THE DEVELOPMENT OF A CONSUMER TEST PROCEDURE FOR PEDESTRIAN SENSITIVE AEB

Colin, Grover
Matthew, Avery
Thatcham Research
UK

Iain, Knight
Apollo Vehicle Safety Limited
UK

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ABSTRACT

In Europe, nearly 20% of all road deaths are pedestrians (Pace et al, 2012). Pedestrians have been protected only by the requirements for passive protection at the front of passenger cars and there has been little evidence to show that this measure has been effective. Autonomous Emergency Braking (AEB) systems have been clearly demonstrated to substantially reduce the incidence of car-to-car rear crashes and manufacturers have now extended the functionality to pedestrian, and in some cases pedal cyclist, collisions. If a comparable level of effectiveness is proven, then these systems will offer substantial reductions in the number of those killed and seriously injured on our roads. The research challenge described by this paper was the development of a test procedure that could be used to encourage the fitment of these systems and the development of high levels of performance in a way that could be linked to real world safety.

Thatcham Research led the AEB Group (a partnership of insurance research centres, OEMs and Tier ones) in the development of test procedures. This contributed substantially to the Harmonisation Platforms in a major collaboration with the vFSS group and the EU funded ASPECCS project. Work began with studies of real-world accident data. A cluster analysis identified the most prevalent collision scenarios and smaller samples of more detailed data were used to characterise each scenario in terms of speeds, impact points, relative positions and sight lines. Physical testing identified the characteristics required of the pedestrian test target and the performance of production and advanced prototype vehicles as well as establishing the conditions required for repeatability and reproducibility.

In Europe almost 75% of serious pedestrian crashes can be characterised by three scenarios: walking from the nearside of the road with open sight lines; running from the far side of the road; and walking out from behind a parked vehicle. In the vast majority of crashes the vehicle involved was travelling at 60 km/h or less. To ensure the systems worked well in the real world it was found that the test should involve adults and children, different impact points and different pedestrian speeds. The pedestrian target found to be most effective was the 4A design, and this was further tuned to optimise the radar and visual signatures to ensure consistent function across different sensor types and proving ground locations.

AEB has considerable potential to reduce the frequency and severity of vulnerable road user collisions. Robust test procedures, representative of real world collisions, have been developed and adopted by Euro NCAP for implementation in the 2016 ratings. However, VRU collisions are a problem in many areas of the world and the harmonisation of these tests and assessments in other NCAP regimes remains a priority, alongside the continuous technical development to expand the tests to include night-time performance and functionality in pedal cycle collisions.

INTRODUCTION

While collisions between cars and pedestrians are relatively rare (for example, representing approxiamtely 1% of insurance claims in the UK) they tend to be very severe in terms of injury outcome, representing 20% of all road deaths in Europe (Pace et al, 2012). While Regulations and consumer test procedures have been implemented in order to reduce severity of injury when a collision does occur, the number of deaths and serious injuries remains substantial and does not appear to be reducing as fast as for other collision types. Autonomous Emergency Braking (AEB) systems have been clearly demonstrated to substantially reduce the incidence of car-to-car rear crashes and manufacturers have now extended the functionality to pedestrian, and in some cases pedal cyclist, collisions. If a comparable level of effectiveness is proven, then these systems will offer substantial reductions in the number of those killed and seriously injured on our roads. The research challenge described by this paper was the development of a test procedure that could be used to encourage the fitment of these systems and the development of high levels of performance in a way that could be linked to real world safety.

The work involved collating evidence on the circumstances of pedestrian collisions from around the world in order to develop a small number of generalised collision scenarios that could be considered representative of a large proportion of all pedestrian crashes. These scenarios were then converted to test scenarios and procedures that assessed the performance of vehicles equipped with pedestrian sensitive AEB.

USING REAL WORLD COLLISION DATA TO DEFINE TEST SCENARIOS

An extensive analysis of GB accident data was undertaken in order to provide the primary evidence under-pinning the development of the test procedures, and this was reported in full by Lenard & Danton (2010). Studies were made of police reported crash data covering the whole of Great Britain (STATS19) and of a detailed sample of crashes that were attended by research personnel On-The-Spot (OTS) of the accident. Both data sets were subjected to a multi-variate cluster analysis, which defined several groups of accidents with common features. In both sets of data, it was found that the single largest cluster involved pedestrians crossing from the nearside during daylight in fine conditions with moderate speeds (average 43 km/h). Less than half of the vehicles involved braked and the average speed reduction was 7 km/h. Children were over-represented in the data but remained a minority.

The next largest cluster (14%) was characterised by children crossing from the nearside (running) during fine daylight conditions but masked by vehicles or other obstruction of view.

Clusters 3 and 4 were similar and in combination represented 21% of the population with common characteristics including crossing from both farside and nearside in darkness and sometimes wet weather without obstructions to the field of view. On average the speeds were slightly higher at 50 km/h. It is worthy of note that the analyses above are for all casualties. When considering only fatalities, clusters 3 and 4 combined represent 42% of the populations, showing that darkness is associated with lower frequency but higher severity crashes.

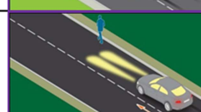
When all frontal collisions with pedestrians were considered in terms of the lateral position at which the collision occurred, it was found that 42% occurred in the nearside quarter of the front and a further 22% the most offside quarter. Thirty-six percent collided with the two quarters either side of the vehicle centerline.

Children under the age of 16 were frequently involved in the crashes (43% of those with known age) but less frequently killed (11% of those with known age). Conversely, those over the age of 65 were less frequently involved (11%) but more frequently killed (33%). However, it was young adults between the age of 19 and 45 that were most likely to be killed (50%).

Information from these analysis was collated into a subset of collision types and international comparisons were sought from other partners in the AEB Group (a partnership of insurance research centres, OEMs and Tier one suppliers). The results are shown in summary form in **Table *1***, below.

Table 1.

International comparison of the frequency of different pedestrian crash types.

Combining accident data from international sources		UK	UK	Germany	USA
		STATS 19 n=10,574 cluster analysis frontal collisions	OTS n=175 cluster analysis frontal collisions	UDV n=234 (N=18,571) 3rd party vehicle claims 2002-2006 frontal collisions	IIHS 1997-2006 FARS & GES all car-pedestrians
Pedestrian walks from nearside		51%	59%	32%	27%
Pedestrian walks out from behind obstruction		14%		7%	
Pedestrian runs out from the far side		9%	37%	28%	
Pedestrian walks along in the dark		3%	5%	8%	9%
Pedestrian walks out into the path of turning car		6%	Overall: going ahead 87%, Turning 13%	18%	-

It can be seen that, within Europe at least, there is broad agreement that in the region of three quarters of all frontal collisions with pedestrians fall within the first 3 groups listed of walking from the nearside, walking out from behind an obstruction and running from the far side. Within this, there was variation between UK and Germany with UK finding collisions with obscured pedestrians more of a problem and Germany finding pedestrians crossing from the far side more of a problem.

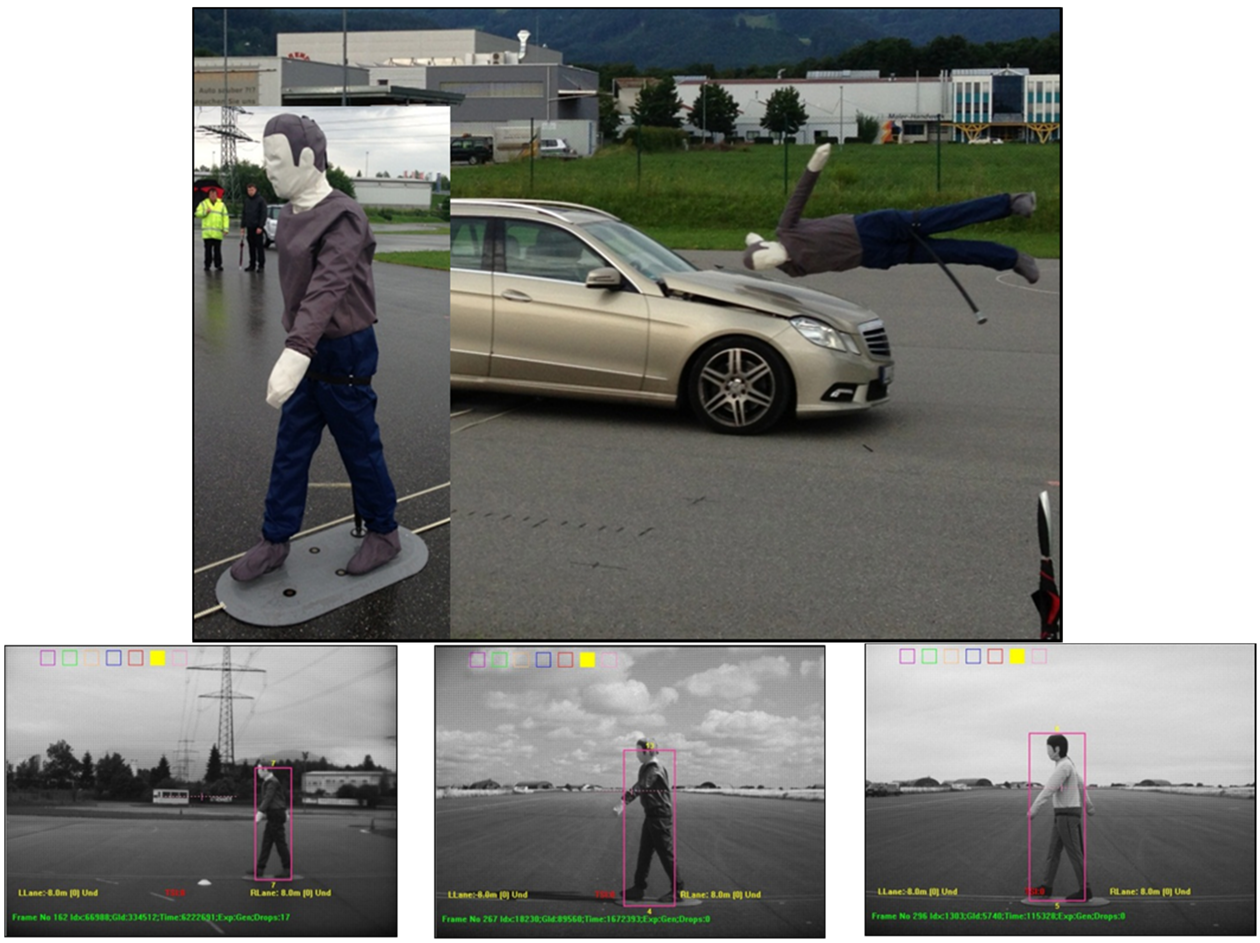
The data also suggested that the vast majority of collisions occurred when cars were travelling at less than 60 km/h before the collision.

DEVELOPING REPRESENTATIVE TEST TARGETS

The development of the test targets has been the subject of a previous ESV paper (Lemmen et al, 2013) so within this paper the results will simply be summarized briefly and updated for the latest status. The previous work identified a range of dummy attributes that were important enablers of recognition by different sensors and proposed specifications for them. These included:

- Size and posture
- Infra-red reflectivity
- Radar Cross Section (RCS)
- Contrast with background

In terms of the propulsion system required to deliver the dummy to the point of impact, it was decided to use a low profile platform approach rather than an overhead gantry. The rationale for this was the reduced visual and radar signature of the platform and the more realistic appearance of the test, from a consumer point of view. At that stage, a range of dummy and delivery system solutions remained under consideration. However, since that time extensive further development was undertaken such that the static dummy produced by 4A emerged as a leading contender. Preliminary testing in partnership with Thatcham and Continental in Austria and the UK showed that the dummy was remarkably robust, surviving regular impacts at 60 km/h with only very minor cosmetic damage to either dummy or vehicle. The preliminary tests also suggested that the recognition by visual sensors was good but that variations in performance were found between the two test sites, suspected of being a contrast problem as a result of different backgrounds. The radar signature was found to be adequate for some vehicles. However, for the Mercedes E class, it was found to be inadequate, discussion with the manufacturer suggesting that this was because the radar signature was "brighter", i.e. a stronger radar return, than that of a real pedestrian and this reduced detection confidence for their algorithm, whereas for the algorithms of other manufacturers this was not considered a problem.



v1 Clothes – Rothis (cluttered background) | v1 Clothes – UH (plain background) | v2 Clothes – UH (plain background)

Figure 1: Illustrations of the 4A dummy, it's durability and contrast.

In late 2014, two further dummy workshops were organized by the Harmonisation Platforms, one hosted by BASt in Germany to fine tune the radar signature of the dummy and the other hosted by Thatcham in the UK to consider the effects of different colour clothes and the contrast with the background. At each event a wide variety of manufacturers brought their instrumented vehicles to test for recognition of the dummy and 4A had prepared different versions of key components such as clothes to allow for tuning.

The results of these workshops were such that modifications were made to interior components of the dummy and the dummies foot in order to amend the radar cross section and the colouring selected as the most suitable against a variety of backgrounds was blue trousers with a black top and black hair, as illustrated below.

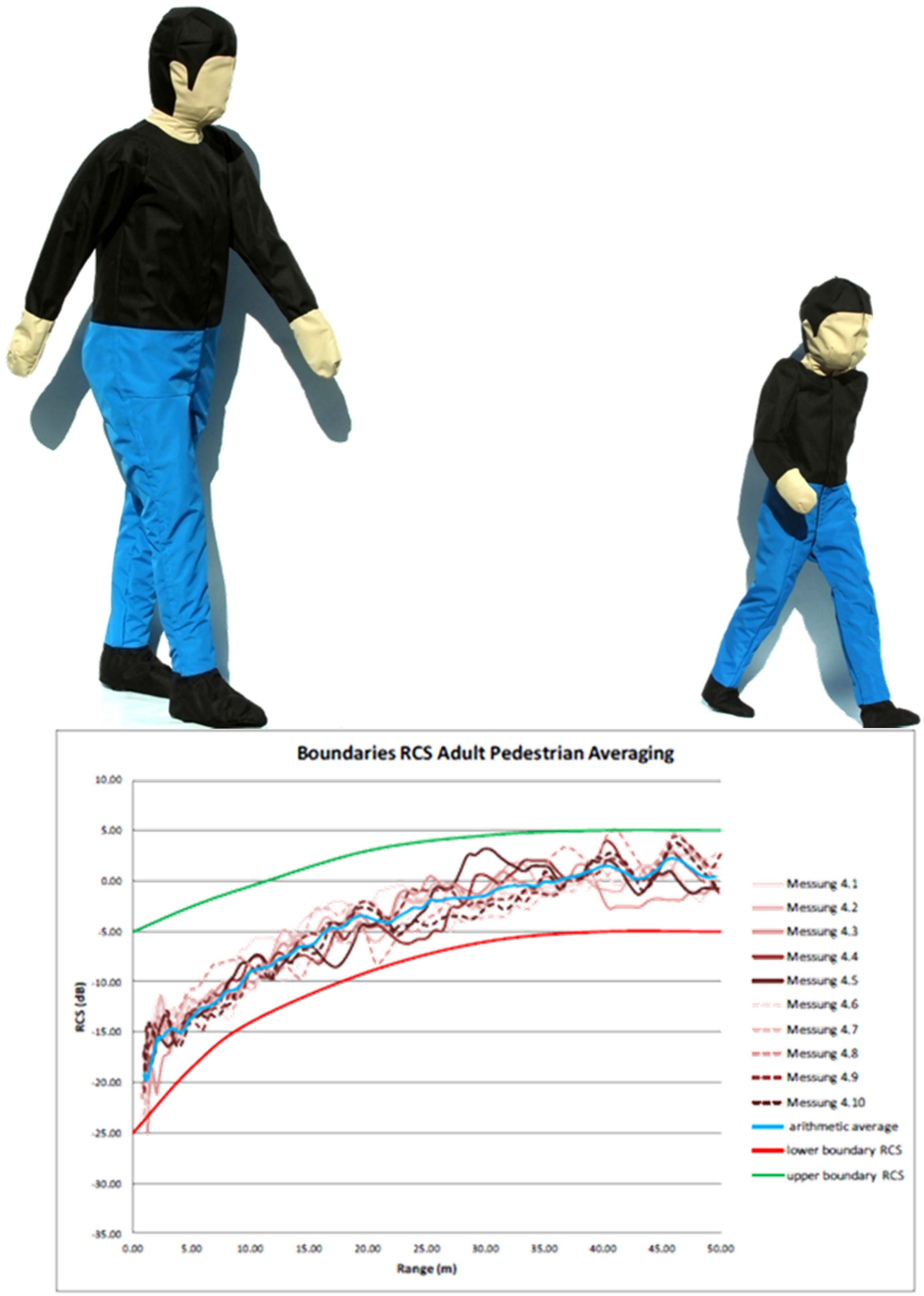


Figure 2: Final version of the static dummy arising from the 2014 Harmonisation Platform Events (Source: 4A)

The OEMs involved in the event considered that this dummy was acceptable for current sensors. However, reservations remained in terms of its future performance for more sophisticated radar systems that were being developed to recognize the radar signature of arm and leg movement in order to provide a more confident classification of the target as a pedestrian, potentially without fusion with a camera sensor. It was, therefore, agreed that if industry successfully developed a dummy with articulated arm and/or leg movement that could operate on the low profile platform delivery systems with levels of robustness and acceptability to visual systems at least equal to that of the standard dummy then this would be accepted.

Such a dummy is under development by industry in partnership with 4A. There has been limited independent testing of this new solution at the time of writing but first experiences suggest that the result is very impressive. The dummy survived high speed collisions well and was easy to re-assemble and the adult version tended to produce similar results (with current sensor systems) to the static dummy. In the version presented, the dummies feet were considered to be too far from the floor, and the articulated child dummy was less well recognized than its static counterpart. This was considered likely to be a postural problem and suitable amendments are underway. If these final modifications are successful then the articulated dummy will be adopted for the final procedure.

Figure 3: Image of the proposed adult articulated dummy (source: 4A).

EVALUATING CANDIDATE TEST SCENARIOS

During the development of the test procedure, a wide range of test scenarios proposed by the various stakeholders. Each of these could have been justified on the basis of the available accident data and each had advantages and disadvantages. However, it was considered that to minimize the test burden the number of test scenarios had to be kept low. The results of preliminary rounds of testing and analysis involving these scenarios is described below.

Testing in Darkness

The accident data showed that for killed and seriously injured pedestrians, performance in darkness would be very important. Some AEB Pedestrian systems will not work in darkness whereas others will. There is, therefore, a strong rationale for implementing a test in darkness. However, such a test would add considerable technical and operational complexity to an already difficult test. For example, to ensure reproducibility the actual level of light would need to be closely controlled to defined levels. Given that most pedestrian collisions occur in urban areas with street lighting then the test should be representative of that condition, however, street lighting can vary considerably by region. Additionally, tuning the characteristics of the dummy to be sufficiently representative of a real human has proved complex. It remains unknown whether those same properties are adequate to be representative of a real human at night.

It was considered that overcoming these difficulties would be likely to take considerable time and delay the introduction of a test procedure. For that reason, it was agreed at an early stage that tests in darkness would not be considered for the protocol due to be implemented in 2016. Instead, it is proposed that manufacturers be awarded additional points on confirmation that the system continues to work at low levels of illumination. Additional night-time performance tests will be considered for inclusion as an update to the protocol for 2018.

Adult walks from nearside, no obstruction

The accident evidence reviewed in this paper agreed closely with that from all other stakeholders that this scenario represented the most common accident mechanism by a substantial margin. Walking speed was generally agreed to be 5 km/h. The main variable considered for discussion was the impact point on the front of the car, whether this should be at a point 25% of the vehicle's width from the nearside, 50% or 75%.

Most of the early testing was done at an impact point of 50%. In this test scenario it was found that all vehicles tested generally showed considerable performance but variation between models existed. For example, a production radar camera fusion system would typically avoid collisions at vehicle speeds of up to 30 km/h and would mitigate a small amount (10 km/h) even at a test speed of 60 km/h. However, an advanced prototype stereo camera (tuned for highest possible avoidance) was capable of avoiding collision from a vehicle speed of 50 km/h. None of the vehicles tested offered performance at a vehicle speed of 10 km/h. This is a function of the lateral field of view of the sensor. When the vehicle is travelling very slowly it is not much faster than the pedestrian dummy, which means the pedestrian dummy does not begin to move until the vehicle is very close. At this point it is not within the field of view of the sensors tested, and then reappears back in the field of view at short Time To Collision (TTC), limiting the opportunity available for the AEB system to activate.

Engineering analysis of this scenario suggests that the time that the sensor detects the pedestrian with sufficient confidence to act should not be affected by different impact points on the front of the car. Thus, the closer the impact point is to the nearside, the less time is available for the car to brake. Thus, it would be expected that performance would be reduced compared to the results above at 25% impact point and increased at a 75% impact point, though in the 75% scenario the system may not fully exploit that opportunity if it does not have early confidence that the pedestrian will not fully pass the vehicle before impact or that the collision cannot be avoided by steering.

Adult walks from farside, no obstruction

It was also clear from the accident data that an adult crossing the road from the farside of the vehicle was one of the more common situations. However, the evidence was more conflicting about the speed of the movements. In this scenario the adult was assumed to walk at 5 km/h.

The lateral separation between the starting position of the pedestrian and the impact point on the car is greater in the scenario than in the one where the pedestrian walks from the nearside. So, the time available for the system to detect and react to the pedestrian is theoretically greater, offering the opportunity for superior AEB performance. However, this is limited by two factors:

- Sensor field of view: the sensor field of view will continue to limit performance at low vehicle speeds
- Confidence in impact prediction: Moving human beings are highly dynamic and can stop or change direction quickly so most AEB systems will not be sufficiently confident of an imminent collision to autonomously brake until the pedestrian is either in the direct path of the vehicle or close to entering the path. This threshold is likely to be symmetrical around the vehicle so in fact the time available to brake in this farside scenario will actually be the same as that for the nearside walking scenario.

Adult runs from farside, no obstruction

In the UK data from the OTS study, it was identified that adults crossing from the farside were often running. It was not possible to identify the actual speed of these pedestrians but it was assumed that this translated to a pedestrian speed of 8 km/h.

In terms of layout and sequence of events this scenario is identical to the adult walking from the farside one. However, the increased pedestrian speed has the effect of exacerbating the sensor field of view difficulty at low speeds because the car will be closer (longitudinally) to the pedestrian at the point the pedestrian first begins to cross the road. Thus, the pedestrian will enter the sensor field of view with a smaller time to collision than at lower pedestrian speed. The additional speed also reduces the time available to brake for systems that will only apply braking when the pedestrian crosses into the vehicle path. Systems that use path prediction might suffer less with the latter problem because a pedestrian moving more quickly will also take longer to stop or change direction so the point at which the algorithm decides a collision is imminent may also become earlier.

As such this is a more challenging scenario for the technology than either of those previously discussed. However, technological opportunities do exist to overcome those challenges and improve performance. This is reflected in preliminary test results at a 50% impact point that suggest a simple mono camera installation was inoperative at speeds below about 25 km/h and above about 50 km/h. At test speeds in-between it reduced collision speeds by a few km/h. However, an advanced sensor fusion system was able to mitigate a 20km/h test speed to a 5 km/h impact speed and was able to fully avoid higher speed impacts from travel speeds of up to 55 km/h. At a test speed of 60 km/h the impact speed was reduced to less than 30 km/h.

Elderly adult walks slowly from farside

Accident data presented by the ASPECCS project suggested that a substantial proportion of those crossing from the farside were elderly and thus moving slowly, estimated to be represented by a test speed for the pedestrian of 3 km/h.

In terms of detection, a slow pedestrian speed could potentially be more challenging, because very low speed movement can be harder to quantify accurately than higher speeds. However, if detected, the slower pedestrian speed would reduce the problems with sensor field of view and allow more time for braking for those systems that will only brake once the pedestrian has entered the path.

Child runs out from behind parked vehicles at the nearside.

The accident data was generally agreed that collision mechanisms involving obstructed line of sight and children were common and that such accidents often involved running. Initially, this was assumed to be represented by a dummy speed of 8 km/h, the same as assumed for the running adult in the farside scenario. In physical terms, the obstruction was achieved by parking a small car immediately in front of the pedestrian and a larger car in front of that. The obstructed view meant that the time for which the pedestrian was visible between emerging from behind the car and entering the path of the test vehicle was very small. This severely limits the amount of time the sensing system has to detect and track the pedestrian. Although it is possible that future sensing systems may find ways of detecting the movement of the pedestrian behind the obstruction, none of those tested to date have demonstrated such performance.

Initial tests of this scenario were undertaken at impact points positioned 25% of the vehicles width in-board of the nearside of the vehicle. This impact point limits the time available for braking, if braking is initiated at a fixed geometric boundary (i.e. when the pedestrian crosses into the vehicle's path). The 8 km/h pedestrian speed also reduces the time available for braking, compared with the benchmark walking scenarios.

The test results for this scenario supported the theory that this was a very challenging one for AEB systems to prevent. Of those systems tested in this scenario, the best performance was modest speed reductions of around 5 km/h from tests speeds of around 20 to 25 km/h. Simulations of the performance that might be expected from future systems suggested that this could be improved upon somewhat but not substantially.

ANALYSIS AND SCENARIO SELECTION

The preliminary tests and analyses of the candidate test scenarios identified a range of variables that were important in relation to the accident data and/or to the ability of current systems to perform. These were:

- Impact point (25%, 50% or 75%): The 25% point is more representative of the most frequent collisions and is more technically challenging for systems
- Pedestrian speed (3, 5 or 8 km/h): Evidence was mixed from the accident data, higher pedestrian speeds are more technically challenging in respect to time available to brake and sensor field of view but the low speed was potentially more challenging for detection and classification.
- View (obstructed or clear): Collisions where the view of the pedestrian is clear 2 seconds before impact are more common than those that are masked from view. However, the latter represents a substantial and sensitive minority, often involving children, and is more technically demanding.
- Pedestrian age/size (adult or child): Adults are more frequently involved but children represent a substantial, over-represented and sensitive minority and could be more technically challenging, particularly in the presence of an obstructed view.

The two most closely agreed scenarios in the preliminary list of candidate scenarios were the adult walking from the nearside unobstructed and the child running from behind cars parked at the nearside. The first of these was a test that closely represented common accident types and the available AEB systems were able to demonstrate a strong positive effect, though the magnitude of effect varied for different systems. However, with respect to each of the variables above it involved the less challenging options for all of them. The second scenario was also representative of the accident data but combined the most challenging option for all of the above variables in one test. Thus, it was found that current and likely future systems would be able to offer only very small benefits.

It was, therefore, considered that the challenging options should be distributed around the test scenarios more evenly. This resulted in the final selection of test scenarios shown in ***Table 2***, below.

Table 2: Final selection of test scenarios for implementation in Euro NCAP in 2016

			
PEDESTRIAN	Far side	Near side	
	Adult	Adult	Child
	8km/h	5km/h	5km/h
	50% (central)	25% & 75%	50% (central)
VUT	20-60km/h	20-60km/h	20-60km/h

In this way, the child emerging from behind a parked car is still represented but with a slightly lower dummy speed than originally considered (though still within the range of a running child) and involving a collision with the centre point of the front of the car. The main baseline scenario remains the adult walking from the nearside but this test should be undertaken at impact points towards the edges of the car, which is representative of collision data and fairly reflects the challenge of avoiding such collisions. The farside test is undertaken with the higher speed dummy, which is representative of the UK association with adults running from that side and which also acts to ensure symmetry of performance, while challenging the sensor field of view and the braking performance.

Of the list of key variables identified above, a 3 km/h elderly pedestrian is the only one not represented in this matrix. The rationale behind this was that for this type of pedestrian the key element was almost binary; could the pedestrian be detected reliably or not. Once detected reliably, such pedestrians would be easier to avoid than those represented by the other scenarios. The ability to detect 3 km/h pedestrians has therefore been included as a pre-requisite of the test and is demonstrated by a single test at one vehicle test speed.

VERIFICATION OF PROPOSED PROCEDURES

Tests have now been undertaken with a range of vehicles against all of the defined procedures to assess how well they work and to test the repeatability & reproducibility of the test procedures and to assess the scoring system (reported separately). In order to demonstrate the effectiveness of the procedures the results from two vehicles, representing the outliers of current production cost and performance, have been shown below. The Mini One is equipped with a single mono-camera AEB and the Lexus LS460 is equipped with a very sophisticated sensor fusion system comprising radar, stereo camera and infra-red sensors.

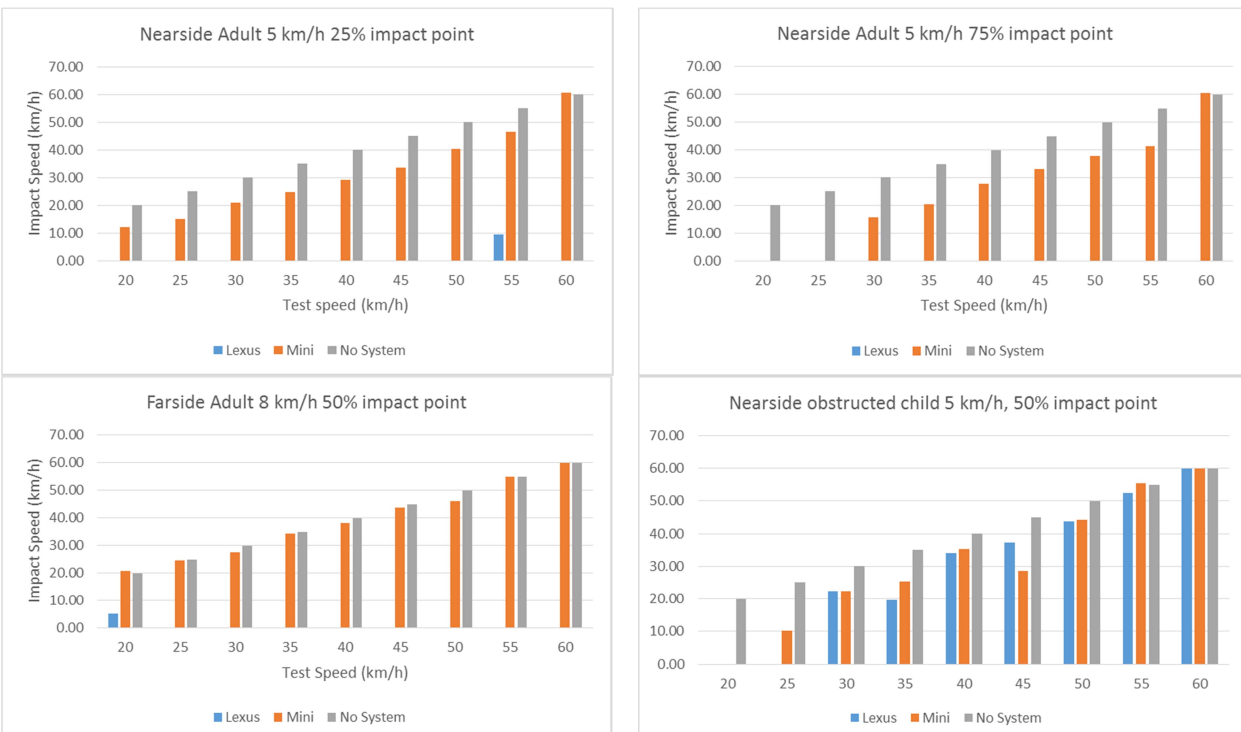


Figure 4: Results of final test procedures applied to single mono-camera and sophisticated sensor fusion systems.

It can be seen that the mono-camera system fitted to the Mini is mainly a mitigation system. There are only a very few scenarios where it is capable of avoidance but it offers useful speed reductions in the baseline nearside adult scenarios and nearside child scenario. By contrast, the sophisticated sensor fusion system fitted to the Lexus avoids in almost every test except the nearside obstructed child test. It is understood that the extremely good performance of the Lexus is enabled by the use of a path prediction algorithm that enables the brakes to be applied a short time before the pedestrian enters the vehicle path. However, the advantage of this system is denied in the obscured scenario where the pedestrian is hidden for large parts of the time required to produce the path prediction.

CONCLUSIONS

Pedestrians remain a serious road safety concern in Europe, representing almost 20% of all fatalities from road traffic accidents. Analyses of the circumstances of those crashes involving the front of the car show that the vast majority involve pedestrians crossing the road approximately perpendicularly to the direction of travel of the car. The largest group of such collisions involve adults walking from the nearside without being masked by parked vehicles or other obstructions. This is followed by adults crossing from the farside of the road. Children crossing from behind parked vehicles represents a significant and over-represented minority of crashes.

Developing test targets that appear sufficiently ‘human-like’ in the eyes of a range of different sensor systems, whilst being sufficiently cheap and robust to be used in full contact testing has proved challenging. However, a static dummy that is effective for all current production sensors tested to-date is now commercially available. An articulated dummy that will future proof the test against the future development of radar sensors that rely on the movement of limbs is in the final stages of development and will be adopted for the test.

Test procedures have been developed based on a combination of the evidence from real world accident data and the ability of current and likely future AEB systems to influence the outcome in such scenarios. A set of three test scenarios have been proposed, offering comprehensive coverage of the variable identified as most important, including varying impact point, pedestrian speed, and vehicle speed, nearside and far side approach, adult and child pedestrians, obstructed and clear views.

These test procedures have been applied to a range of vehicles and do successfully reward fitment of even simple systems while also clearly discriminating between the different levels of performance found in the market today. It is expected that these developments, once fully implemented in consumer testing will be expected to drive significant reductions in pedestrian casualties.

Euro NCAP has agreed to implement these procedures within it’s protocols in 2016 but pedestrian crashes are a problem across the developed world and the globalization of the vehicle industry means that there will be considerable benefits to implementing a harmonized test in as many international programs as possible.

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