

## **EURO NCAP'S FIRST STEP TO ASSESS AUTONOMOUS EMERGENCY BRAKING (AEB) FOR VULNERABLE ROAD USERS**

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### **ABSTRACT**

Following the implementation of AEB City and AEB Inter-Urban systems in Euro NCAP's safety rating in 2014, a third type of AEB technology, Autonomous Emergency Braking for Vulnerable Road Users (AEB VRU), will be added to the overall assessment of new vehicles in 2016. The introduction of AEB VRU will be done in two phases where in 2016 AEB Pedestrian is implemented followed by AEB Cyclists in 2018.

AEB VRU will be awarded as part of the assessment of Pedestrian Protection and represents the next step to improve the protection of vulnerable road users, complimentary to the existing subsystem tests to the vehicle front end. Following system tests in common pedestrian accident scenarios, more challenging and demanding cyclist scenarios are planned in a subsequent phase.

In close corporation with the car industry represented by the ACEA, JAMA and KAMA associations, Euro NCAP has developed detailed test and assessment procedures for AEB Pedestrian. The procedures are based on the existing car to car AEB test and assessment protocols and validated and checked for repeatability and reproducibility at several Euro NCAP laboratories. This paper describes both the test and assessment protocols.

### **BACKGROUND**

In 2009, Euro NCAP introduced the overall rating scheme, which allows new technologies to be implemented in the safety assessment of a new vehicle. The new rating scheme consists of four areas of assessment, also called boxes, which together result in a single overall safety rating. The four areas of assessment are Adult Occupant Protection (AOP), Child Occupant Protection (COP), Pedestrian Protection (PP) and Safety Assist (SA).

Over the last few years, Euro NCAP has rapidly raised the requirements for better protection of vulnerable road users in the event of a crash which was seen to lag behind. After significant updates to the test and assessment protocols in the area of passive safety, the next logical step was to include the assessment of AEB systems. Due to the nature of pedestrian accidents with passenger cars, most AEB systems are only capable of mitigating these crashes and therefore, Euro NCAP considers these systems complementary to passive safety measures already in place.

At the moment different AEB Pedestrian systems are already available on the market, based on radar, (stereo) camera or a combination of these sensors. The performance of these systems vary significantly based on the sensors used. The first generation of camera based systems typically switch off during low ambient lighting conditions as classification of pedestrians in darkness is not reliable enough. Euro NCAP has based its requirements for AEB Pedestrian systems on best practice to push for further development of these lifesaving technologies.

## **WORKING GROUP**

As for all Euro NCAP protocols, the development of the test procedure and assessment criteria was done within a collaborative Working Group. The Primary NCAP working Group, P-NCAP TWG in short, involved Euro NCAP members and laboratories and was given the task to deliver AEB Pedestrian protocols by the end of 2014, for implementation in 2016. Although car makers and suppliers were not directly involved in the working group, several meetings were organised between representatives of both sides to review the procedures. More importantly, the work of the group took advantage of and brought together the results delivered by several main research initiatives in Europe that were looking into the development of AEB test and assessment procedures.

### **Initiatives**

In Europe, several initiatives have been running in parallel, all with the same goal of developing test procedures for assessing AEB systems in general and AEB Pedestrian systems in particular: “AEB”, “AsPeCSS” and “vFSS”. Besides this, ACEA started an internal project to develop so called *articulated* pedestrian targets.

The RCAR Autonomous Emergency Braking group, led by Thatcham aims at designing and implementing a testing and rating procedure for Autonomous Emergency Braking (“AEB”) systems reflecting real world accident data. It is hoped that this will encourage the development of AEB systems that can avoid or mitigate the effects of car-to-pedestrian and car-to-car collisions seen in the most common crash types. The group mainly consists of insurance institutes, supported by Volvo Car Corporation, Subaru, Daimler and first-tier supplier Continental. The work of the RCAR AEB group is ongoing.

The European Commission sponsored FP7 project AsPeCSS (Assessment methodologies for forward looking Integrated Pedestrian and further extension to Cyclist Safety Systems) led by IDIADA had specific project goals to develop harmonised and standardised procedures for the assessment of forward looking integrated pedestrian safety systems. The project partners consisted of nine research institutes, three of which were Euro NCAP laboratories: BAST, IDIADA and TNO. From industry side, BMW, PSA and Toyota participated as car manufacturers and Autoliv, Bosch and TRW as first-tier suppliers. The AsPeCSS project ran from 2011 until 2014.

The third initiative was vFSS (Advanced Forward-Looking Safety Systems) led by DEKRA. The project was supported by the BAST as a Euro NCAP Test Lab. The Insurance Companies Allianz, GDV and KTI as well as the AUDI, BMW, Daimler, Ford, Honda, Opel, Porsche, Toyota and VW as industry partners. One of the main deliverables were the static pedestrian targets that were adopted in the Euro NCAP protocols. They will be described in further detail within this paper.

The outcome and deliverables of all the initiatives were extensively discussed within the working group and formed the basis for the decision on test scenarios and targets used.

## **TEST SCENARIOS AND TARGETS**

There was a large overlap of the proposed test scenarios from the different initiatives, based on an extensive analysis of real world car-to-pedestrian accidents mainly from Germany, Great-Britain and France. Overlaying the proposed test scenarios, the P-NCAP TWG agreed to focus on four test scenarios for AEB Pedestrian. In the Car-to-VRU Farside Adult (CVFA) scenario, the running pedestrian crosses the vehicle path from the farside. It represents the situation where a pedestrian first crosses another lane before entering the lane in which the vehicle is driving. The timing is set such that without any AEB reaction from the vehicle, the adult pedestrian target would end up contacting the centreline of the vehicle. The second adult pedestrian scenario represents a pedestrian stepping of the sidewalk into the lane the vehicle is driving in. There are two variants with different impact locations of 25 and 75% of the vehicles width (CVNA-25 & CVNA-75).

The final scenario is the most challenging one, where a child pedestrian appears from behind two parked vehicles and directly stepping into the lane the vehicle is in. Similar to the farside adult scenario, the impact location will be in the middle of the vehicle (CVNC).

### Car-to-VRU Farside Adult (CVFA)

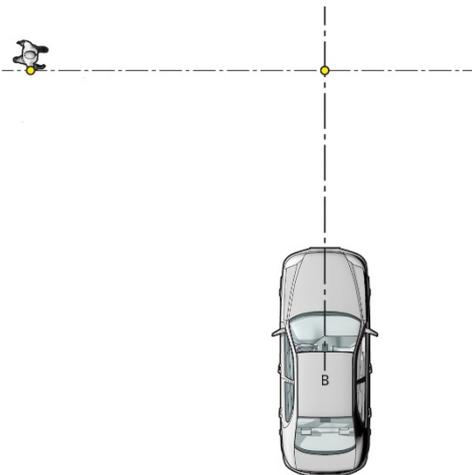


Figure 1. AEB Pedestrian scenario, CVFA  
Car-to-VRU Nearside Child (CVNC)

### Car-to-VRU Nearside Adult (CVNA-25 & CVNA-75)

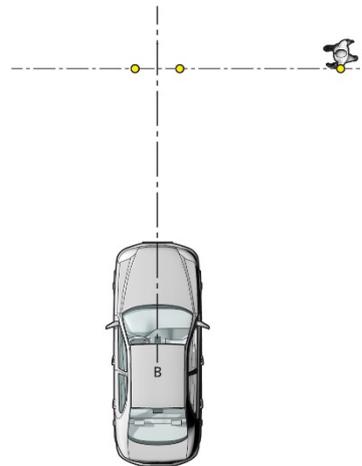


Figure 2. AEB Pedestrian scenario, CVNA-25 & 75

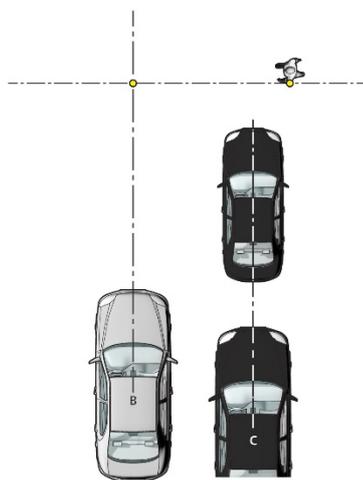


Figure 3. AEB Pedestrian scenario, CVNC



Figure 4. Euro NCAP Pedestrian Targets (EPTa & EPTc)

For the all of the above described AEB Pedestrian scenarios, only the AEB function (i.e. the vehicle braking without driver involvement) is tested and assessed. Possible Forward Collision Warning (FCW) functionality (the driver responding to a warning by applying the brakes) is not taken into account as it assumed that in this type of situations, there is generally not sufficient time to react to a warning.

### Incremental Speed Approach

All of the scenarios will be tested with an incremental approach. Starting at a low speed of 20 km/h, the approach speed of the Vehicle Under Test (VUT) is stepwise increased by 5 km/h up to a maximum test speed of 60 km/h. For each run, the vehicle's speed reduction is recorded.

### Euro NCAP Pedestrian Targets

A large number of different pedestrian targets have been developed over time. Following several workshops, it was decided to take the pedestrian targets as developed within vFSS as a basis. Further events to verify the radar cross section and infrared reflectivity were performed and it was confirmed that the static dummy was detectable by both radar and camera based systems. The figures 5 and 6 show the stance and statures of the adult and child pedestrian targets.

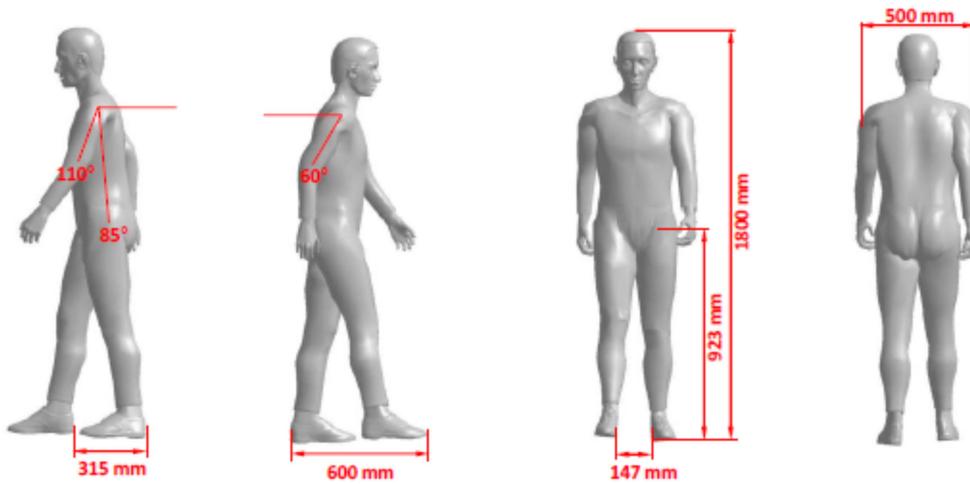


Figure 5. Euro NCAP adult Pedestrian Target stance and dimensions

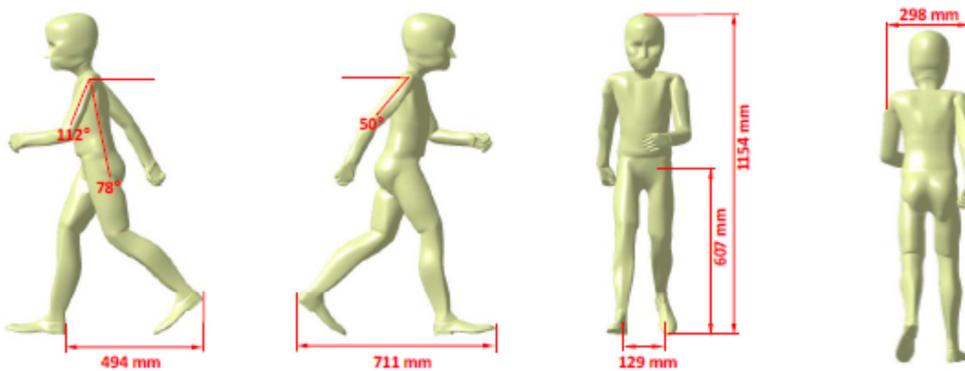


Figure 6. Euro NCAP child Pedestrian Target stance and dimensions

At a later stage, industry started the development of an articulated dummy with moving legs that would reflect a more realistic Doppler image, used by more advanced radar systems. Apart from the moving legs, the dummy radar cross section, clothing and stature are the same as for the static pedestrian targets. It was agreed by Euro NCAP to consider specifying this dummy as the pedestrian target in the protocols when all parties involved had verified and approved it. The evaluation and fine-tuning of this dummy is ongoing at the time of writing of this paper.

### Test equipment and test track

Euro NCAP uses different facilities for all of its tests. To ensure repeatable and reproducible results now and in the future, the WG had already decided to set strict tolerances for testing all of the AEB systems, even though it was acknowledged that this may not always be necessary to evaluate the performance of these systems in the scenarios described earlier. The tolerances used for the AEB Pedestrian tests are listed below:

- |                                    |                               |
|------------------------------------|-------------------------------|
| - Speed of VUT (GPS-speed)         | Test speed + 0.5 km/h         |
| - Lateral deviation from test path | $0 \pm 0.05$ m                |
| - Yaw velocity                     | $0 \pm 1.0$ °/s               |
| - Steering wheel velocity          | $0 \pm 15.0$ °/s              |
| - Speed of EPT during steady state |                               |
| o CVFA                             | $8 \pm 0.2$ km/h              |
| o CVNA                             | $5 \pm 0.2$ km/h              |
| o CVNC                             | $5 \pm 0.2$ km/h              |
| - EPT Steady state                 |                               |
| o Nearside                         | 3.0 m from vehicle centerline |
| o Farside                          | 4.5 m from vehicle centerline |

Due to these strict tolerances, all of the Euro NCAP test facilities are using both steering and brake robots to control the vehicle during test.

Another, less controllable, influencing factor is weather condition. The tracks used for the assessment are spread over Europe with different climates. Although the weather may influence the performance of the systems, it is thought that in day-to-day use these systems also encounter various weather conditions and hence should be robust enough to deal with normal variations. To minimise test to test variability, limits are set to temperature (between 5 and 40°C) and wind (below 10 m/s). There may be no precipitation falling and horizontal visibility at ground level must be greater than 1km. Finally, the natural ambient illumination must be homogenous in the test area and in excess of 2000 lux for daylight testing. For practical reasons, Euro NCAP does not physically test the performance of these systems in low ambient lighting conditions even though accident data reveals this is relevant. It is also ensured that testing is not performed driving towards or away from the sun when there is direct sunlight.

## ASSESSMENT

The assessment of AEB Pedestrian systems is based on two aspects: the Autonomous Emergency Braking function, i.e. how well the system reacts to an imminent pedestrian impact, and the Human Machine Interface. The latter assessment carries less weight but is important to promote the use of the system.

### Assessment of AEB function

The only assessment criterion used is the impact speed reduction. For each run into the target at incremental speed, a full score is given when the impact is completely avoided. Where a contact occurs, the points are awarded on a sliding scale basis for speeds up to and including 40 km/h, where the proportion of speed reduction based on the relative test speed determines the proportion of available points scored.

$$Score_{test\ speed} = ((V_{test} - V_{impact})/V_{test}) \times points_{test\ speed}$$

For test speeds above 40km/h points are available on a pass/fail basis only. For each of these test speeds points are awarded when a speed reduction of at least 20 km/h is achieved related to actual test speed. It was acknowledged within the working group that at the moment it is not realistic to ask for full avoidance at speeds above 40 km/h as this would require a relatively early AEB activation at a point in time where the pedestrian has not yet entered the vehicle path. By requiring the impact speed to be reduced with at least 20 km/h, it brings the severity of the crash into the range where passive safety measures are designed to work.

The number of points available for the different test speeds is the same for each of the 4 scenarios based on exposure multiplied by injury levels coming from the accident data. The available point distributions for all scenarios are shown in the figure below.

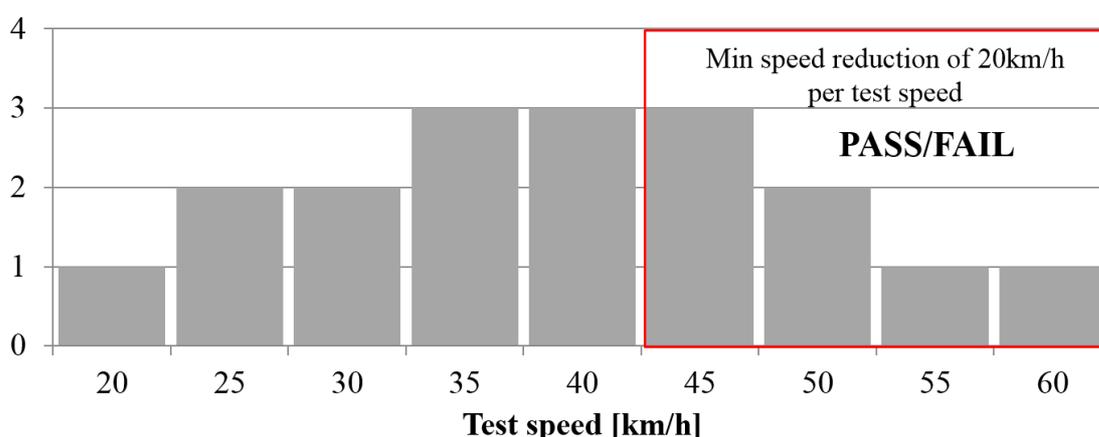


Figure 6. Maximum points per test speed

### Human Machine Interface

The effectiveness of the whole system does not only depend on the speed reduction achieved. The ON/OFF rate of the system is highly influencing the actual performance. At this moment, Euro NCAP has not defined qualitative criteria for warning due to the limited knowledge available on this subject. However, points are

awarded to systems that encourage use, for instance making it less easy to switch the system off or avoiding the system to automatically switch off at low ambient lighting conditions.

### Scoring

For AEB Pedestrian, only the autonomous emergency braking functionality is considered and HMI points will only be awarded if the AEB system is default ON at the start of every journey.

For the total score of these systems, the normalized sub-scores (as a percentage of the maximum points available) of AEB and HMI are weighted and summed.

$$AEB\ Pedestrian\ total\ score = (AEB\ score \times 5) + (HMI\ score \times 1)$$

A scoring example for an AEB Pedestrian system is provided below.

**Table 1**  
**Example of AEB function test results in CVFA scenario**

Vtest	points <sub>test speed</sub>	Vimpact	Score <sub>test speed</sub>
20 km/h	1.000	0 km/h	1.000
25 km/h	2.000	0 km/h	2.000
30 km/h	2.000	0 km/h	2.000
35 km/h	3.000	0 km/h	3.000
40 km/h	3.000	20 km/h	1.500
45 km/h	3.000	25 km/h	3.000
50 km/h	2.000	30 km/h	2.000
55 km/h	1.000	40 km/h	0.000
60 km/h	1.000	Not tested	0.000
<b>Total</b>	<b>18.000</b>		<b>14.500</b>
<b>Normalised score</b>			<b>80.6%</b>

#### Assumed normalized scored for this example in the other scenarios

- Normalized score in CVNA-25 scenario: 76.7%
- Normalized score in CVNA-75 scenario: 100.0%
- Normalized score in CVNC scenario: 45.3%

Averaged AEB score for the four scenarios = 75.7%

#### HMI score:

- De-activation of the system not possible with a single push on a button **2 points**
- No FCW at speeds over 40 km/h **0 points**
- System switches off at low ambient lighting conditions **0 points**

Based on the above, the normalized HMI score = 50.0%

In total, the AEB Pedestrian total score will be:

$$\begin{aligned} AEB\ Pedestrian\ total\ score &= (AEB\ score \times 5) + (HMI\ score \times 1) \\ &= 5.0 \times 75.7\% + 1.0 \times 50.0\% \\ &= 4.285\ points \end{aligned}$$

Finally, the AEB Pedestrian score is included in the overall rating for the vehicle within the Pedestrian Protection box. It should be noted that Euro NCAP will only include the AEB Pedestrian score when the total passive safety protection score (headform, upper legform and lower legform) is 22 points or higher.

### DISCUSSION

With the introduction of a relatively simple test to assess advanced systems like AEB, Euro NCAP would like to promote the introduction of these systems in the market. From the start of the development of the protocols, it was clear that the protocol would have to be reviewed and updated within a couple of years. For AEB VRU, additional cyclist scenarios will be included in 2018. On top of that, Euro NCAP will consider how and if it is

needed to also include other scenarios in daytime or obscure lighting conditions to the assessment of these systems.

The final decision whether the articulated pedestrian targets are to be used from 2016 onwards is yet to be made. As sensor systems get more advanced, the articulated dummy seems to support a more robust decision making process which improves system performance and acceptance.

All in all, Euro NCAP will continue to develop the requirements for AEB technologies to keep up with the development of these technologies and to ensure high quality systems for consumers.

## **CONCLUSIONS**

Almost half of European road deaths in urban areas are pedestrians and cyclists. Vehicle design and technology such as forgiving front-ends and avoidance systems can help address this problem. In recent years, a number of vehicle manufacturers have started to offer AEB Pedestrian systems that mitigate the consequence of a potential crash with pedestrians and/or cyclist. To promote and guide the further development of these systems, Euro NCAP will adopt AEB Pedestrian systems in the rating from 2016 onwards. Based on the expected performance of current systems and accident priorities, test scenarios and an assessment scheme have been agreed between the main stakeholders in Europe. The proposed procedures are considered a first step and will be updated and expanded upon in the coming years.

## **ACKNOWLEDGEMENT**

The P-NCAP working group was able to deliver the test and assessment protocols in time for implementation in 2016 due to all the valuable work done within and outside of the working group.

### **P-NCAP WG members**

ADAC, BAST, IDIADA, NL-MOT/RDW, Swedish Transport Administration (STA), Thatcham, TNO and UTAC.

The members of the P-NCAP WG have all put significant effort and resources into the development and verification of these protocols. OEMs and suppliers are acknowledged for their support and feedback on the protocols, and special thanks goes out to the OEMs represented in ACEA/JAMA/KAMA for supporting the development of the protocols by funding and supporting round robin test series.