IMPLEMENTATION OF AUTONOMOUS EMERGENCY BRAKING (AEB), THE NEXT STEP IN EURO NCAP'S SAFETY ASSESSMENT

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ABSTRACT
Euro NCAP has released its updated rating scheme for 2013-2016 that outlines, amongst other technologies, the implementation of Autonomous Emergency Braking (AEB) technologies within the overall rating scheme. Three types of AEB technologies will be included in the rating scheme, starting with low speed car-to-car AEB City and higher speed car-to-car AEB Inter-Urban in 2014, followed two years later by AEB Pedestrian.

In 2011 the Primary Safety Technical Working Group (PNCAP TWG) started working on AEB protocols, where Euro NCAP members have contributed to the development of the Test and Assessment protocols. They have been developed in a relatively short time, by finding the commonalities and discussing the differences between different initiatives from industry, insurers and others that were the main source of input to the working group.

Recently, both AEB City and AEB Inter-Urban protocols were finalized. The test protocol details a series of tests, following an incremental speed approach for systems with AEB and Forward Collision Warning (FCW) functionality, and specifies in detail the target vehicle to ensure the highest level of reproducibility and repeatability. The assessment protocols identify the scoring principle and relative weight of each scenario for inclusion in the overall rating scheme. This paper describes both protocols.

BACKGROUND
In 2009, Euro NCAP introduced its new rating scheme [1], which allows new technologies to be implemented in the overall assessment of a new vehicle. The new rating scheme consists of four areas of assessment, also called boxes, which together result in one overall rating. The four areas of assessment are Adult Occupant Protection (AOP), Child Occupant Protection (COP), Pedestrian Protection (PP) and Safety Assist (SA).

With the introduction of the new rating scheme, Euro NCAP also released a roadmap for the years 2010-2015 [2] where the implementation of AEB technologies was outlined. Low speed AEB systems, AEB City, were directly linked to whiplash prevention and therefore added to the AOP box. It is noted that AEB City systems primarily avoid or mitigate whiplash injuries in the opponent vehicle and are seen as partner protection systems. Euro NCAP deliberately does not make a distinction between self or partner protection when appointing technologies to a certain box.
With regards to high speed AEB Inter-Urban systems, these are included in the SA box as their benefits are broad and are not directly related to any of the tests performed in the other boxes.

Euro NCAP Advanced
By opening the rating scheme for new technologies, Euro NCAP also introduced an award system called Euro NCAP Advanced to be able to promote new important technologies, explain their safety potential and learn how they are evaluated by the carmakers themselves. Amongst other technologies, AEB systems from several manufacturers were put forward to achieve such a Euro NCAP Advanced reward. The accident analyses carried out to support their applications suggest that AEB systems could reduce rear end crashes by more than 25%.

AEB Survey
Although the expected benefit of AEB technology is significant, the functionality and availability of AEB in Europe is far from standardized. In 2012, Euro NCAP carried out a survey on the current (per model) market availability of AEB systems within the EU-27. The survey revealed that AEB is still not offered on 79% of the car models on sale in Europe and that 66% of manufacturers do not offer an AEB system on any of their new car models. The survey showed that information on AEB was generally hard to find at manufacturers websites and that there was no consistency in naming between brands. The equipment that was offered was mostly optional, even though there were encouraging signs of serial fitment of AEB City technology on small class cars in particular.

Detailed results can be found on the Euro NCAP website [3].

WORKING GROUP

As for all Euro NCAP protocols, the development was done within a collaborative Working Group. For AEB, the P-NCAP TWG was given the task to deliver a test and assessment procedure by the end of 2012, for implementation in 2014. Although car makers and suppliers were not directly involved in the working group, several meetings were organised between representatives of both sides to discuss the procedures. More importantly, the work of the group took advantage of and brought together the results delivered by several main initiatives in Europe that where looking into the development of AEB test and assessment procedures.

Initiatives

Within Europe, four main initiatives were running in parallel, all with the same goal of developing test procedures for assessing AEB and FCW systems: ADAC, AEB, ASSESS and vFSS.

The German automobile club ADAC, one of the Euro NCAP's member organisations, had developed an inflatable vehicle target to be able to perform a Comparative test of advanced emergency braking systems on high end vehicles [4] with support from automotive first-tier suppliers Continental and Bosch. Their first test series using the target concluded that any of the advanced emergency braking systems tested were capable of significantly reducing the severity of rear-end collisions.

The RCAR Autonomous Emergency Braking group [5], led by Thatcham has the aim of 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 consisted of insurance institutes, supported by Volvo Car Corporation and first-tier supplier Continental.

The European Commission sponsored project ASSESS (Assessment of Integrated Vehicle Safety Systems for improved vehicle safety) led by Humanetics Innovative Systems had specific project goals to develop harmonized and standardized assessment procedures and related tools for selected integrated safety systems [6]. The project partners consisted of nine research institutes, four of which were Euro NCAP laboratories: BASt, IDIADA, TNO and TRL. From industry side, Daimler, PSA and Toyota participated as car manufacturers and Bosch and TRW as first-tier suppliers.

The fourth initiative was vFSS (Advanced Forward-Looking Safety Systems), a German partnership led by DEKRA, in which all German vehicle manufacturers were represented (Audi, BMW, Daimler, Porsche and VW) along with Ford, Opel, Honda and Toyota [7]. Other project partners were insurance institutes Allianz and GDV and the research institute BASt. The aim of the vFSS project was in line with the other initiatives: the development of test procedures for driver assistance systems (in particular advanced emergency braking systems) in order to ensure a robust assessment of such systems.

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 target used.

TEST SCENARIOS AND TARGET

Within the different initiatives, there was a large overlap of the proposed test scenarios, based on an extensive analysis of real world rear-end crashes. Overlaying the proposed test scenarios, the P-NCAP TWG agreed to the following test scenarios for AEB City and AEB Inter-Urban:

AEB City

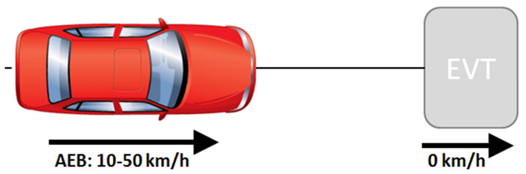

Figure 1. AEB City scenario, CCRs

AEB Inter-Urban

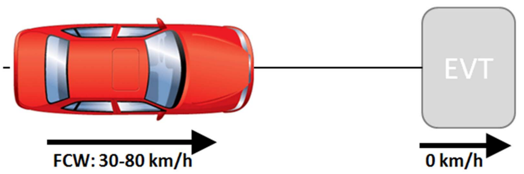

Figure 2. AEB Inter-Urban scenario, CCRs

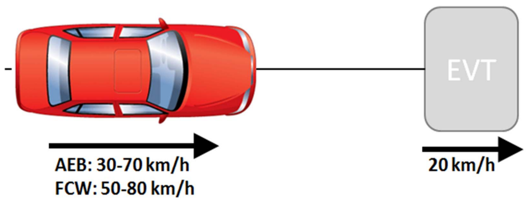

Figure 3. AEB Inter-Urban scenario, CCRm

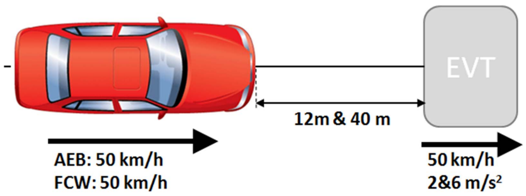

Figure 4. AEB Inter-Urban scenario, CCRb

For the AEB Inter-Urban scenarios CCRm and CCRb, the FCW function tests are performed in case there is no complete avoidance by the AEB function. For the CCRs scenarios, there is no AEB function assessment.
FCW functionality is assessed by reacting to the warning that is issued after an imminent collision has been detected. A brake robot will apply the brakes 1.2s after the warning starts to simulate driver reaction time.

Incremental Speed Approach
The range of speeds shown in the figures above will be tested in an incremental approach. Starting at a very low speed, the approach speed of the Vehicle Under Test (VUT) is stepwise increased by 10 km/h while impact with the Euro NCAP Vehicle Target (EVT) is fully avoided. When there is first contact between the VUT and the EVT, an additional test is performed at a speed 5 km/h lower and testing continues with 5 km/h increments until the speed reduction achieved of the VUT is less than 5 km/h.

Euro NCAP Vehicle Target
Different types of target were studied within the aforementioned initiatives but also by the vehicle manufacturers for in-house evaluation. A number of the most promising targets were evaluated at a number of vFSS events to verify their ability to be seen by different types of sensors and their robustness. It was concluded that the ADAC inflatable target was the preferred target for the moment, based on its sensitivity to current generation Radar, LIDAR, camera and PMD sensors. The details of the target are presented by ADAC in separate paper [8]. Euro NCAP adopted this target for its first phase of testing. For this purpose, it has a new cover that matches a real car and was subsequently referred to as the Euro NCAP Vehicle Target.

Figure 5. Euro NCAP Vehicle Target (EVT)

Test equipment and test track
Euro NCAP uses different laboratories for all of its tests. To ensure repeatable and reproducible results now and in the future, the WG decided to set strict tolerances for testing 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 are listed below:

- Speed of VUT	+ 1.0 km/h
- Speed of EVT	+ 1.0 km/h
- Lateral deviation	0 ± 0.1 m
- Relative distance (CCRb)	0 ± 0.5m
- Yaw velocity	0 ± 1.0 °/s
- Steering wheel velocity	0 ± 15.0 °/s

Due to these strict tolerances, all of the Euro NCAP laboratories will use both steering and brake robots to control the vehicle during test. Details on the test execution and the equipment used can be found in a paper by Thatcham, one of the Euro NCAP's test laboratories [9].

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. However, 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 with no strong shadows cast across the test area other than those caused by the VUT or EVT. 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 systems includes three different functionalities: the Autonomous

Emergency Braking function, the Forward Collision Warning function and the Human Machine Interface. For AEB City systems, the FCW function is not taken into account as, for low speeds, warning is not considered effective.
The assessment protocol is able to cope with AEB systems that have AEB (auto-brake) or FCW (warning only) functionality only or a combination of both functionalities. AEB only and AEB/FCW combined systems are able to score full points, whereas FCW only systems can only score the points available for FCW and HMI.

Assessment Criteria
For both the AEB and FCW functionality, 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 target is completely avoided. Where contact occurs, the points are awarded on a sliding scale basis, where the proportion of speed reduction based on the relative test speed determines the proportion of available points scored, until the speed reduction achieved is less than 5 km/h and testing stops.

Score = $[(v_{rel\ test} - v_{rel\ impact})/v_{rel\_test}] \times points_{test}$

The number of points available for the different test speeds is based on accident frequency, where the most frequent speed crashes are given more weight than others. The available point distributions for FCW and AEB for the CCRs and CCRm scenarios respectively are shown in the figures below. The point distribution is based on GIDAS accident data.

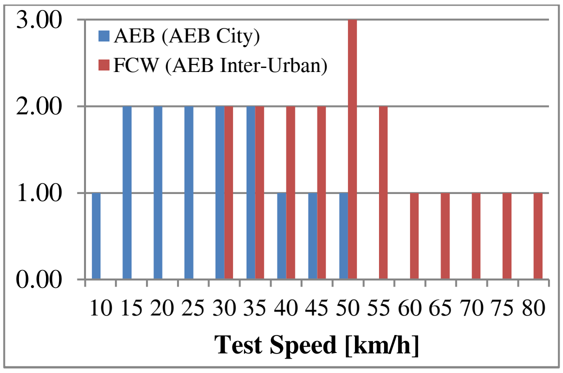

Figure 6. Maximum points per CCRs test speed for AEB (City) and FCW (Inter-Urban)

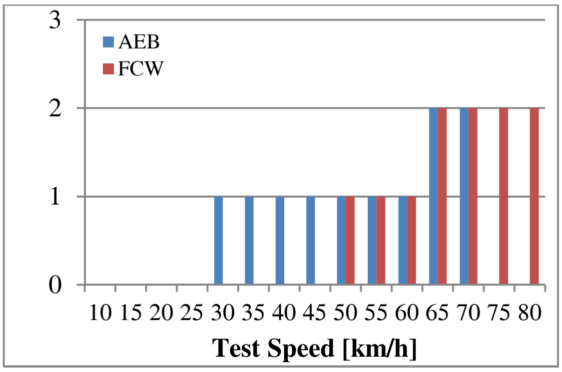

Figure 7. Maximum points per CCRm test speed for AEB (Inter-Urban) and FCW (Inter-Urban)

The points available for the CCRb scenarios for both AEB and FCW functionality are as follows:

Table 1
Available points for CCRb scenarios

		EVT deceleration level	
Headway		**2.0 m/s²**	**6.0 m/s²**
	12 m	1.00	1.00
	40 m	1.00	1.00

Human Machine Interface
The effectiveness of the whole AEB system, both AEB and FCW functionality, highly depends on the HMI of the warning and the ON/OFF rate of the system, especially for the FCW functionality. At this moment, Euro NCAP has not defined qualitative criteria for warning due to the limited knowledge available on this subject. However, some points are awarded to systems that encourage use and offer supplementary warnings.

AEB City
To be eligible for assessment, the AEB City system needs to be fitted as standard to all vehicle models sold within the EU-27. Additionally, the system needs to completely avoid the impact up to 20 km/h.
As for AEB City, only the autonomous emergency braking functionality is considered.HMI points will only be awarded if the AEB system is default ON at the start of every journey. When this condition is met, points are awarded for the ON/OFF switch when this is more sophisticated than a simple “push on a button”, e.g. hold button for several seconds, hence discouraging easy disconnection at each journey.

AEB Inter-Urban
The fitment rate requirement for AEB Inter-Urban systems to be eligible for assessment is less stringent than for AEB City. In the first two years 50% of all sales of a vehicle model should have the

system fitted. In 2016 this should be 70%, and in 2017 the AEB Inter-Urban system has to be standard fit.

In AEB Inter-Urban, the AEB and FCW functionality needs to be default ON at the start of every journey, when available. In addition, the forward collision warning must be loud and clear to the driver. When the above conditions are met, HMI points can be scored for the following items:

- Activation/deactivation of AEB and/or FCW Needs to be more sophisticated than just pushing a button once
- Supplementary warning for FCW. In addition to the required audiovisual warning, a more sophisticated warning like head-up display, belt jerk, brake jerk or any other haptic warning is available.
- Reversible pretensioning of belt. When the system detects a critical situation that can possibly lead to a crash, the belt can already be pre-tensioned to prepare for the oncoming crash.

Total Score

For the total score of AEB City and AEB Inter-Urban, the normalized sub-scores (as a percentage of the maximum points available) of HMI, AEB and FCW functionality weighted and summed.

For AEB City:
Score = (AEB x 2.5) + (HMI x 0.5)

For AEB Inter-Urban:
Score = (AEB x 1.5) + (FCW x 1.0) + (HMI x 0.5)

Scoring example for an AEB Inter-Urban system:

Table 2
Example of AEB function test results in CCRm scenario

Vtest [km/h]	Vrel test [km/h]	Vimpact [km/h]	Vrel impact [km/h]	Score
30	10	0	0	1.000
35	15	0	0	1.000
40	20	0	0	1.000
45	25	0	0	1.000
50	30	30	10	0.667
55	35	45	25	0.286
60	40	55	35	0.125
65	45	-	-	0.000
70	50	-	-	0.000
Total				**5.078**
Normalised				**46.2%**

AEB function in CCRb scenario: 67.5%

AEB score = average(CCRm,CCRb)
= 56.9%

FCW function (assumed normalized scores for this example)

- CCRs scenario: 84.7%
- CCRm scenario: 76.4%
- CCRb scenario: 100.0%

FCW score = average(CCRs,CCRm,CCRb)
= 87.0%

HMI score:
Prerequisites not met. System can be switched OFF with a single push on a button.
AEB Inter-Urban total score:
(AEB x 1.5) + (FCW x 1.0) + (HMI x 0.5)
56.9% x1.5 + 87.0% x1.0 + 0% x0.5 = 1.724 points

Finally, the AEB scores are included in the overall rating for the vehicle. The AEB City scores are awarded in the Adult Occupant Protection box and the AEB Inter-Urban scores are awarded in the Safety Assist box.

DISCUSSION

With the introduction of a relatively simple test to assess advanced systems like AEB, Euro NCAP wants to push the introduction of these systems into the market. From the start of the development of the protocols, it was clear that there would be a revision of the protocol within a couple of years.

The target used during the tests represents only half a car's length and can only be used in non-offset car-to-car rear scenarios. In addition, the target is relatively easy to identify and can be seen as an overrepresentation, especially for radar systems. As sensor systems get more advanced, the target should align better with the vehicle it is representing.

For the moment, only rear end impacts are included, where it is foreseen that systems will advance rapidly and more scenarios can be added, which can be more challenging in the next phase.

The requirements for HMI are very basic and these requirements will be reviewed in the next years when a number of systems are assessed and best practice is identified.

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

In 2014 Euro NCAP will start assessing both AEB City and AEB Inter-Urban systems, which are taken into account in the Adult Occupant Protection and Safety Assist boxes respectively. The assessment is based on three functionalities; AEB, FCW and HMI.

The working group will continue to develop protocols for AEB pedestrian and an extension of the AEB City and Inter-Urban protocols.

ACKNOWLEDGEMENT
The P-NCAP working group was able to deliver the test and assessment protocols in time for implementation in 2014 due to all the hard work done within and outside of the working group.

P-NCAP WG members
ADAC, BASt, DEKRA, Department for Transport (DfT), IDIADA, NL-MOT/RDW, Swedish Transport Administration (STA), Thatcham, TNO and UTAC

Euro NCAP wants to thank the OEMs and suppliers for their support and feedback on the protocols and all the members of the P-NCAP WG for all effort and resources they put into the development and verification of these protocols.

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