) and adjust the thresholds for the algorithm's variables to improve robustness with potential loss of tracking.

RESULTS

Performance of the algorithms was determined using receiver operator characteristic (ROC) approach. Plots of the ROC show the true positive rate and false positive rate for algorithms across a range of detection thresholds. The best algorithms would be represented by points in the upper left and the worst by points along the diagonal. The area under the curve (AUC) measures algorithm performance and is 0.5 for the diagonal and 1.0 for a perfect algorithm.

Capabilities by Road Type

Figure 7 - Figure 9 show ROC plots comparing the performance of the algorithms across the three road types. The MDD and the EOFR algorithms performed better than the RVSP and AttenD algorithms

across all road types. The EOFR and RVSP algorithms generally performed best in the urban environment, whereas the AttenD algorithm always performed best in the rural environment. None of the algorithms performed best on all metrics in the freeway environment.

For visual distraction, the MDD algorithm showed the best performance across all evaluation metrics (accuracy, precision, AUC). Although the EOFR algorithm had promising AUC values, the AttenD algorithm often yielded better accuracy and precision. The RVSP algorithm consistently yielded the lowest values for both accuracy and precision, but yielded a slightly higher AUC value than AttenD. All of the algorithms succeeded in detecting distraction well above chance detection (AUC = 0.5).

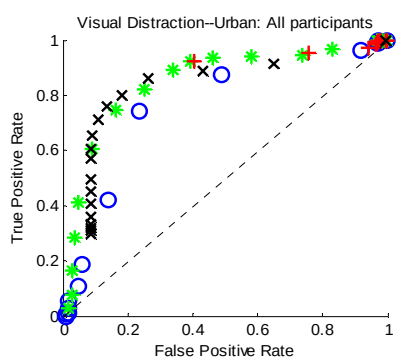

Figure 7. ROC plot in the Urban Environment for each algorithm for Visual distraction.

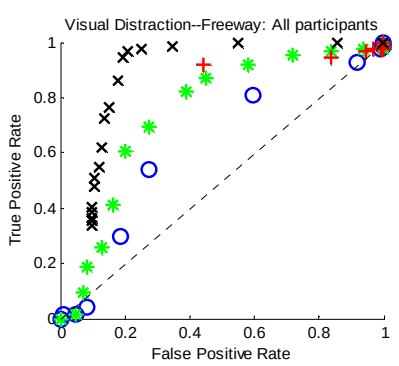

Figure 8. ROC plot in the Freeway Environment for each algorithm for Visual distraction

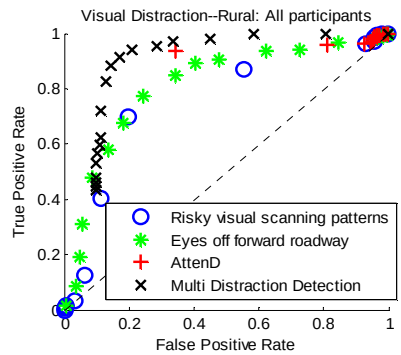

Figure 9. ROC plot in the Rural Environment for each algorithm for Visual distraction

Capabilities by Distraction Task Type

The performance of the algorithms varied by task, with little difference in performance for the looking and reaching task (bug) but more stark differences for the looking and touching (arrows) and cognitive tasks (menu). The AUC for each task for each algorithm is provided in Table 1.

Table 1. AUC comparisons by algorithm across tasks

		Algorithms			
		RVSP	EOFR	AttenD	MDD
Tasks	Arrows	0.67	0.75	0.71	0.87
	Bug	0.78	0.87	0.80	0.86
	Menu	n/a	n/a	n/a	0.68

The looking and reaching task which required the participants to turn to the backseat and follow an animated bug shown on a touch-screen display produced similar results across all four algorithms (see Figure 10). This is likely because performing the bug task sent a clear signal that the drivers' eyes were not on the road. All four algorithms performed the best during the bug task.

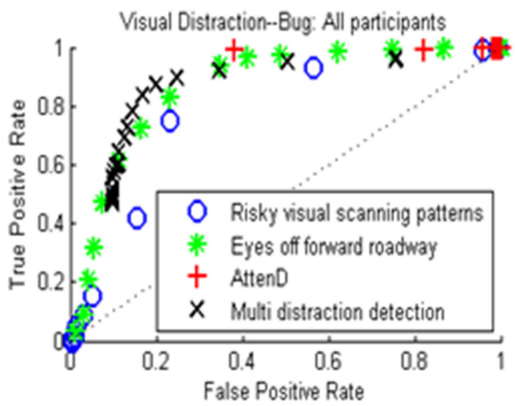

Figure 10. ROC plot for the looking and reaching task.

The looking and touching task required participants to scan a matrix of arrows located to the right of the steering wheel and identify a target. The MDD distinctly outperformed the other algorithms (see Figure 11). The AttenD algorithm yielded high true positive rates, but at the expense of high false alarm rates—the lowest false positive rate was 0.4. The two less complex algorithms (Eyes off forward roadway and Risky visual scanning patterns) performed similarly.

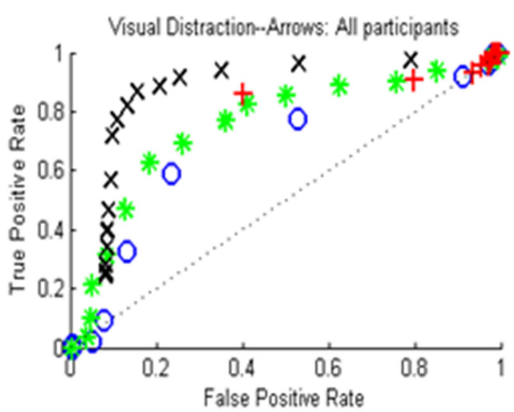

Figure 11. ROC plot for the looking and touching task.

The cognitive task required participants to access airline flight information and then to recall several pieces of flight information to determine whether a flight was on time without requiring visual attention. The MDD algorithm was the only algorithm designed to detect cognitive distraction and it did so imprecisely, but at a rate substantially greater than chance (see Figure 12).

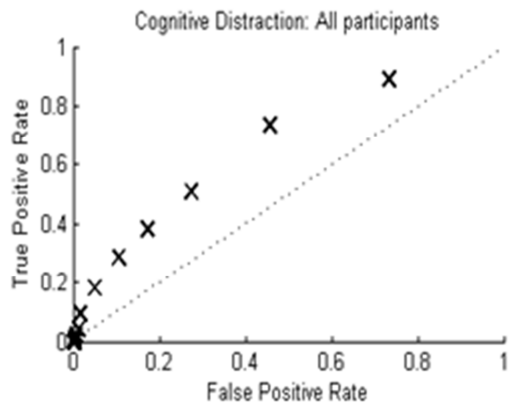

Figure 12. ROC plot for the cognitive task.

CONCLUSIONS

Considering the results of the ROC curves, AUC values, accuracy and precision, it is apparent that a trade-off exists between ensuring distraction detection and avoiding false alarms that complicates determining the most promising algorithm for detecting distraction. Depending on how feedback is presented to drivers, high false alarm rates could undermine drivers' acceptance of the system. For example, the AttenD algorithm consistently yielded high true positive rates, AUC values, accuracy, and precision, yet the lowest false positive rate exceeded 0.4. Choosing this algorithm for distraction detection would ensure detection of distraction, but it would also generate many false alarms. Depending on how this information is presented to drivers, such a high false alarm rate would likely undermine drivers' acceptance of the system.

This study demonstrates the ability for distraction detection algorithms to identify distraction with success rates much greater than chance. However, the differences in the algorithms' abilities across evaluation

criteria, road type, and distraction task type demonstrate critical trade-offs in capabilities that need to be considered. The study shows the importance of designing and testing algorithms with a variety of challenges to assess performance across a range of representative road and task types.

Further, the study shows that more complex algorithms can perform better, suggesting that additional driving metrics should be incorporated into future distraction algorithms.

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INNOVATIVE TEST METHODS AND FACILITIES FOR PREDICTIVE PEDESTRIAN PROTECTION

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ABSTRACT
The development of new forward looking sensor generations has created new possibilities in enhancing vehicle safety. The capabilities of forward looking sensors have been systematically extended from the recognition of well defined objects such as road signs to the identification and classification of other vehicles. New generations of forward looking sensors are now also able to detect pedestrians in different road traffic conditions.
Using these new sensors the car can be equipped with predictive protections systems. In predictive protection systems the sensor provides information on objects such as pedestrians to the vehicle, so that the vehicle can react by warning the driver, reducing speed or even braking or steering. Predictive pedestrian protection systems can thereby help to further improve the level of vehicle safety on the roads, especially with regards to vulnerable road users.
During the development of the related sensors and vehicle functions such as advanced autonomous emergency brake systems (AEB) it is key to have appropriate testing tools which help to validate the sensors and the safety functions of the vehicle. Different working groups especially in Europe have focused on the definition of system testing of AEB systems. Test scenarios have been derived from accident statistics and general design rules for the testing methods, test rigs and test methods have been established.
Continental has developed a testing environment which allows a qualified testing of different predictive pedestrian protection systems.
Based on a description of relevant test scenarios this paper refers to the tool chain required for testing of these protection systems. This testing environment consists of the following main elements:
1. Position reference system based on sophisticated transponder technology
2. Pedestrian Target Device (PTD) for a precise conduction of pedestrian tests with high repetition rate
3. Drive robot systems for precise vehicle path control

The paper discusses the usability of the described tool chain with regards to relevant test scenarios. A special focus is put on a new transponder based technology for the localization of vehicles and test objects. This technology has been developed by Continental as a result of the German research initiative Ko-TAG and applies a trilateration technique between transponders in the infrastructure and transponders attached to the moving objects to measure the precise position. Being less bulky than conventional localization systems, the transponder based localization can provide a localization quality which is similar to sophisticated DGPS systems. Moreover, due to its independence from satellite signals it can be applied on any test track and any test scenario, independent from the local signal quality of nearby satellites.

OVERVIEW PREDICTIVE PEDESTRIAN PROTECTION SYSTEMS

Pedestrian protections systems have been introduced in different stages within the last decade accompanied by succeeding tightening of the related rules and consumer group demands. These pedestrian protection systems can be distinguished in “passive” and “active” protection systems.

Passive pedestrian protection systems:
A basic passive pedestrian protection is nowadays provided through purposeful “softening” of the potential impact areas at the car front structure. This provides a basic protection for the pedestrian.

Active pedestrian protection systems:
These measures can be improved by the activation and subsequent inflation of damping elements for the softening of the pedestrian impact after the detecting of the collision. A straightforward and very robust sensor concept for the detection of the impact is the pressure tube of Continental, which will be integrated in the front bumper and allows a precise discrimination between use- and misuse-cases [1].

The above passive and active pedestrian protection systems have already led to a continuous reduction of the number of fatalities among pedestrians in Germany [2]. The underlying measures however cannot reduce the effect of the secondary impact when the pedestrian is colliding with the ground after the impact at the car. At least 25% of the serious and fatal injuries of pedestrian accidents are caused by this secondary impact [3]. In order to reduce the consequences of the secondary impact it is necessary to reduce the impact velocity of the car significantly before the impact of the pedestrian occurs. This ultimatively requires *predictive pedestrian protection (PPP) systems* which enable a speed reduction of the vehicle in advance to a collision by either initiating a specific driver warning leading to a driver intervention or by activation of an autonomous brake maneuver.

These systems however require a highly reliable detection and classification of the pedestrian in order to activate such a drastic maneuver. Different sensors can be applied for the solid pedestrian detection:
A pure mono camera system using a straightforward classification will be sufficient to initiate a driver warning. A sophisticated radar system could also be applied stand-alone. Besides of the precise distance measurement capability, the usage of sub-doppler information would allow the classification of a moving pedestrian.
The most reliable sensor systems for pedestrian protection, however are those which supply two complementary information: The distance to the object and the image information about the object. An appropriate and integrated sensor supplying such information is the stereo-camera as it is illustrated in the figure beneath.

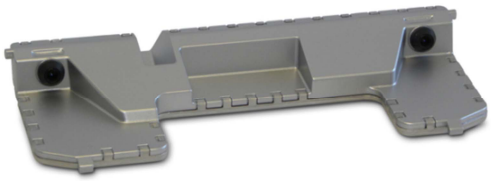

Figure1. Stereo Camera from Continental

This sensor technology seems to be the most promising for PPP systems. Thus significant development and qualification efforts had been spend within Continental to set-up this stereo-camera sensor. All system tests concerning the stereo-camera pilot project have been conducted with the tests rigs in the Continental Safety Park in Alzenau. These test methods and facilities will be explained in the following chapters.

TESTING DEMANDS

This document does not include the significant efforts which have to be performed for real-world testing but focuses on the development and qualification tests which have to be conducted at test tracks.

Test scenarios

In Europe two independent working groups (WG) , vFSS and AEB, have worked on the definition of test scenarios for predcitive pedestrian protection systems. Both WGs have set-up quite similar test scenarios for the testing of the Predictive Pedestrian Protection function. The initial test catalogue included crossing manouvers of the pedestrian with and without obstruction. The test vehicle could move either straight towards the crossing pedestrian or would conduct a turning manouver. These scenarios

derived from accident statistics are illustrated in the figure beneath.

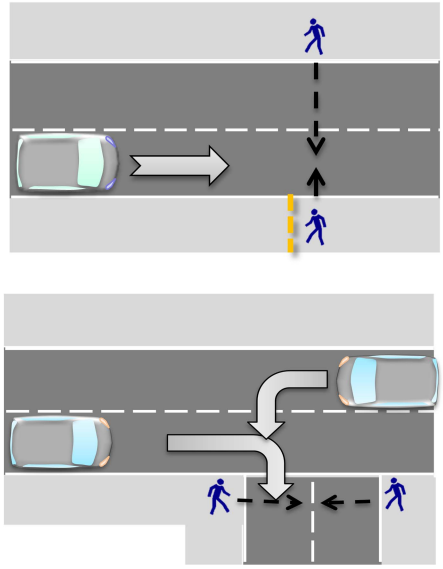

Figure2. Envisaged test scenarios for PPP testing

Currently only the scenarios with the straight moving vehicles are expected to be the requested scenarios. However the other scenarios with turning vehicle or with turning pedestrian remain interesting in order to proof the robustness of the system and might be conducted nevertheless.

Test dummies and boundary conditions for test conduction

Currently an adult dummy representing an 50% male person and a child dummy representing a 6-year-old child are selected as test devices.

Both dummy types have to fulfill minimum criteria with respect to the applied sensor. Thus the Radar cross section, the near-infrared characteristics and the general characteristics of the clothing have to be representative for a broad range of pedestrians. The values for these characteristics ar still under discussion.
The typical dummy types which are applied by Continental Safety Engineering are illustrated in the following figure

Figure3. Lightweight test dummies at Continental

The following test velocities are under discussion depending on the test scenario:

Vehicle speed range: 10 … 60 km/h
Dummy speed range: 5 … 10 (12) km/h

Currently the test tolerances are not specified for the accuracy of the test conduction. According to the latest test protocols of EuroNCAP with respect to Safety Assist Systems the following tolerances might be realistic:

- Collision speed + 1.0 km/h
- Lateral deviation from test path 0 ± 0.05 m
- Yaw velocity 0 ± 1.0 °/s
- Yaw acceleration 0± 4.0 °/s2
- Steering wheel velocity 0 ± 15.0 °/s

These tolerances might require the application of drive robots at least for release test campaigns.

TEST METHODOLOGY OF CONTINENTAL SAFETY ENGINEERING

Testing principles

System tests for Predictive Pedestrian Protection systems can be conducted with different test set-ups regarding the test specifications as explained in the chapter above.

The main trade-offs are firstly connected to the motion concept of the dummy: Cable way and hanging dummy or moving platform and standing

dummy. The second trade-off concerns the point whether a collision with the dummy can take place.

Cable-way Platform [4]

Figure4. Main pedestrian test facility concepts

Continental has selected a cableway concept allowing a dummy collision due to following reasons

1 Reproducability:
The cableway allows a precise movement of the dummy along the trails without any deviation. Different kind of curved trails allow nevertheless a variation of the dummy movement as it is illustrated in the figure beneath:

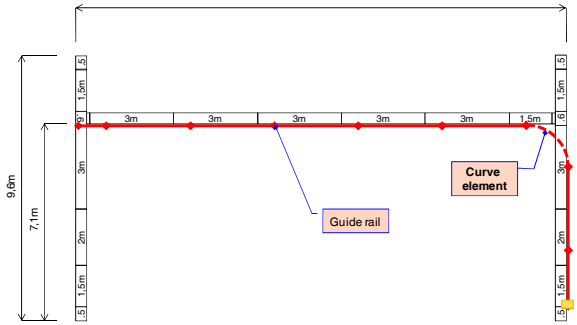

Figure5. Top View Test Rig

2 Repetition rate
The simplicity of the cableway concept allows a quick repetition of the test scenarios. The dummy can be moved quickly back into the starting position and the test can be repeated immediately.

3 Robustness:
The cableway concept with the decoupling of drive unit and dummy makes the system much more robust against malfunctions, allows lightweight dummies and thus allows test conduction up to dummy collisions.

4 Flexibility and extensions
The animation of the dummy limbs can be much easier achieved with a “hanging” dummy than with a standing dummy. This motion of the extremities might become a significant test condition especially for radar based PPP systems.

Test conduction

Predictive Pedestrian Protection tests in the Continental Safety Park are conducted following the master-slave principle. This principle has been described in [5] and works in the following way: The motion of the test vehicle initiates and controls the motion of the pedestrian dummy. In the most simple form the dummy motion will be initiated through a trigger signal when the test vehicle passes a light barrier. In order to achieve the right contact point between vehicle and dummy the motion of the dummy is started after a delay time which is calculated by using the measured velocity at the light barrier. The speed of the test vehicle is either kept constant by using an already in the car integrated speed limiter or by using a throttle control, if accessible or by using a pedal-drive robot.

If the vehicle speed shall be left variable, an online velocity measurement has to be applied to adjust the dummy motion then accordingly. This is currently not implemented at Conti Safety test facilities.

If the test shall be conducted with a high lateral accuracy the test vehicle will be equipped with a steering robot unit to keep the vehicle on track with a lateral deviation of maximum 2 cm. Also dedicated evasive maneuvers for false positive avoidance tests can be properly conducted with this steering robot.

Figure6. High-g steering robot system in the Continental Safety Park

TEST RIG

The Pedestrian Testing Device (PTD) in the Continental Safety Park is a cable way system as it is illustrated in the figure beneath.

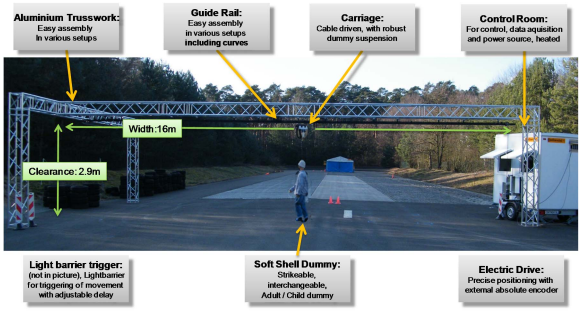

Figure7. Pedestrian Testing Device (PTD) at Continental Safety Park

The main structure consists of a gantry made of truss elements. The rail system of the cableway is attached underneath the truss elements. The rail system can consist of curved and straight elements, such that the dummy motion can be either completely straight or can include turning maneouvers. The regular set-up in the Continental Safety Park includes one curve which allows the simulation of a veering pedestrian.
The rail system guides a trolley unit which can be moved by a cable control system. The pedestrian dummy is attached to this trolley in the following way: At the trolley a hinge unit is attached which allows the upwards movement of the dummy when a collision with the test vehicle will take place.
The dummy itself is attached to the hinge by using a robust CFRP rod. The height of the dummy over ground can be adjusted by shifting the rod within the hinge unit.
Usually the proofing ground has usually a certain curvature for “water outlet”, This curvature can be adapted by adaptation of the distance between rail and truss elements. Thus the dummy feet will remain close to the ground throughout the entire path length of the dummy motion.

Figure8. Attachment of the Pedestrian Dummy at the trolley

The dummy motion is controlled by using a revolving rope which is powered by a variable transmission unit which itself is driven by an electromotor. The transmission ratio can be adapted to achieve different speed ranges of the dummy. The electromotor is controlled by a standard PC unit. With this computation unit different motion profiles can be pre-progammed varying the distance, speed and accelerations. The motion profile is initiated by the car motion as explained above. This set up allows the following performance data of the dummy motion:

Performance data	**Value**
Max. acceleration	5 m/s²
Max. deceleration	10 m/s²
Max dummy velocity	15 km/h

Table 1 Performance data dummy motion

Most of the cable-way based dummy test facilities struggle with unfortunate osciallations of the dummy caused by acceleration or eventually occurring gusts. These oscillations are suppressed in the PTD facility in 2 ways: The stiff structural attachment of the dummy to the cableway using the CFRP-rod and the rigid hinge element reduce the low-frequency oscillations. An active control mode of the motion control software additionally suppresses further unfortunate oscillations.

The PTD facility shall allow tests with various sensors of PPP systems. Besides of camera based systems also Radar based systems shall be testable. Thus the PTD had been optimized with respect to Radar reflections. The Radar cross section has been minimized by using stealth technology to cover the test rig. The test rig with the stealth sheets enables now a clear visibility of the dummy in the radar raw data. The test rig is invisible to the applied Radar sensors.

Figure9. PTD with stealth sheets

TAG-BASED REFERENCE SYSTEMS

Development and testing of modern driver assistance systems makes it essential to get highly accurate positioning data of all objects involved in the test. To meet this demand with adequate effort, Continental has developed a landmark-based positioning system.

The basic task is quite common an there have been lots of different approaches which can be seen in [6]. The most common approach is the use of satellite guided positioning systems (GNSS) since these systems are used for different daily navigation tasks (vehicle, marine and aircraft). But accuracy of these systems is heavily dependent on the availability of a sufficient number of satellites and for adequate positioning offset correction data is needed. So if either not enough satellites are available or no correction data is received precise positioning is not possible.

Here the Continental system is located. It is intended to provide a navigation solution in areas with weak GNSS availability which is comparable in quality for a reasonable price.

The basic measuring principle of the system is the distance measuring of radio waves using the round trip of flight principle (RTOF). Despite of the pure time of flight (TOF) measurement principle this technique has the advantage that the distance measurements can be clearly assigned to the radio tag. Further the used correlation principle gives the ability to determine the measurement quality. The system operates at a frequency of 2.4 GHz and reaches under optimal conditions a standard deviation of 4.7cm. Measurement hard- and software have been developed within the research project Ko-TAG, detailed information can be found in [7] and [8].

The position system setup is as follows: Eight radio tags are placed around the testing ground on precisely measured landmarks. Each tag is equipped with two antennas in different heights. This has the advantage that two distance values for each landmark are measured and ground interference effects can be corrected due to plausibility checks of both distances. Counter-part to the radio tags on the roadside is an onboard unit (OBU) which calculates the position directly on the measurement object. Differently to [9], where the angle of arrival (AOA) is used, the Continental positioning system is based on pure distance data. This brings the advantage that the antenna can be kept much smaller since no antenna array for the DoA is needed. Also the field of view of the system is wider (360° compared to 120°) since an omnidirectional antenna can be used.

To calculate the actual position out of the single distances each value is tested for plausibility and forwarded to a trilateration algorithm which calculates a raw position value. This value is then used as input for a Kalman-based position filtering based on a constant velocity model. [10]

Before the predicted position in the filter is corrected by the measurement value it has to match a certain gating criteria. The gating value is the Mahalanobis distance between the predicted value and the raw position value. Since there is no directly measured speed the speed is taken into account which would have been needed to reach the measured position based on the prior filtered position.

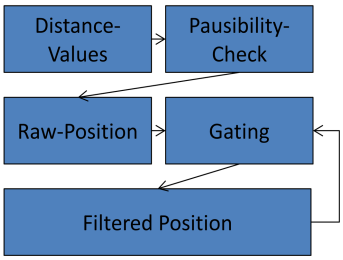

Figure10. Functional diagram of the position filter process

In addition to position filtering the Kalman-filter is used to derive dynamic values as velocity and heading of the measured object.

To test the quality of the system it was set up on the area of the Continental Safety Park in Alzenau, Germany and the positioning data was compared to the output of a corrected GNSS system. Since the standard deviation of this system is 2cm this deviation was not taken into account for the quality benchmark.

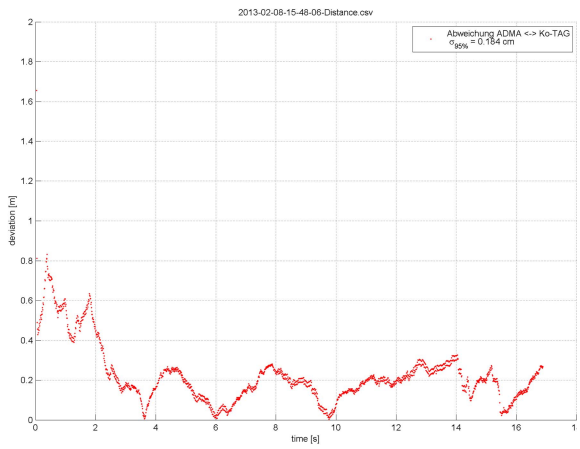

Figure11. Benchmark result

As a result it can be said that after the startup-process (within first 3s) the system offers track-accurate positioning in combination with an affordable effort. The smaller installation effort makes it possible to equip not only vehicle but also real pedestrians or in the case of the Continental Safety Park testing devices like the moving target device (MTD) or the pedestrian target device (PTD).

CONCLUSIONS

A new generation of forward looking sensors enables sophisticated predictive pedestrian protection systems. The accurate identification and classification of pedestrians by the forward looking sensors is a prerequisite for any predictive pedestrian protection system.
The Continental Safety Park, situated in Alzenau, Germany, provides a wide range of state of the art test tools which are developed to test active vehicle safety functions such as predictive pedestrian protection systems. This paper describes a newly developed tool chain which is focusing on these protection systems. The tool chain consists of the following elements:

1. Position reference system based on sophisticated transponder technology
2. Pedestrian Target Device (PTD) for a precise conduction of pedestrian tests with high repetition rate
3. Drive robot systems for precise vehicle path control

The paper describes the underlying technology of the tool chain as well as its usability. Based on the discussion of state of the art test scenarios the Pedestrian Target Device reveals the following advantages:

- accurate representation of all state of the art test cases
- robustness for high repetition rates
- precise control for dummy movement
- flexibility with regards of usage of different dummy types
- flexibility for extensions such as different movement patterns of the dummy
- facilitation of dummy animation (feets and legs)
- collision of dummy possible without damage to dummy or ego vehicle
- Damping of dummy oscillation

Additionally the paper describes the usage of transponder based technology which supports a precise localization of the ego vehicle and the dummy during the tests. Due to the transponder technology this technology is independent of any GPS based localization. This is a significant advantage for many test tracks. Finally, the paper presents the application of a sophisticated drive robot system which helps to automate the movement of ego vehicle during repetitive tests. The combination of the describe tools has proven to be accurate, robust and cost effective for the extensive testing of different kind of Predictive Pedestrian Protection Systems. Thus with this tool chain the Continental Safety Park provides an ideal testing environment to support present and future development programs for the further enhancement of vehicle safety for pedestrians.

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DEVELOPMENT OF AN ASSESSMENT PROTOCOL FOR AFTER-MARKET SPEED LIMIT ADVISORY DEVICES

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ABSTRACT

Advisory Intelligent Speed Assist (ISA) systems are those that integrate data about vehicle location with information about the speed limit of the current section of road and direction of travel, and which will alert the driver if the speed limit is exceeded.

We examine the potential of after-market portable navigation devices (e.g., smartphones and portable satellite navigation devices) to inform drivers about posted speed limits and to assist them to travel within the speed limits. Data sources include ISA effectiveness studies, manufacturer's product specifications, GNSS signal and device positioning theory, information related to performance characteristics and method of operation of GNSS signal emulators, digital speed limit maps provided with ISA-related software and human factors research associated with in-vehicle alerts.

At the time of the research project there were no standards or assessment protocols directly relevant to assessing after-market ISA devices therefore a draft assessment protocol was developed. It was found that it is feasible to assess and rate the performance of after-market ISA devices in an objective and repeatable manner. It is estimated that the better performing devices could reduce fatal and serious crashes by around 19% assuming widespread fleet penetration. An analysis of various implementations scenarios shows that a modest uptake in advisory ISA enabled PNDs is required to break even on implementation costs.

INTRODUCTION

This paper examines the potential of after-market portable navigation devices ("PNDs", e.g., smartphones and satellite navigation devices, commonly known as 'Sat Navs') to inform drivers about road speed limits and to assist them to travel within the speed limits. While the primary functionality of PNDs is wayfinding, many devices incorporate additional functions such as points-of-interest (POIs) and speed limit information.

Intelligent Speed Assist is any system that constantly monitors vehicle speed and the local speed limit on a road and implements an action when the vehicle is detected to be exceeding the speed limit. Advisory ISA systems are those that integrate data about vehicle location with information about the speed limit of the current section of road and direction of travel, and provide an alert to the driver if the speed limit is exceeded. Feedback may be an audible alarm, a visual signal, haptic feedback such as a vibrating throttle pedal, or a combination of these.

This paper is based on a research project conducted for the New South Wales Centre for Road Safety. The scope of the research was limited to portable advisory ISA systems available for retail purchase that include a database of road speed limit zones. OEM devices, customised products, prototype devices or products for other vehicle types or non-road environments were out of scope.

BACKGROUND

Advisory ISA devices that provide information to drivers about the posted speed limit have been available for more than 5 years in Australia. Many models of PND include a display of the current speed limit for a road section. Most models on the market provide the option to indicate to the driver (via an audible or visual signal) when the vehicle exceeds the displayed speed limit.

Several applications for 'smartphones' are available that also display the speed limit and generally will provide an alert to the driver if the speed limit is exceed by a specified amount.

It is apparent that there are varying degrees of performance between different products on the market. These variations can be due to the capabilities of the hardware, the coverage or accuracy of the speed zone information, the design of the software or a combination of these.

Unfortunately, it is very difficult for consumers to differentiate between the performance of different

products on the market as technical information for these systems is not readily available.

It is postulated that a consumer scheme, which assesses and compares the performance of devices on the market then provides the assessment results to consumers, would allow consumers to make a more informed purchase. The scheme may also motivate manufacturers to improve their products by subjecting the performance of their products to public scrutiny in direct comparison to their competitors. The scheme would also provide a mechanism for objective feedback to manufacturers in specific areas in which their products could readily improve to be of most benefit to consumers.

The scheme may also increase uptake of advisory ISA devices as customers who would have otherwise not purchased an ISA product may become aware of the capabilities and benefits of ISA products.

STATE OF ADVISORY ISA MARKET IN AUSTRALIA

Retail environment

There are numerous PNDs (including smartphone devices with navigation applications) on the Australian market with the potential for ISA and these are identified to consumers at the point of sale through packaging and marketing material using terminology such as 'Speed Assist', 'Speed Alert', 'Speed Warnings' or 'Speed Sign Alert' and pictorial information such as the commonly recognized speed sign pictogram for Australian roads (black text on white background inside a red annulus).

Some products include statements such as

- 'Never drive too fast again' (Navigon)
- 'Alerts you when you're speeding, even if you're not in navigation mode' (TomTom GO 1050
- 'Speed Sign Alerts will make sure you're driving at the right speed to avoid trouble' (Navman Ezy30)
- 'Knows the exact speed limit where you are. Knows how fast you are traveling. Alerts you when you are speeding' (SpeedAlert)

Some manufacturers provide video demonstrations or explanations of how devices work at point of sale (on a screen or on the device itself).

Retail staff knowledge of ISA products was found to be poor, with incorrect claims made about several products, poor knowledge of coverage and an inability to differentiate between poorer or better performing devices (based on coverage, alert type and accuracy of zones).

The variety and inconsistency of marketing terminology along with paucity of technical information on how the systems work and poor sales support means that the market is currently confusing for consumers.

While some models retail for several hundreds of dollars many models were available below AU$200. This pricing is much less than is common for the cost of factory fitted vehicle navigation systems.

Device types and functions

Most devices on the market had a compatible cradle or dock in which the device could be mounted for use in a vehicle. The most common mounting method was the use of a suction cup and bracket, however some systems used vehicle cigarette sockets for mounting (and also for power supply). These mounting methods were designed for installation without tools by the consumer.

All ISA devices on the market use both audible and visual alerts to indicate when the vehicle is travelling above the legal posted speed limit. Often the user can select to disable these alerts. In most cases devices used an image of black text on a white background inside a red annulus to display the current speed limit, however some devices used different visual indicators for the speed limit. Intensity of alert, duration of alert, volume of audible alerts and size of visual alerts vary from device to device. There are more than 12 brands currently on the market with at least three major suppliers of speed zone data (Whereis, Metroview and Navten).

Each device identified on the market had the capability to receive updated speed limit data, either by CD (available from the manufacturer) or via file download from the Internet.

DEVELOPMENT OF A RATING SYSTEM FOR ISA DEVICES

The purpose of the rating system is to clearly and concisely convey to consumers information about how devices perform as advisory ISA devices.

Possible rating methods include descriptive ratings (e.g. 'Good', 'Marginal', 'Poor'), numeric ratings (e.g. a score or a percentage), a star rating (e.g. 4 out of 5 stars) or an endorsement (e.g. Pass/fail, tick of approval).

Principles for selection of a rating system

An ISA device *rating system* should:

- Clearly discriminate between good and poor performers
- Spread the field so that marginally performing products can be differentiated from the good performers
- Be credible and easily recognized as associated with road safety
- Be associated with ISA stakeholders
- Be simple and easily understood by the target audience
- Be familiar to consumers
- Allow consumers to obtain further information if they wish
- Be easy to reproduce results consistently across various media (i.e., results can be reproduced consistently in brochures, websites print and television advertising)
- Be attractive for journalists and others to use
- Be a single credible source of the information
- Be relevant and viable in the long-term (future proof)
- Use a method that has been proven to be effective
- Meet community expectations

DEVELOPMENT OF AN ISA ASSESSMENT SYSTEM

Principles for the assessment system

The following principles have been identified to guide the development of the assessment system.

- Devices which lack fundamental features or minimum performance should be prevented from achieving high scores
- Test methods should test one aspect of the device's performance only
- Tests should be quick as possible to conduct
- Tests should be fair, repeatable, objective and relevant
- The same test method should apply to all devices
- Tests should not advantage/disadvantage any device (i.e. there should be a 'level playing field)
- Tests should be performance based where possible
- Criteria should allow for discrimination between products available on the market
- Tests should be robust and be free from any 'loopholes' that manufacturers may exploit to improve a score
- The tests program should be efficient and allow quick turnaround as the product lifetime of PNDs is relatively short (it is important to get information to consumers while the device is still a current product)

Furthermore, the following operating procedures are recommended.

- That if any aspect of performance or use which may compromise safety becomes apparent, then relevant information be reported to consumers
- That devices be tested in their default state (i.e., 'out of the box') unless the assessment requires the changing of a default parameter
- That any ISA functionality that engages at greater than 10km/h over the posted speed limit not be assessed (i.e., the maximum speed over the posted limit for testing is 10km/h).
- Where devices allow the threshold to be customisable and set by the driver, the factory default settings will be used.

Assessment options, issues and benefits

Testing of ISA devices has the potential to be complex, resource intensive and time consuming. ISA devices may have many features and settings therefore the testing should allow all options to be evaluated in a way that provides an accurate assessment of real world performance.

Simply testing ISA devices on public roads is one means of assessment, however it is resource intensive, may be affected by environmental conditions and carries some safety risk to the assessors. Furthermore, the issue of how to test on-road without exceeding the speed limit must be adequately addressed.

An alternative identified method to test ISA devices in a laboratory environment involves the use of a Global Navigation Satellite System (GNSS) simulator that is able to record and replay location data collected during actual road trips. The use of this device has the following advantages over on-road testing:

- Less susceptible to environmental effects
- Testing is highly repeatable with each device subjected to exactly the same test scenario
- Lower resource and labour requirements
- Reduced OHS risks
- Tests can be conducted in a shorter timeframe
- If a test must be redone it is possible to recreate the scenario easily

- The ability to record test conditions and results with great detail and accuracy
- Ability to simulate exceeding the speed limit using software
- Testing can be carried out far from the geographic region of interest

GNSS simulation allows the capture of GNSS satellite transmissions (e.g., GPS satellite transmissions) by capturing the exact signal a GNSS device receiver would receive and recording the signal for later playback (in the laboratory). The signal is captured by driving a route of interest, so that a real world GNSS signal is obtained and downloaded via laptop into a memory storage device (e.g., an external USB hard disk). An advantage of a GNSS simulator is that it can be used to modify the captured data (acquired at legal speeds) to include episodes of speeding. This enables the alerting functions of the device to be tested in the laboratory. Since the captured signal is stored each device being assessed can receive exactly the same test signal, allowing objective comparison between results. If necessary the exact signal can be replayed if an assessment item needs to be rechecked and the same signal can be reused for later assessment phases.

Tests that could be conducted using a GNSS simulator include:

- GNSS receiver sensitivity
- Minimum time to GNSS fix (warm start, cold start)
- Alert triggering and lag
- Alert types and settings
- Map completeness and accuracy
- Positioning accuracy
- Out of area functionality
- Error detection (frequency and duration)

Performance based assessment method

It is envisaged that one outcome of an ISA assessment program is that manufacturers are encouraged to develop improved products in the future.

Since future advances in location and human-machine interface technology are likely it is preferable that motivation for the development of ISA devices (which are fundamentally a location based human-machine interface) is not constrained by current technology or popular design characteristics. How a device performs its function is more critical than meeting specific definitions or conditions. As such a performance based assessment method is recommended so that new and better ideas can emerge without being constrained to meet limiting definitions.

AUSTRALIAN ISA FEASABILITY STUDIES AND COST BENEFIT ANALYSES

Paine (2009) included a review of earlier studies of ISA effectiveness. Since that time a trial of ISA advisory systems has been completed by the NSW Centre for Road Safety in the Illawarra region south of Sydney (NSW Centre for Road Safety 2010).

This trial involved 104 vehicles fitted with an advisory ISA system. Analysis of data collected during the trial found that 89% of drivers of vehicles fitted with the ISA device reduced the amount of time they previously spent exceeding the speed limit. Reduction in speeding in all speed limits was observed, as was a reduction in mean and median speeds. It was estimated that there would be an 8.4% reduction in fatalities and a 5.9% reduction in injuries for the region in which the trial was conducted if all vehicles were fitted with advisory ISA. The estimated saving to the community was between AU$39 million and AU$63 million.

Subsequently, the University of Adelaide Centre for Automotive Safety Research (CASR) published a cost benefit analysis (CBA) of advisory, supportive and limiting ISA systems (Doecke and Woolley 2011). For advisory ISA systems a reduction in all crashes of 7.7% was estimated, equating to an estimated saving of over AU$1.2 billion per year.

Even with the most conservative discounting rate applied (8%) an advisory ISA system on the Australian retail market returned a benefit cost ratio of 1.92 with a payback period of 4.3 years and a break even price of AU$511. Since this time a free smartphone ISA application from the same developer of the above system has become available in Australia.

In 2011, CASR (Doecke, et al, 2011) also published an economic analysis of four advisory ISA systems including two dedicated ISA devices (i.e., the devices have no other functionality) a portable navaid system with ISA functionality and an OEM installed in-vehicle multimedia system with ISA functionality. The estimated crash savings for the analysis were based on the results of the Illawarra trial (above) and the Kloeden risk curve for travel speed (Kloeden et al 2002). The study concluded that advisory ISA has the potential to reduce casualty crashes in government fleets by 20% in each Australian state (the two Australian territories were not included in the analysis).

Further analysis of the NSW ISA Trial results by

CASR determined that if all Australian vehicles were fitted with an advisory ISA device then serious injuries could be reduced by 19.3% and fatalities reduced by 18.9% (Creef, et al. 2011)

Benefit Cost Analysis

It is not possible to predict the total number of devices that might be used through a successful ISA rating program. However the costs and benefits derived above can be used to estimate the minimum number of devices that will need to be used in order for the ISA rating program to break even. That is, the number of devices that will produce societal crash cost savings which match the discounted costs of the ISA rating program. This number was derived by entering present-value data in an Excel spread sheet and using the Goal-seek function of Excel to calculate the number of devices needed to produce a benefit-cost ratio of one.

Benefit-cost ratio = Present value of net annual savings / Initial cost of scheme

It was estimated that the scheme would cost AU$180,000 to implement. Annual costs depend, in part, on the marketing effort that is put into promoting the scheme, while annual savings depend, in part, on the effectiveness of the recommended devices. Various scenarios were evaluated as shown in Table 1.

Using a five year evaluation period and a 4% discount rate (Doecke & Woolley 2011), the net annual savings (NAS) need to be at least AU$40,433 for the scheme to break even (PV of AU$40,433 = AU$180,000 = initial costs).

It is evident that a very small proportion of the total PND market needs to be influenced by the rating program in order for the scheme to break even. Annual sales for PNDs alone are estimated at more than 800,000 across Australia (Gallagher, 2010). NSW sales are roughly 250,000 so the 1,552 devices needed for Scenario A to break even represent just 0.6% of annual sales.

The numbers of devices needed for the scheme to break even remain relatively low even if some of the assumptions are varied, as shown in Table 1. Based on this analysis the prospects of the rating program having a very high benefit/cost outcome are excellent. For example, the B/C would increase to 10 if, under Scenario A, 5543 devices were put into use instead of the break even number of 1552. This is considered feasible as the main purpose of an ISA rating program is to influence buyer choice - not to convince them outlay money for an expensive device. The prospective buyers have usually already made a decision to buy a PND and it seems likely that devices/applications with a good rating will cost no more than poorer performing devices.

TRIAL ASSESSMENT OF SAMPLE ISA DEVICES

A trial assessment of four ISA devices (currently available on the Australian market) against selected assessment criteria was carried out.

The purposes of the trial assessment were to demonstrate the feasibility of the scoring system and to identify practical issues that may arise during assessments. The trial assessments were designed to determine if the assessments are repeatable, relevant and objective.

Four devices were assessed against twenty selected criteria. There was one smartphone based ISA application (Device A) and three PND based ISA products (Devices B, C and D).

Trial Assessment Method

Devices were tested on-road in a scenario similar to how the devices would be commonly used. Functionality was observed in use and where necessary settings were checked via the device menus.

Trial Assessment Criteria

For selection of the trial assessment criteria the following principles were followed:

Table 1. Break even calculation for several scenarios (in AU$)

Scenario	Set-up cost	Annual cost	No. in use for break even	Est. annual crash savings	Net Annual Sav & PV	B/C
A. Low marketing ($30K/year)	$180,000	$101,000	1552	$141,433	$40,433 $180,000	1
B. High marketing ($100K/year)	$180,000	$171,000	2319	$211,433	$40,433 $180,000	1
C. Low (1/3rd) effectiveness, low marketing	$180,000	$101,000	4638	$141,433	$40,433 $180,000	1
D. Low marketing, 3 year eval period	$180,000	$101,000	1820	$141,433	$40,433 $180,000	1
E. Low marketing, 6% discount rate	$180,000	$101,000	1577	$143,731	$42,731 $180,000	1

- Criteria were selected to include assessment of key parameters but with consideration of the ease and repeatability of testing (noting that the purpose of the trial assessments was to demonstrate the feasibility of the test method and had certain limitations).
- Assessments where environmental conditions could significantly affect results were avoided.
- Criteria were not chosen to provide differentiation between devices (i.e., criteria were not selected to show that any device performs better or worse than any other and was not designed to highlight or penalise any particular feature).

Furthermore, some of the selected criteria related individually to the performance of the device hardware, speed limit data or software performance. This was to examine whether it was feasible to assess hardware, data and software performance separately as it is possible that software and/or data may be compatible with multiple hardware devices in future.

The 20 criteria selected for the trial assessment are included in Appendix A1.

Trial Assessment Scoring (Rating)

For each criterion devices were scored in accordance with the observed performance and obtained 3 points for a good result, 2 points for an acceptable result, 1 point for a marginal result and 0 points for a poor result. If an item could not be assessed the device was awarded a default score of 3. (For Device A it was not possible to travel through an active school zone during the test).

All points awarded were summed to provide a final score for each device.

For the trial assessment the numeric score for each device was used to differentiate performance and provide a rating. A higher score represented better performance and a better rating. The maximum possible score achievable was 60 and the lowest score achievable was zero.

Trial Assessment Results

Table 2 shows the results of the trial assessments. Note that for the purpose of the assessments it is not necessary to compare the devices scores in detail as the trial assessment criteria only represent a partial list of the potential assessment criteria (if a more complete set of criteria were applied the scores could vary significantly).

Table 2. Trial Assessment Results

Criteria Description	DEVICE			
	A	B	C	D
Must include school zones*				
Must display current time				
Displays vehicle speed				
Displays current speed limit				
Displays correct speed limit for school zones when zone is active				
Provides driver with alert when speed limit is exceeded				
School zones enabled as default				
Audible Alert volume				
Redundant/back up location system				
School zones - correct time/day of operation				
Electronic variable signs				
New speed zone alert				
Default application				
Alerts are enabled as default				
Default tolerance of alerts				
Minimum alert tolerance				
Maximum alert tolerance				
Unit can only fit into limited number of vehicle models				
School zones can not be disabled				
Driver interaction required				
Score (max possible score 60, min possible score 0)	**47**	**41**	**50**	**25**

* Temporal speed limits apply in some Australian states.

Key to results

(3) Good
(2) Acceptable
(1) Marginal
(0) Poor
(3) Not Assessed

Discussion of the Trial Assessment

Subject to the limitations of the trial assessments as stated previously it is evident that there is variation between the selected devices. In several criteria there are substantial differences and therefore scope for improvement. A consumer education program that uses the assessment method outlined above does have the potential to encourage manufacturers to improve devices.

Furthermore, in many criteria where a device has achieved less than a 'Good' result, another device has achieved a better rating, which suggests that improvement in these areas is technically possible.

In a practical sense, the assessments appeared repeatable, relevant and objective.

Investigation as to whether the on road tests could be replaced by a laboratory based method concluded that each of the criteria could be assessed in a laboratory using a GNSS emulator system. Furthermore it was apparent that resource requirements, particularly the time to carry out assessments would significantly decrease for laboratory based assessments. It was concluded that the trial assessment outcomes would not have been altered using a laboratory based assessment.

While selected assessment criteria were used for the trial assessment a more complete set of assessment criteria are required for a consumer rating program.

It was possible to assess aspects of the systems hardware, software or speed data performance independent of each other and it seemed feasible that, if desirable, sub-ratings for each of these could be generated. This would allow for the rating of software packages compatible with multiple hardware devices (e.g. a smartphone application that can be used on several different models of phone). The trial assessment scoring was not weighted at all. If priority areas of assessment were identified a weighting could be applied to related criteria (e.g. as a method to encourage good performance in this area).

While a simple numerical score was used in this case to rate the devices it may be desirable to use a different method for a consumer rating program. One rating method that appears appropriate is a star rating system as used by New Car Assessment Programs (NCAPs) and for rating the quality of hotels. This system appears a good fit as it is

- widely recognised
- capable of differentiation between poor and good performers
- simple to understand
- already has an association with safety due to the use of star ratings for NCAP

CONCLUSIONS

It is feasible to assess and rate the performance of after-market ISA devices in an objective, relevant and repeatable manner.

The assessment process can be structured to assess hardware performance, speed-limit map performance and software performance separately.

It appears technically possible that all of the assessed devices could improve performance in some areas.

It is estimated that based on an advisory ISA system that performs well that fatal and serious crashes could be reduced by more than 19% assuming widespread fleet penetration.

The cost of many devices is comparatively low (when compared to factory fitted navigation systems or comparable electronics) and as such are very affordable. The relatively low cost, and minimal installation requirements mean that these systems can be taken up by consumers very quickly.

Furthermore, these devices are available on the market and speed limit data can be readily updated.

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APPDENDIX A1. TRIAL ASSESSMENT CRITERIA

Table A.1 Trial Assessment Criteria

Criteria Description	Good	Acceptable	Marginal	Poor
Must include school zones	Includes School Zones	NA	NA	Does not includes School Zones
Must display current time	Displays current time	NA	NA	Does not display current time
Displays vehicle speed	Displays Vehicle speed	NA	NA	Does not display Vehicle speed
Displays current speed limit	Displays current speed limit	NA	NA	Does not display current speed limit
Displays correct speed limit for school zones when zone is active	Displays correct speed limit for school zones when zone is active	NA	NA	Does not display correct speed limit for school zones when zone is active
Provides driver with alert (audible/visual/haptic or combination) when speed limit is exceeded	Provides driver with alert when speed limit exceeded	NA	NA	Does not provide driver with alert when speed limit exceeded
School zones enabled as default	School zones enabled as default	NA	NA	School zones not enabled as default
Audible Alert volume	Easy to hear alerts over loud vehicle/traffic noise on default setting	Alerts sometimes difficult to hear over loud vehicle/traffic noise on default setting	Alerts sometimes difficult to hear over normal vehicle/traff ic noise on default setting	Constantly difficult to hear alerts over normal vehicle/traffic noise on default setting
Redundant/back up location system	System has back up location system that requires no infrastructure	System has back up location system that requires infrastructure	System has no back up location system	
School zones - correct time/day of operation	Enables school zones at correct school time only on school days and differentiates school zones from other speed zones audibly	Enables school zones at correct school time only on school days	Enables school zones at correct school time OR only on school days but (but not both)	School zones enabled permanently (irrespective of time of day or date) or does not differentiate school zones audibly from other speed zones

Criteria Description	Good	Acceptable	Marginal	Poor
Electronic variable signs	Detects variable zones and informs driver of default speed	NA	Detects variable zones but does not inform driver of default speed limit	Does not detect variable zones
New speed zone alert	Audible alert distinguishable from other alerts and visual alert	Audible alert not distinguishable from other alerts (select if only one type of alert)	Visual alert only	No alert
Default application	ISA is the default (or only) application on the device (select for smartphone ISA applications where ISA is enabled as default for the application)	ISA is not default but can be selected in one simple action (no need to refer to instructions) except for smartphones (see 'Good')	ISA is not default but can be selected in two simple actions (no need to refer to instructions)	ISA is not default and is selected in more than two steps or steps are not simple (need to refer to instructions)
Alerts are enabled as default	Alerts are enabled as default	NA	NA	Alerts are not enabled as default
Default tolerance of alerts	0km/h tolerance as default	1km/h tolerance as default	2km/h tolerance as default	>2km/h tolerance as default
Minimum alert tolerance	0km/h	1km/h	2km/h t	>2km/h t
Maximum alert tolerance	2km/h	5km/h	10km/h	>10km/h
Unit can only fit into limited number of vehicle models	Device cane likely be fitted to all models of vehicle	Device can likely be fitted to most models of vehicle with some exceptions	Device can be fitted to limited models of vehicle (greater than 50 current models)	Device can be fitted to limited models of vehicle less than 50 current models)
School zones can not be disabled	School zones can not be disabled	NA	NA	School zones can be disabled
Driver interaction required	Driver does not need to interact with device at all during use	Driver may need to interact with device, single touch, ISA functions still run	Driver may need to interact with device, single touch, ISA functions temporarily disabled	Driver may need to interact with device, multiple touch

Safety Potential of ADAS – Combined Methods for an Effective Evaluation

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ABSTRACT

This paper addresses the research question, how the depending criteria effectiveness, acceptance, controllability and functional safety of advanced driver assistance systems (ADAS) can be evaluated and considered already during the vehicle development process starting at a very early stage.

On the basis of a systematic overview and classification on safety evaluation methods an ADAS development and evaluation process is introduced, in which system, vehicle, driver and the traffic environment are either represented virtually or experimentally.

This evaluation concept, called "circuit of critical driving situations" provides a methodological connection of the mutual dependencies between system effectiveness, acceptance, controllability and functional safety.

The necessary interaction of competences and scientific disciplines is described, in order to implement this approach, namely vehicle technology, psychology and functional safety.

INTRODUCTION

While accident numbers are decreasing in Europe, still over 1 Mio people worldwide are killed in traffic accidents [1]. Half of the deaths are vulnerable road users (pedestrians and cyclists) [2]. Due to the change in mobility behaviour, urbanization, increasing fuel prices and the introduction of electric scooters and pedelecs it is expected that the share of vulnerable road users will increase among the killed individuals [3].

Next to the improvement of passive safety the introduction of advanced driver assistance systems (ADAS) and active safety systems in the market increases road safety. ADAS offer a substantial safety potential, since they are based on one or more sensors perceiving the environment and/or traffic around the vehicle. After interpreting the information, ADAS inform, warn, support or intervene in order to assist the driver in performing the driving task. A positive influence of these systems can be found in accident statistics. An example is the first significant statistical proof of the high safety potential for such a system for electronic stability systems (ESP, DSC) on basis of German accident data [4]. Adaptive cruise control (ACC) and brake assistance also show an accident reduction potential of 20 % within a study of 800 vehicle collisions according to [5].

Since the perception and interpretation of traffic and road parameters is a highly complex task which cannot be fulfilled without faults, ADAS may not always be able to assist the driver in a critical situation and seldom act in situations which do not appear critical to the driver. In very rare cases a system fault may lead to an adverse behaviour of the vehicle, which needs to be controlled by the driver – unless the consequences of this system fault are covered by functional safety.

The acceptance of these systems is growing slowly [6], [7], [8], [9], since manifold systems are hardly integrated in terms of human machine interface (HMI) and function. The initial interaction with these systems when first driving a vehicle may result in an additional burden to the driving task of the driver. Systematic approaches for improvements of the interaction concepts [10], [11] are limited by the car maker's strategy to market every single system separately.

Further integration and enhancement of today's systems will also increase the future need for evaluation and validation, which already by today exceeds costs for development of these systems. Therefore a structured evaluation process is required, which facilitates the effective evaluation of ADAS. This causes three major methodological challenges:

- The first challenge refers to the definition of relevant driving situations, which form the basis for a valid system evaluation.
- A second challenge is due to the fact, that during the process different representations of driver, vehicle and traffic situation need to be used, in order to efficiently combine virtual and experimental methods.
- The third challenge is caused by the mutual dependencies between system effectiveness and acceptance on the one hand, and controllability and functional safety on the other hand.

Therefore the objective is to provide an effective ADAS development and evaluation process, combining a limited number of interconnected evaluation methods, which is also in accordance with ISO 26262.

In the following, relevant evaluation methods are presented and discussed and finally combined forming an effective evaluation process.

ADAS CLASSIFICATION

A methodical approach for the classification of ADAS is a formal description of these systems. In accordance to the levels of the driving task the driver can be supported or replaced on the navigation, guidance and stabilization level by different assistant systems. Figure 1 visualizes the three levels of the driving task as input for the control loop driver - vehicle - environment.

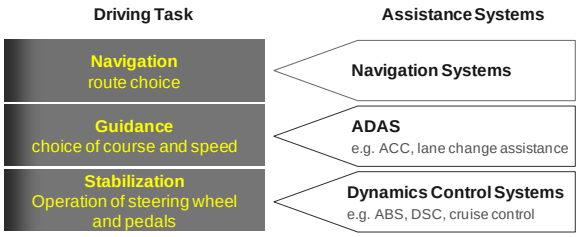

Figure 1. Classification of assistance systems on the basis of the three levels of the driving task.

First prerequisite for competent interaction with ADAS is an active role of the driver in the control loop (Figure 2).

The driver needs to be able to take the final decision independent on the level of support he is receiving by the vehicle's systems. Second prerequisite for competent interaction is that he can perceive all relevant information in time, thus enabling him to anticipate the future development of the traffic situation.

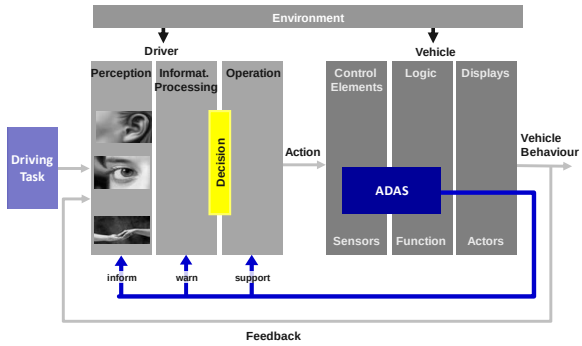

Figure 2. ADAS control loop.

In general the driver can provide an individual and varying amount of cognitive resources depending on physiological preconditions, driving education, experience and current conditions. Depending on the complexity of the driving task the cognitive resources of the driver cover the demand of all levels of the driving task. In critical situations the guidance level and the stabilization level require increasing cognitive and physical resources. With increasing traffic density the driver may first overlook traffic signs relevant for navigation. Increasing variance in traffic speed may lead to safety critical distances. If the driver is not able to react appropriately on the stabilization level, an accident may occur. Therefore the goal of ADAS is to provide the appropriate support, e.g. ease monotonous tasks (traffic jam) or issue warnings/interventions (Figure 3).

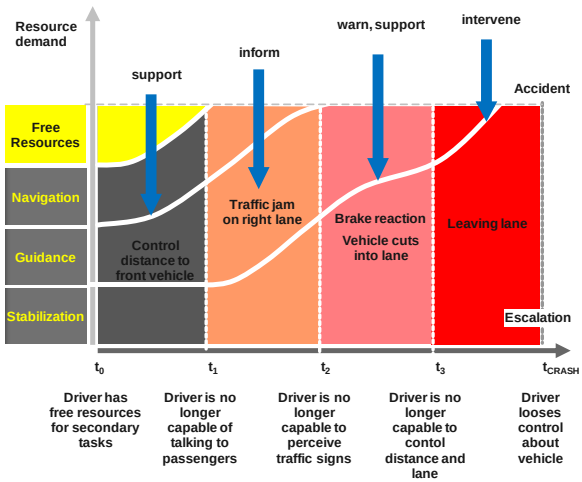

Figure 3. ADAS provide time to act appropriately and de-escalating driving situations.

Especially the analysis of the driving task on the stabilization level reveals that the driver is a controller in the control loop ‘driver-vehicle-traffic’. He compares set and current values and tries to compensate deviations by adapting control variables of the vehicle (Figure 4).

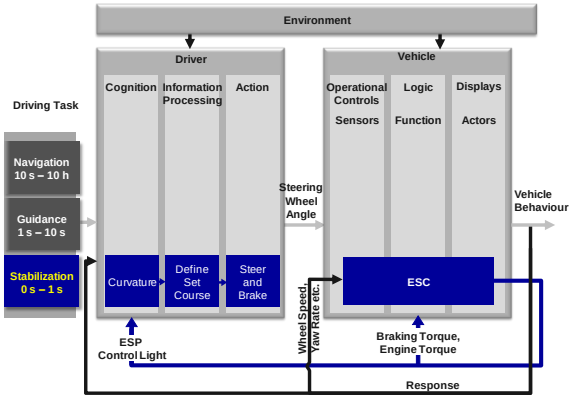

Figure 4. ADAS control loop for safety systems, e.g. ESP.

Also his driving tasks on navigation and guidance level can be seen as control tasks (Figure 5). The system ‘driver-vehicle-traffic’ is thus a closed loop system consisting of driver, vehicle and surrounding environment.

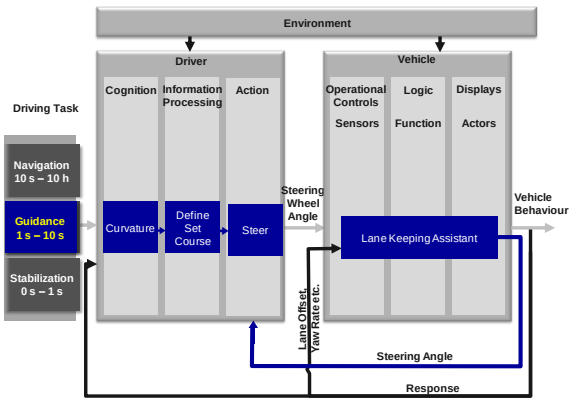

Figure 5. ADAS control loop for comfort systems, e.g. lane keeping assistant.

The three elements of the control loop are the main focus of methods for effective evaluation.

ADAS EVALUATION METHODS

In order to evaluate ADAS a variety of methods is already being used today. Due to the progress during the vehicle development process, they use different representations of the driver, the vehicle and the traffic situation.

Classification

As Figure 6 shows, one can distinguish easily between evaluation methods using four levels of abstraction. These basically differ according to the fact, whether the three elements of the control loop ‘driver-vehicle-environment’ are represented by a virtual simulation model or are real. In general validity increases when combining more and more real elements leading to field operational tests (FOT), where normal drivers interact with real (instrumented) vehicles driving in public traffic.

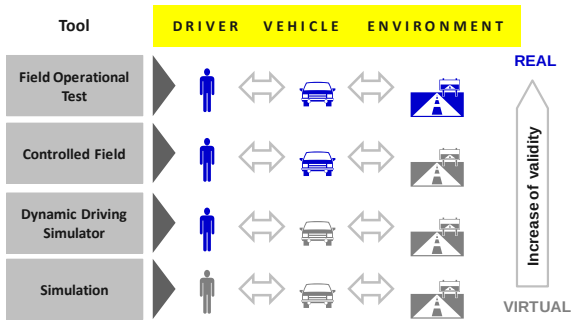

Figure 6. Classification of evaluation method, virtual elements in grey, real elements in blue.

In the controlled field test a real driver is driving a real car, but the traffic situation is ‘simulated’ in terms of a test environment. Using a driving simulator a real driver is sitting in a simulator mock-up, while the vehicle behaviour and the traffic are simulated using high performance simulation tools. If all three elements of the traffic control loop are represented by mathematical models, the result is called a traffic simulation.

Description of Tools

At a very early stage only an abstract system concept exists which is based on a system idea often resulting from analyzing accident statistics. In-depth accident analysis reveals weaknesses in the interaction between the three elements driver, vehicle and environment. This concept is to be designed according to the Code of Practice for the Design and Evaluation of ADAS [12].

The system concept is often depicted in a model (e.g. implemented in MATLAB/Simulink) and can be used in order to simulate the systems effect on traffic flow and traffic efficiency using **traffic simulation software**. This software should be able to depict driver behaviour, environmental conditions and vehicle dynamics in order to yield sufficiently valid results. Especially driver models for different situations (following, lane change, intersections etc.), driving styles (e.g. aggressive, defensive, reaction times, brake forces) and different conditions (traffic density, sight, velocity regulations etc.). A good example is the simulation tool PELOPS (Program for the DEvelopment of LOngitudinal Traffic Processes in System Relevant Environment) [13]. Modelling driver behaviour is a research topic on its own, which has been solved in PELOPS by analyzing many experiments. Another major challenge using a traffic simulation tool is the representation of relevant driving situations, which are infinite in number.

Since traffic simulation can only give results on the effectiveness of a system but not on usability and acceptance, the driver model needs to be replaced by a sufficiently large population of drivers at an early stage in the development process, which can be achieved by using a **driving simulator**. *Figure 7* shows the dynamic driving simulator at ika, which consist of a simulator dome containing the vehicle mock-up, which is being moved by six electromechanical actuators, controlling six degrees of freedom according to the driving situation.

Figure 7. ika dynamic driving simulator.

Driving Simulators have many advantages, but also limitations, which largely depend on the specific simulator concept. Important advantages comprise that a traffic situation is identical for every subject (reliability) and that highly critical situations can be depicted with no danger in a very efficient way. Limitations result especially from the validity of the motion cuing, which is usually not sufficient in order to investigate questions regarding vehicle dynamics. The present ika driving simulator has been optimized in order to evaluate ADAS under normal driving conditions. In order to obtain statistically meaningful results, the number of traffic situations which can be analysed is fairly limited.

Since vehicle dynamics can only be depicted to a limited extent in today's driving simulators, **controlled field tests** are an important methodology in order to obtain more valid results on a system's effectiveness. An overall methodology for the technical assessment is provided in the European research project interactive [14].

On the other hand the prerequisites for this method are rather high: the system's functionality needs to be integrated in a suitable test vehicle, the traffic situations need to be 'simulated' by appropriate means and a test track is needed with sufficient space in order to guarantee for the safety of all persons involved. *Figure 8* shows a slap car on the ika test track, which is used for the evaluation of collision mitigation or autonomous emergency braking systems.

Figure 8. Slap Car on ika test track.

Figure 9 shows the final layout of the Aldenhoven Testing Center (ATC) which is currently being built with the support by ika [15].

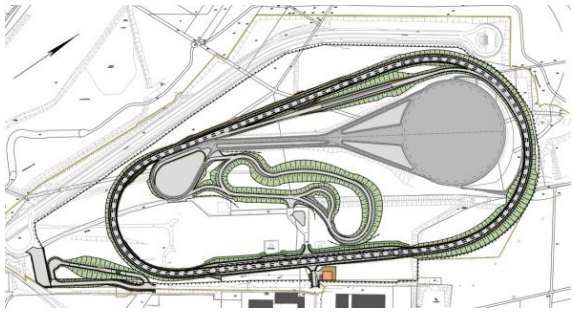

Figure 9. ATC test track layout, to be finished by October 2013.

The Aldenhoven Testing Center comprises relevant infrastructural elements for ADAS and dynamic vehicle testing in the controlled filed. These consist of a vehicle dynamics area (200 m diameter), a high speed oval for velocities up to 110 km/h, a handling course and further elements such as braking tracks or climbing hills. A unique feature is the Galileo infrastructure which simulates the signals of Galileo satellites enabling research and development of Galileo-based applications. Due to the available road elements different driving situations can be simulated and research results of critical situations for Galileo enhanced safety systems can be obtained.

Finally every ADAS functionality needs to be evaluated on public roads, because the variance of critical traffic situations is in real life is infinite. Only a small portion of situations can be depicted and evaluated in the driving simulator and the controlled field test. So called f**ield operational tests (FOT)** or n**aturalistic driving studies (NDS)** aim to investigate short- and long-term effects of ADAS under normal driving conditions. Carrying out tests on public roads requires road legal vehicles which are highly instrumented in order to gather all relevant data – but the subject driving the vehicle should hardly recognize the measurement equipment. *Figure 10* shows a typical test vehicle, which ika uses for implementing and testing ADAS applications.

Figure 10. ika ADAS test vehicle.

Since critical situations are fortunately quite rare events, it is usually not sufficient to perform a FOT with one vehicle, but with 10 to 100 vehicles.

In order to gather and process the data of e.g. 100 vehicles an appropriate data communication and handling structure needs to be set up. The process of collecting FOT/NDS data requires full automation in terms of data acquisition, management, processing and data analysis, in order to guarantee fast and complete evaluation of the data. Figure 11 provides the fully implemented process of ika, which was developed and applied within the framework of the European research project euroFOT. In euroFOT a total of almost 2 Mio. km data (493 GB raw data) were collected and analysed with focus on ACC and FCW [16].

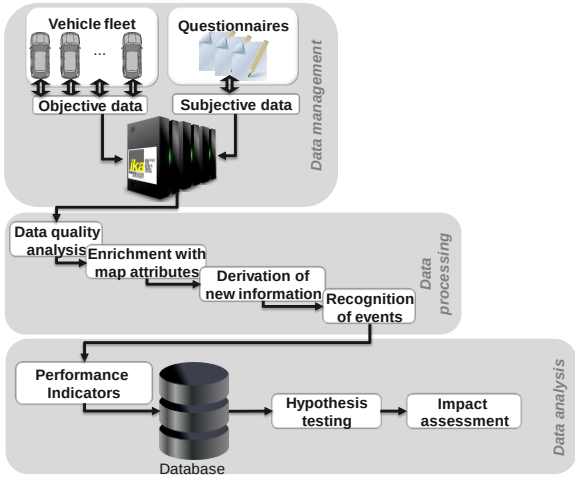

Figure 11. ika's FOT data management process.

While critical situations have been depicted in all other methods on an analytical basis, the FOT is the only setting which continuously generates new critical driving situation. In order to make use of these valuable data the 'circuit of critical situations' is proposed and described in this paper for the very first time.

Circuit of critical situations

The general idea is first to make use of the valuable data obtained when performing tests on public roads and secondly to make sure that critical situations are used in a consistent and effective manner. *Figure 12* depicts the principle idea of collecting hundreds of critical situations during field operational tests and naturalistic driving studies and feeding them into the traffic simulation data base.

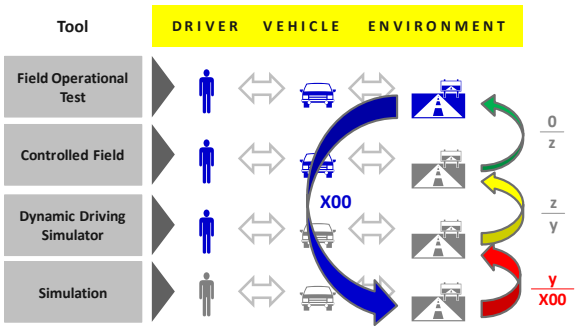

Figure 12. ika Circuit of critical situations.

This data based is continuously updated by data from different sources such as projects, which provide data collection. The critical situations are clustered into different categories depending on the areas of effective applications.

When a new system concept is defined, these comprehensive set of critical situations can be used in traffic simulation in order to identify those situations which appear to play an important role for the innovative system. Those *y* critical situations which have been identified, are depicted in the driving simulator using the same simulation format. The tests in the driving simulator allow a much more in-depth analysis of the situations and of the interaction between driver and vehicle in these situations. On this basis the system concept can be optimized and implemented in an appropriate ADAS test vehicle. Since critical situations are even more difficult to 'simulate' on a test track, the number should be reduced significantly to a value *z* before conducting tests in the controlled field, which typically amounts low numbers. Again the results are used in order to finalize the system design. Ideally, no critical situation remains, which is of special interest for the tests on public roads.

ADAS EVALUATION PROCESS

The circuit of critical situations already forms a connecting element between the various methods – but it is only a logical link. From a process point of view it is decisive that driving simulator tests are being carried out at a very early stage of the development process, far before the system has been decided for market introduction. One important reason is the potential to derive quantitative input for the system specification in terms of controllability and functional safety. Any system fault, which cannot be controlled by the driver, needs to be addressed by functional safety, e.g. by redundancies in signal processing or actuators.

The same is true for controlled field tests: they can also provide valuable input for system specification. It should therefore be performed quite early in the development process, compare Figure 13. Expert tests provide a detailed insight in the system design and first indications on robustness and reliability of the development.

The final validation and approval is conducted in FOTs.

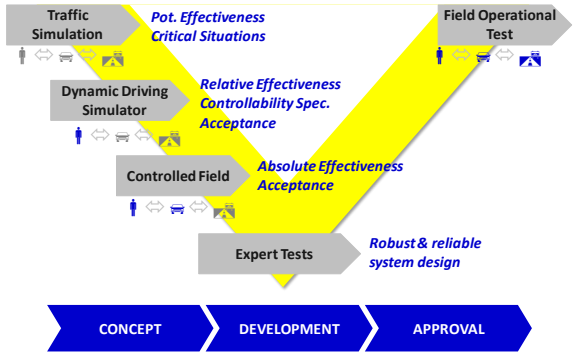

Figure 13. ADAS development process.

The definition of reliable and distinct evaluation criteria for the development process is most challenging in order to determine "safe" and "unsafe" functions and provide a reliable sign off. Especially the lack of boundary values on the driver behaviour level in terms of controllability, effectiveness and acceptance is one of the major research areas. A first approach to solve this need is to establish a driver behaviour related data base of characteristic values resulting from available research and evaluation work in this respective field. This approach will be elaborated by ika in the German research project UR:BAN [17].

Evaluation of functional safety needs to be already integrated in the concept and development phases. Guidelines for verification and validation in the evaluation process are provided by ISO 26262 [18]. Test cases need to be derived ranging from fault injection tests to user tests under real-life conditions depending on the ASIL of the ADAS function. Based on the fundaments of the ADAS development process including methods and evaluation criteria a first set of requirements for the functional safety tests are derived. The given linkage between acceptance, controllability, effectiveness and functional safety can therefore be depicted in total.

While the overall ADAS evaluation process as well as the 'circuit of critical situations' can be described in a generic way, the specific criteria and the experimental design of the interconnected methods also depend on the individual advanced driver assistance system under investigation.

Therefore the application of this process requires an interdisciplinary cooperation between automotive engineers and experimental psychologists in order to implement this approach. Only the interaction between vehicle technology,

psychology and functional safety allows an overall consideration of all necessary aspects of the evaluation process.

CONCLUSION

This paper introduces an integrated and effective approach for ADAS evaluation, which is based on extensive research within numerous national and European research projects as well as on ika's long experience in ADAS development and evaluation in cooperation with industry, leading to many patents and publications of the authors.

The concept of the "circuit of critical situations" is introduced and discussed. Based on critical situations identified in FOT or NDS critical driving situations are fed into traffic simulations, driving simulator studies and controlled field testing. Using the same format in all evaluation methods provides the possibility to optimise the ADAS function suggestively.

The circuit of critical situations requires availability and in-depth knowledge of different evaluation tools and methods as well as the necessary data base on driving situations in order to cover all aspects of the developed ADAS. The linkage between controllability, effectiveness acceptance and functional safety is considered in the methodological approach.

In the next step the first implementation of the concept will be provided and circuit of critical situations will be applied to the development of an ADAS function.

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