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.

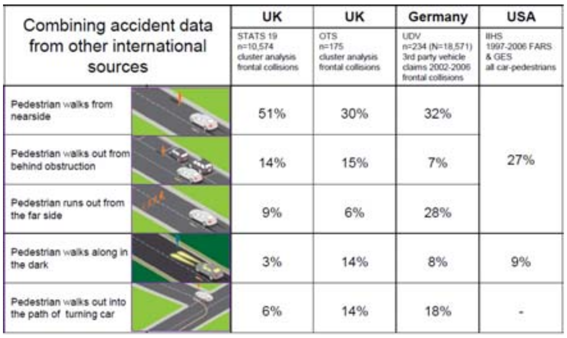
CHARACTERISTICS OF TYPICAL ACCIDENT SCENARIOS – INPUT TO TEST SET-UP

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].

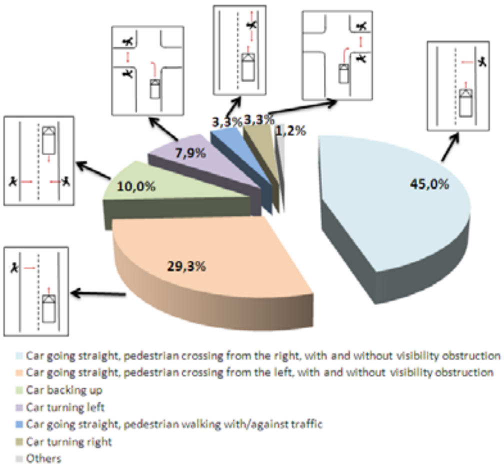
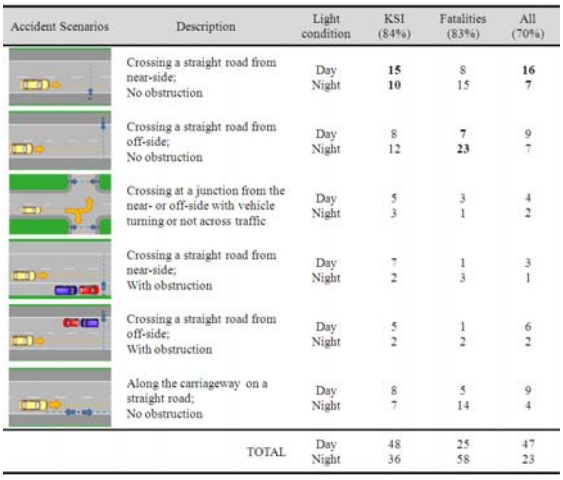


Figure 2 - Design-relevant accident scenarios (vFSS Group)



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.

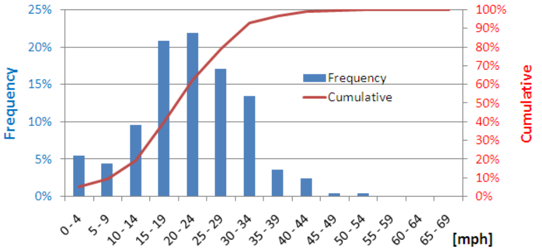


Figure 5 - Initial vehicle speed of crossing scenarios (vFSS Group)

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 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.).

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

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.

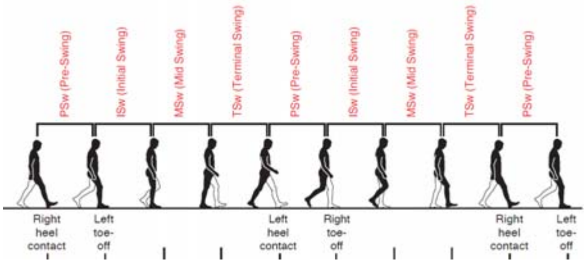


Figure 7 - Phases of the human gait

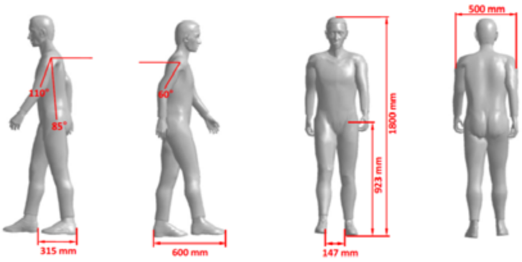


Figure 8 - Adult viewed from left (impact side), right (non-struck), front and rear side.

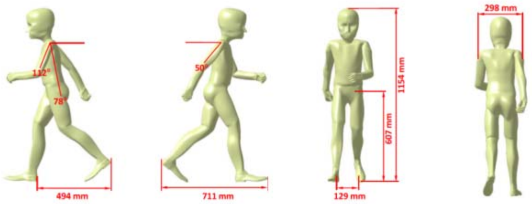


Figure 9 - Child viewed from left (impact side), right (non-struck), front and rear side.

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 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.

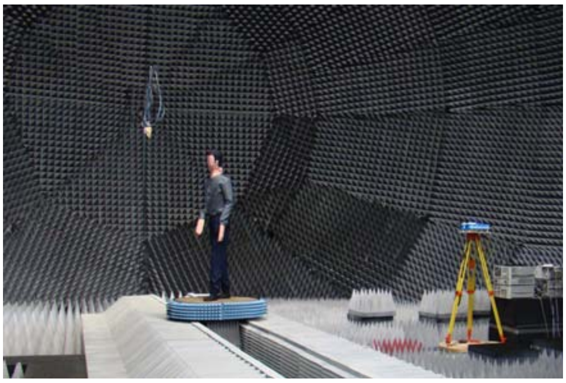


Figure 10 - Setup of the RCS measurements in the EMSL in Ispra, Italy

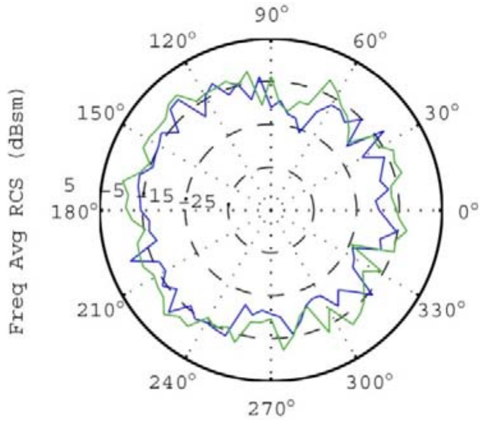


Figure 11 - Polar plot of frequency-averaged RCS of a human for the 23-28 GHz band (green) and the 76-81 GHz band (blue) [10].

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

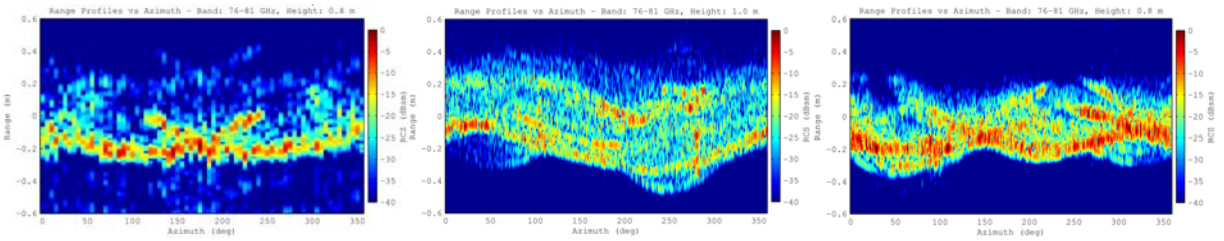


Figure 12 - Range profiles of Human and Dummies [10]: a) Human in standing position (left); b) Dummy with spotty scattering centres (middle); and c) Dummy with distributed scattering capabilities (right)

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.

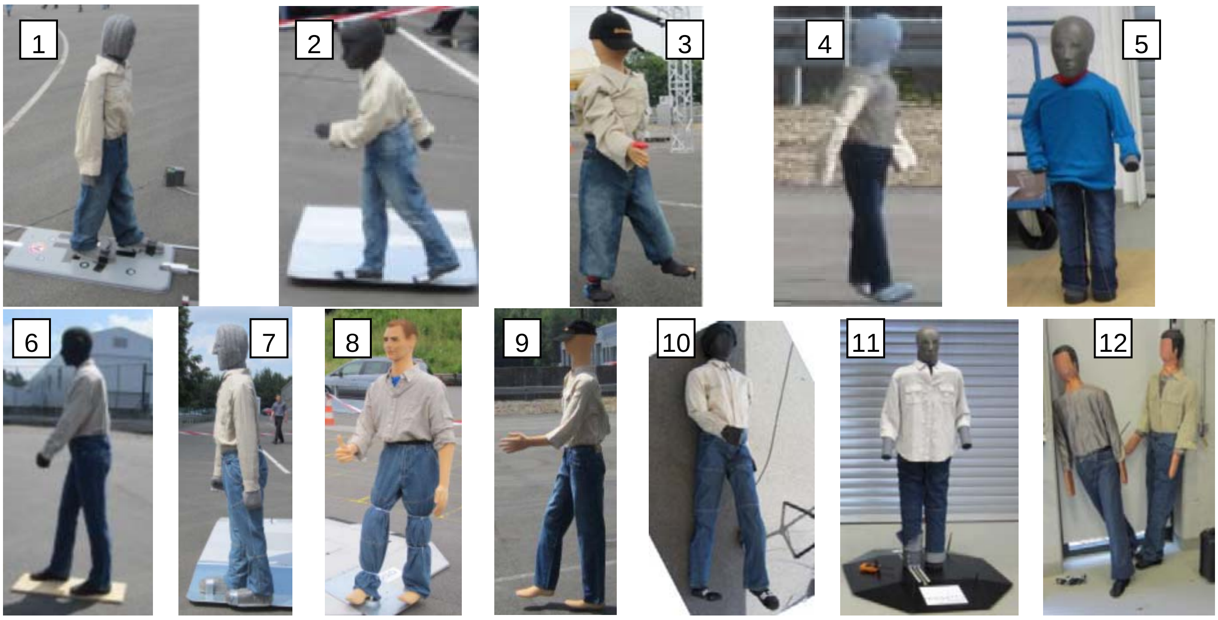


Figure 15 - Dummies evaluated: child dummies (top row) and adult dummies (bottom row)

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 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 16 - Propulsion systems

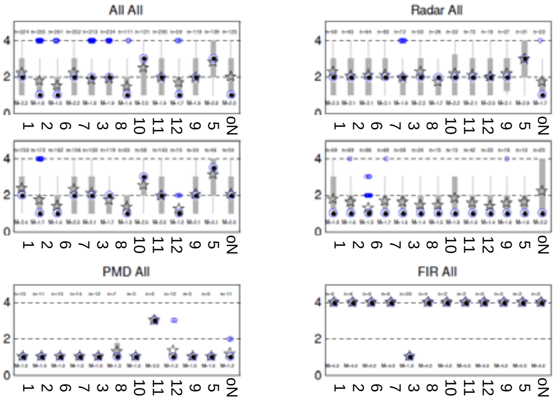


Figure 17 - Dummy assessment by test drivers (numbers refer to dummy/target numbers indicated in Figure 15)

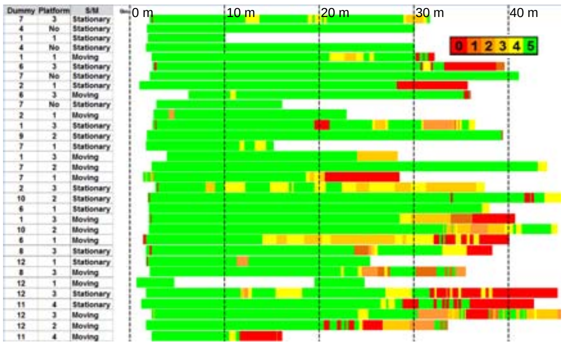


Figure 18 Performance of some test targets in terms of confidence levels (5 is high, 0 is low) versus distance to target.

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

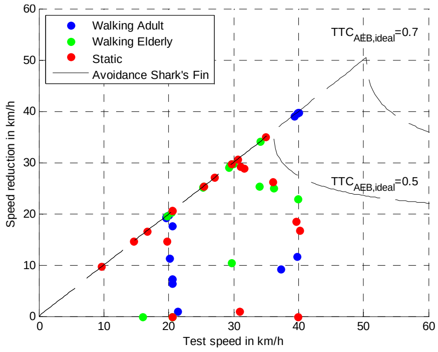


Figure 19 - Speed reductions for unobstructed cases (adults)

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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