

# **BEYOND SAFETY LEGISLATION: CONTRIBUTION OF CONSUMER INFORMATION PROGRAMMES TO ENHANCED INJURY MITIGATION OF PEDESTRIANS DURING ACCIDENTS WITH MOTOR VEHICLES**

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## **ABSTRACT**

During the past five years, a Euro NCAP technical working group on pedestrian safety has been working on improving test and assessment procedures for enhanced passive pedestrian safety.

After harmonizing the tools and procedures as much as possible with legislation, the work was mainly focused on the development of grid procedures for the pedestrian body regions head, upper leg with pelvis and lower leg with knee. Furthermore, the test parameters for the head and the upper leg were revised, a new lower legform impactor was introduced and the injury thresholds were adjusted or, where necessary, the injury criteria were changed. Finally, the assessment limits and colour scheme were refined, widening the range and adding two more colours in order to provide a more detailed description of the pedestrian safety performance.

By abstaining from an assessment based on a worst point selection philosophy, the improved test point determination procedures that were introduced during the years 2013 and 2014 give a more homogeneous, high resolution picture of the pedestrian safety performance of the vehicle frontends. By using a uniform grid for each test zone approximately 200 test points, evenly distributed within each area, can now be assessed per vehicle. The introduction of the flexible pedestrian legform impactor in 2014 enables a more realistic injury prediction of the knee and the tibia using a biofidelic test tool.

With the new upper legform test that has been launched in 2015 the assessment in that area is now focusing on the injured body region instead of the injury causing vehicle part and thus is aligned with the approach in the remaining body regions head and lower leg. At the same time, a monitoring test with the headform impactor against the bonnet leading edge is closing the possible gap between the test areas to identify injury causing vehicle parts that moved out of focus due to the introduction of the new upper legform test.

The paper describes the new test and assessment procedures with their underlying philosophy and gives an outlook in terms of open issues, specifying the needs for further improvement in the future.

In parallel to the work of the pedestrian subgroup, a Euro NCAP working group on heavy vehicles introduced a set of protocol changes in 2011 that were related to the assessment of M1 vehicles derived from commercial vehicles, with a gross vehicle weight between 2.5 and 3.5 tons and 8 or 9 seats. The paper also investigates the applicability of the new pedestrian test and assessment procedures to heavy vehicles.

## **INTRODUCTION**

A Euro NCAP technical working group on pedestrian safety has elaborated during the past five years updated protocols for testing and assessment of passive pedestrian protection systems of passenger cars. After harmonizing the test tools and procedures as much as possible with pedestrian legislation, the overall objective of the group was to make the assessment of the pedestrian protection offered by the vehicle front-end more robust, reproducible, accurate and realistic. The work was mainly focused on the improvement of test procedures for the body regions head, pelvis, upper leg and lower leg, also including a new impactor for the lower leg test as well as a vehicle grid markup, the adaptation of injury criteria and a modified visualization by introducing a five colour scheme for all rated test procedures.

In parallel to the activities undertaken by the pedestrian working group, an ad hoc group of Euro NCAP developed specific test procedures for active systems of passive pedestrian safety, in particular active bonnets, that were as from version 5.3 onwards included within the pedestrian testing protocol. Another working group dealt with issues related to heavy M1 vehicles derived from commercial vehicles and the applicability of the new pedestrian test and assessment procedures to this class of vehicles.

This paper describes the main results of work undertaken by the pedestrian safety working group of Euro NCAP with input from the ad hoc working group on active pedestrian protection systems and the working group on heavy commercial vehicles that were successively implemented within the Euro NCAP test and assessment protocols for pedestrian protection.

## **EURO NCAP UNTIL 2012**

The first phase of work performed by the pedestrian safety group was mainly focused on a harmonization with Commission Regulation (EC) No. 631/2009 prescribing the test and assessment procedures for M1 vehicle type approval in Europe (European Commission, 2009). The borderline of test areas for child and adult headform impactors that were previously, in principle, described by wrap around distances (WAD) between 1000 and 1500 for the child headform impactor and between 1500 and 2100 for the adult headform impactor, was changed from WAD 1500 to WAD 1700, following the technical prescriptions of the Commission Regulation. Different to a hard borderline between both headform impact zones in legislation, Euro NCAP defined a transitional area between WAD 1500 and WAD 1700 where to use the adult headform impactor in the windscreen and windscreen base area and the child headform impactor on the bonnet and its periphery. In 2010, by introducing testing protocol version 5.0, the headforms themselves were changed from a 4.8 kg adult headform impactor with 165 mm diameter to a 4.5 kg impactor with unchanged dimensions, and from a 2.8 kg child headform impactor with a diameter of 130 mm to a 3.5 kg impactor with a diameter of 165 mm.

The philosophy of a worst point selection remained unchanged within Euro NCAP until the end of 2012: Both, the adult and the child headform areas were divided into six sixths, each of them subdivided into four quarters. While Euro NCAP selected the potentially most injurious impact point within each of the twelve sixths, the vehicle manufacturer was allowed to nominate up to three quarters within each sixth where then Euro NCAP again picked the expected hardest impact point. Altogether between 12 and 24 head impact points were selected, each sixth scored with a maximum of 2 assessment points. Although being assessed entirely, not all of these points were actually tested, given that points located on certain structures were defaulted either red (no score, e.g. on the A-Pillar) or green (full score, e.g. on the centre of the windscreen), symmetry occurred or that previous tests on adjacent areas already indicated the performance in the area to be assessed. For the upper and lower legform area, the method of worst point selection remained unchanged as well: both areas were divided into three thirds, each of them subdivided into two halves. Again, Euro NCAP selected the most injurious point within each third, while the manufacturer was given the possibility to nominate the remaining half of each third, where afterwards Euro NCAP again selected the hardest point. Altogether, between 3 and 6 impact points were determined in both, the upper and the lower legform area, each third scored with a maximum of 2 assessment points. Like in the headform area not all of these points were tested, given that symmetry occurred or there was agreement between the manufacturer and Euro NCAP of particular points defaulted red (no score) without being tested.

The last version of the Euro NCAP test and assessment protocols applying the philosophy of worst impact point selection is still valid nowadays as fall back scenario when the manufacturer opposes to the grid procedure that will be described in the following. In that case, the five colour scheme has to be applied.

An overview of the Euro NCAP test and assessment procedure before 2013 is depicted in Figure 1:

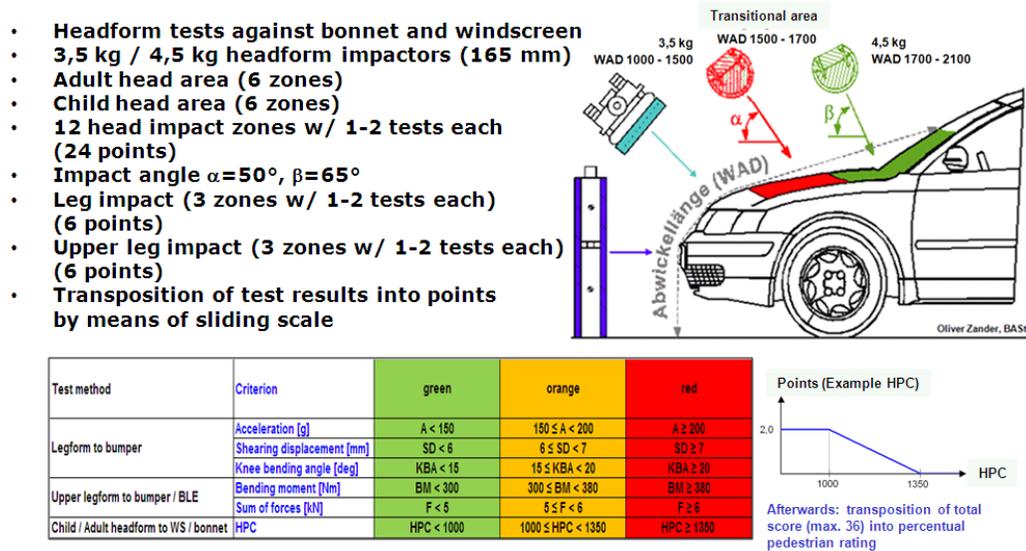


Figure 1. Euro NCAP test and assessment procedure before 2013.

## EURO NCAP 2013

The second phase of work performed by the pedestrian safety working group mainly concentrated on the grid procedure for the headform impactor tests. The principal idea of the new method was to abstain from a, to some extent, subjectively performed selection of worst case head impact points, towards an objective and homogeneous assessment of the entire headform area. By introducing the possibility of providing in-house simulation results by the vehicle manufacturer, the amount of tests was limited, keeping the testing effort in the previous range. At the same time, the sliding scale assessment procedure between HIC 1000 and HIC 1350 with three colours was changed to an incremental approach between HIC 650 and HIC 1700 and five color bands, the middle three of them having a range of HIC 350: HIC below 650 - green, 2 points; HIC between 650 and 1000 - yellow, 1.5 points; HIC between 1000 and 1350 - orange, 1 point; HIC between 1350 and 1700 - brown, 0.5 points; HIC over 1700 - red, no point.

According to the new method and starting from the intersection between the vehicle's vertical longitudinal centerplane and the WAD 1000 (C 0,0, see Figure 2) a grid with 100 mm \* 100 mm resolution on the xy plane is vertically projected onto the headform area that is, in principle, described by the WAD 1000 and 2100 and the side reference lines, where all grid points within a distance of less than 50 mm to the side reference lines are deleted, and additional grid points are marked on the side reference lines on the A-pillar. After the provision of the safety performance by means of colour information for each of the determined grid points by the OEM, a default minimum of 10 and, on request of the vehicle manufacturer, a maximum of 20 verification points is generated randomly. Additionally, the manufacturer is given the opportunity to select a maximum of 8 blue zones, each consisting of 1 or 2 grid points, where the safety performance is unknown or previous tests have indicated instable results, and which are tested once on the point selected by Euro NCAP, unless symmetries are being applied. Thus, in total a minimum of 10 and a maximum of 28 head impact tests are to be performed according to the headform grid method. After testing, a correction factor is calculated by the quotient of the sum of actual verification test results and the sum of the points resulting from the colour predictions. The correction factor provides an indication of how accurate actual testing matches the prediction and should be between 0.75 and 1.25 for the predictions to be accepted by Euro NCAP. By multiplying the sum of points obtained by the colour predictions times the correction factor, the actual performance of the predicted grid points is calculated.

In a last step, the total head score is calculated by including the number of green defaulted points and the actual test result from the blue zones, and scaled to the 24 points that are available for the head performance in box 3 (pedestrian protection) of the Euro NCAP overall rating scheme. A visualization of the test results by applying a five colour code scheme defined by the underlying results to each individual grid point completes the head assessment.

A flowchart describing the principal markup, test and assessment procedures for the headform grid is illustrated in Figure 2:

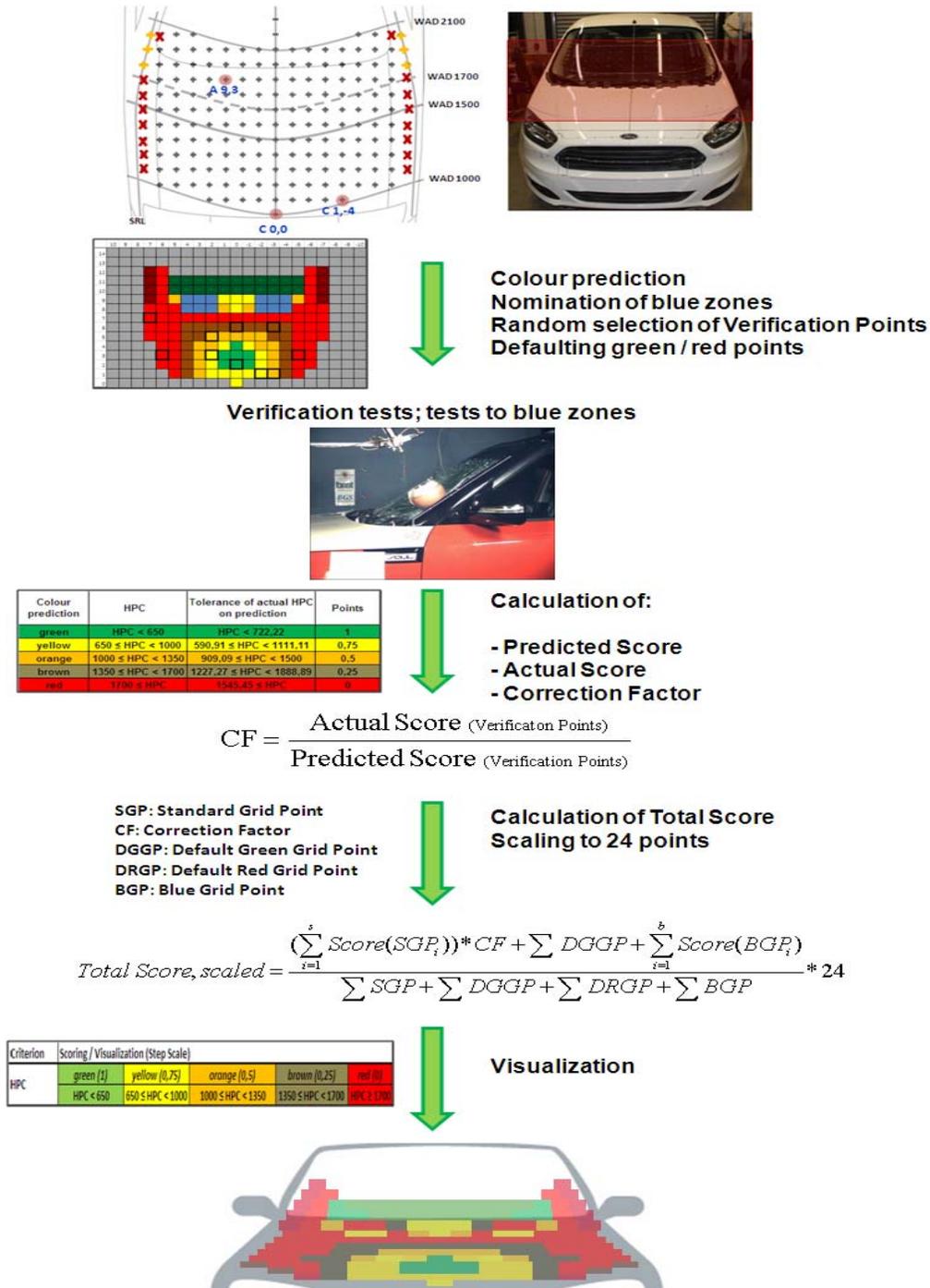


Figure 2. Euro NCAP headform grid procedure.

## EURO NCAP 2014

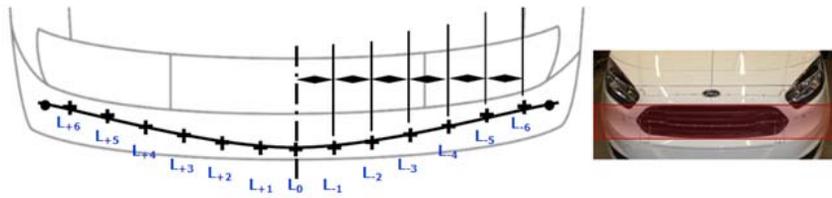
The next big step in the further development of the Euro NCAP pedestrian test and assessment procedures was finalized with the introduction of the flexible pedestrian legform impactor (FlexPLI) from the beginning of the year 2014 on. The FlexPLI with enhanced biomechanical properties compared to those of the lower legform impactor according to EEVC, in particular in the knee and tibia area, was developed by the Japan Automobile Research Institute (JARI) as from the year 2000 onwards and evaluated by a technical evaluation group (TEG) under the umbrella of the Working Party on Passive Safety (GRSP) of the United Nations Economic Commission for Europe (UNECE) since 2005. Last issues with the impactor were dealt with by an Informal Working Group on Phase 2 of GTR9 before UNECE Working Party 29 finally adopted the FlexPLI, in a first step, for the 01 series of amendments of UN Regulation No. 127 on Pedestrian Safety (UNECE, 2015) that has become effective on 22 January 2015. Until the mandatory use of the FlexPLI as from 1 September 2017 onwards, the vehicle manufacturers are given the choice to either submit new vehicles to type approval using the new test tool or to alternatively use the lower legform impactor developed by Working Group 17 of the European Enhanced Vehicle-safety Committee (EEVC).

With the implementation of tests with the FlexPLI, the Euro NCAP markup and test procedures changed from the subdivision of the upper and lower legform test area into six subareas each to a grid markup, testing every second grid point and allocating the test result to the corresponding adjacent grid points; besides, where possible, application of symmetry.

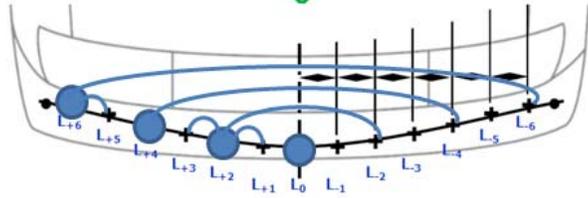
For the lower legform tests with the FlexPLI, starting at  $y_0$  (vehicle centreline), a grid with 100 mm resolution is marked in lateral direction onto the upper bumper reference line. If the distance between the last (outermost) grid point and the end of the test area is greater than 50 mm, an additional grid point is marked at a lateral distance of 50 mm to the last grid point onto the upper bumper reference line. After defining the starting point which is located either on  $y_0$  or one of its adjacent points, every second grid point is selected and tested. Where possible, symmetries are to be applied. All asymmetrical grid points not being tested are awarded with the worse of the two results coming from both adjacent grid points. Prior to the determination of the starting point by Euro NCAP, the vehicle manufacturer is given the choice to nominate grid points to be exempted from being assessed by taking over the results from adjacent or symmetrical identical grid points, thus these grid points need to be tested.

Along with the introduction of the FlexPLI in Euro NCAP, Zander (2011) derived upper performance limits from the injury criteria of the FlexPLI as equivalents for 20% tibia fracture risk, 15 deg knee bending angle of the EEVC WG 17 pedestrian legform impactor and a transposition of the results of PMHS testing reported by Bhalla et al. (2003) to the FlexPLI. In terms of assessment of the lower legform test results, the pedestrian subgroup decided to equally balance the injury risks related to the medial collateral ligament (MCL) and the tibia segments, whereas points for the MCL are only awarded in case of not exceeding the identified risk of 10 mm elongation for cruciate ligament rupture (ACL/PCL). Furthermore, as far as the tibia is concerned, only the highest of the four bending moments is taken into account for the assessment. Between the defined upper and lower performance limits for MCL elongation and tibia bending moment, a sliding scale is applied to both criteria. The total score for the lower legform area is calculated by adding the points for the individual grid points and scaling the results to 6 points. For visualization, a five colour scheme is applied.

Figure 3 describes in principle the markup, test and assessment procedure for the tests with the FlexPLI:



OEM to nominate points to be tested in either case  
 Definition of starting point (L<sub>0</sub> or L<sub>+1</sub>)  
 Use of symmetry, where applicable  
 Testing of every second grid point  
 Allocation of results to adjacent points



Criterion	Full score	Sliding Scale	0	Points
Tibia BM [Nm]	BM <sub>max</sub> < 282	282 ≤ BM <sub>max</sub> < 340	BM <sub>max</sub> ≥ 340	0-0,5
MCL-EL [mm]	El <sub>MCL</sub> < 19	19 ≤ El <sub>MCL</sub> < 22	El <sub>MCL</sub> ≥ 22	0-0,5
ACL/PCL-EL [mm]	El <sub>ACL/PCL</sub> < 10		El <sub>ACL/PCL</sub> ≥ 10	n/a

Calculation of grid point score:  
 - Tibia BM & MCL (use 10 mm ACL/PCL switch)  
 - Use of sliding scale  
 - Weighting of tibia and knee (50%/50%)

$$Score(GP) = Score(TibiaBM_{max}) + Score(MCL)$$

Calculation of total score  
 Scaling to 6 points

$$\frac{\sum_{i=1}^n Score(GP_i)}{n} * 6$$

Score (GP)	S=1	1>S>0,75	0,75≥S>0,5	0,5≥S>0,25	0,25≥S
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Visualization

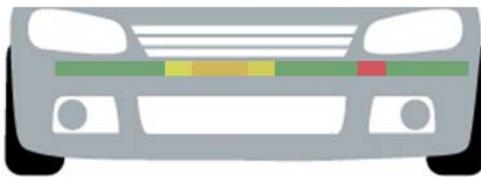


Figure 3. Euro NCAP FlexPLI grid procedure.

In 2014, the test procedure and the injury criteria for the upper legform impactor remained in principle unchanged. For the markup, however, a grid along with a five colour scheme based on grid point scores as for the headform and the lower legform tests was introduced. Besides, in 2014 only, a requirement was applied that in case of the distance between the last (outermost) grid point and the corner reference point being greater than 75 mm, an additional grid point was to be marked at a lateral distance of 50 mm to the corner reference point onto the bonnet leading edge reference line.

## **EURO NCAP 2015**

In 2015, Euro NCAP introduced two new pedestrian protection tests, namely the new upper legform test replacing the upper legform to bonnet leading edge test, and the headform to bonnet leading edge test.

### **Upper legform test**

As from 2015 onwards, the test with the upper legform impactor was fundamentally changed. Main reason for the significant change was an analysis of accident data showing a decreasing number of upper leg injuries caused by the bonnet leading edge, mainly due to the development of passenger vehicle frontends away from the typical Sedan design with sharp and high leading edges towards rounded frontends with lower and significantly softened leading edges. Besides, a change of injury patterns could be observed. Thus, a test with the upper legform impactor against the bonnet leading edge was no longer seen as best representing present real world injury data. However, real world accident data also showed that injuries of femur and pelvis are still of a high importance and therefore need to be addressed. Therefore, since this point in time, the injured body regions (pelvis, femur) rather than the injury causing vehicle parts are in the focus of assessment. Thus, the new test procedure is in line with the assessment of head and lower leg injuries. The new upper legform test aims for a more realistic simulation of the correct impact height and position of the human thigh and pelvis during an impact. Therefore, the nominal impactor weight is standardized to 7.4 kg and the upper load cell of the impactor is approximately aligned with WAD 930 as the height of the human hip joint. As the impactor centerline always aims at WAD 775, the corresponding WAD line is used as markup line for the upper legform grid points. The angle of impact  $\alpha$  depends on the outer vehicle contour and is perpendicular to a line on the same vehicle vertical longitudinal plane as the respective grid point, connecting the WAD 930 with the internal bumper reference line (IBRL). The IBRL is a connection line of the averaged grid point bumper beam heights (i.e. averaged height of the bumper beam at the lateral grid point position and its two adjacent markings at a distance of 33,3 mm from the grid point), marked on the bumper beam and projected onto the bumper fascia. The nominal vehicle speed  $v_0$  at time of first pedestrian contact, the relative speed  $v_c$  and the angle of impact  $\alpha$  of the upper leg, both measured at time of mid femur contact with the vehicle front, are used for calculation of the test speed  $v_t$  under application of a uniform impactor test mass of 10.5 kg (Figure 4). These calculations lead to possible impact angles of up to 44.7 degrees and maximum test speeds of 9.3m/s. As a comparison with the previous energy calculation procedure shows that the impact energy is reduced for many vehicles, the lower energy limit is reduced to 160 J, i.e. tests will now also be performed with energies below 200 J up to a minimum of 160 J. The upper energy limit of 700 J is not needed anymore because the results from the energy calculation are limited to 456 J.

For the upper legform test, starting at  $y_0$ , a grid with 100 mm resolution is marked in lateral direction onto the WAD 775 reference line up to a distance of no less than 50 mm to the lateral projection of the corner reference point. After defining the starting point which is located either on  $y_0$  or one of its adjacent points, every second grid point is selected and tested. Again, wherever possible, symmetries are to be applied. All asymmetrical grid points not being tested are awarded with the worse of the two results coming from both adjacent grid points. As for the lower legform tests, prior to the determination of the starting point by Euro NCAP, the vehicle manufacturer is given the opportunity to nominate grid points to be exempted from being assessed by taking over the results from adjacent or symmetrical identical grid points which thus must be tested.

Regarding the test evaluation, in contrary to the tests with the FlexPLI, no weighting of the maximum bending moments and the maximum sum of forces is done, but, as before, the worst of the two results is taken into account only. For the allocation of points to the particular test results, a sliding scale is applied between the upper and lower performance limits, which in terms of the maximum bending moments has been decreased to 285 or 350 Nm respectively.

The total score for the upper legform area is calculated by adding the points for the individual grid points and scaling the results to 6 points. For visualization, the five colour scheme that was already introduced in 2014 remains unchanged.

The flowchart of the upper legform markup, test and assessment procedure is shown in Figure 4:

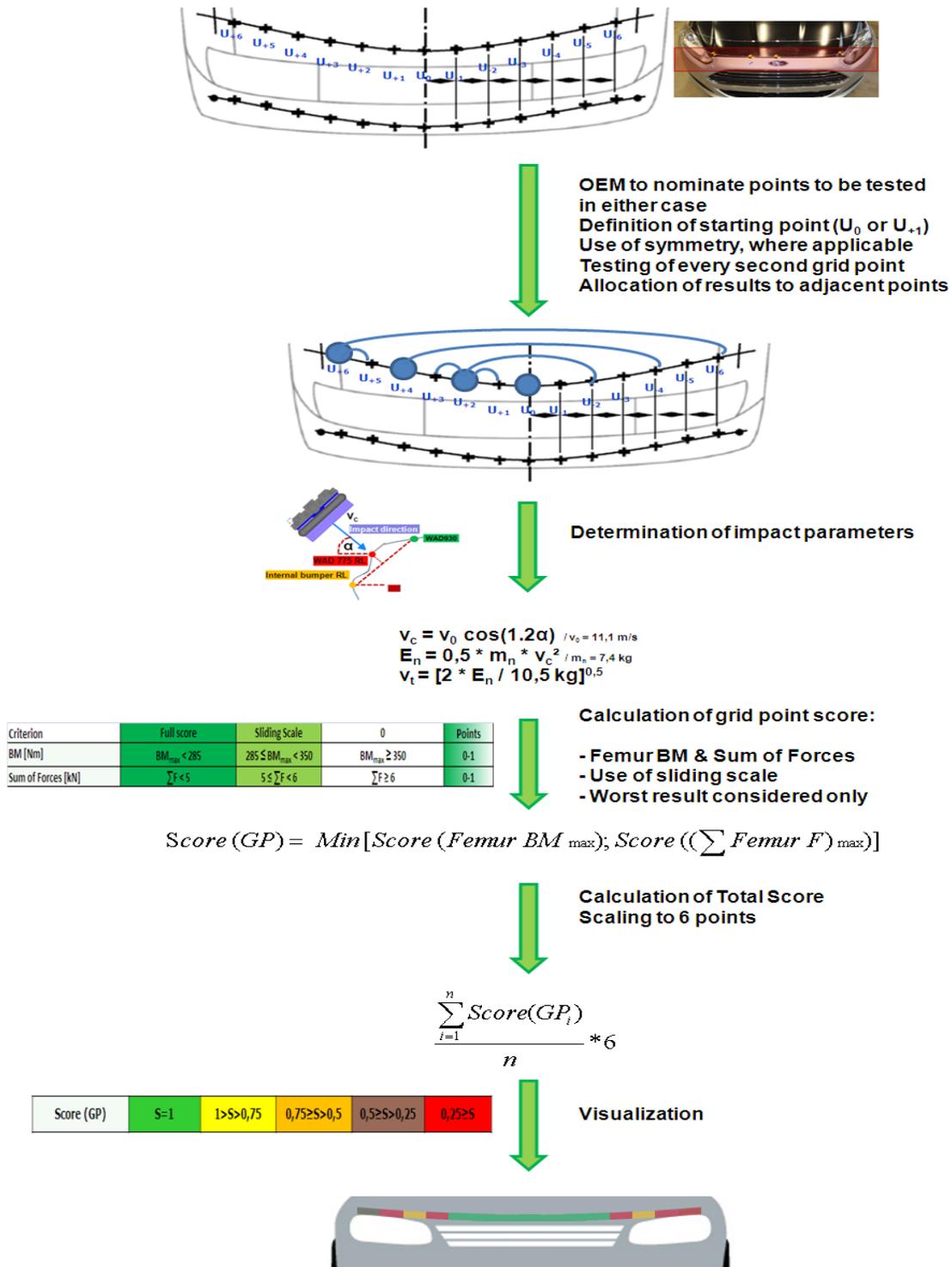


Figure 4. Euro NCAP New Upper Legform grid procedure.

## Headform to bonnet leading edge test

With the introduction of the new upper legform test, the bonnet leading edge is not anymore in the focus of Euro NCAP passive pedestrian safety assessment. Longhitano et al. (2005) and Zander (2014) found the bonnet leading edge having a high relevance as injury causing part in real world accident data. While in most cases, the bonnet leading edge is to some extent also covered by the new upper legform test, in case of being located between WAD 930 and WAD 1000 the bonnet leading edge reference line (BLE-RL) is not assessed anymore, see Figure 5.



*Figure 5. Untested critical area after introduction of Euro NCAP New Upper Legform grid procedure.*

To encounter the injury risk for vulnerable road users, in particular head injuries of small children, that is related to the bonnet leading edge, BAST had proposed to the Euro NCAP pedestrian safety working group a supplementary test with the child headform impactor against the bonnet leading edge as illustrated in Figure 6. The proposal was adopted by Euro NCAP and is detailed in Technical Bulletin 019 (Euro NCAP, 2014). For the vertical longitudinal plane of any upper legform grid point where the bonnet leading edge reference line is located between WAD 930 mm and WAD 1000 mm, an additional test with the child headform impactor is performed at the intersection of the vertical longitudinal plane with the bonnet leading edge reference line at an impact speed of 40 km/h under an impact angle of  $20^{\circ} \pm 2^{\circ}$  to the Ground Reference Level. The result of this test will be monitored against a HIC value of 650.



*Figure 6. Headform to bonnet leading edge test.*

## ACTIVE PEDESTRIAN PROTECTION SYSTEMS OF PASSIVE PEDESTRIAN SAFETY

An ad hoc Euro NCAP working group on active pedestrian protection systems has developed test and assessment procedures for deployable (non-static) systems, in particular pop up bonnets. As the legal requirements in that area do not cover significant aspects related to a pedestrian impact on a deployable system, the working group defined additional test and assessment procedures such as requirements for sensor systems and actuators to detect the hardest to detect pedestrian, requirements in terms of the total response time (TRT) of the system (time between the first contact of the pedestrian and full deployment of the safety system), performance requirements below the deployment threshold as well as at higher speeds after initiation of the deployment. Furthermore, the bonnet deflection due to pedestrian torso contact at pedestrian head impact location at time of the impact is required to not exceed a certain extent. Finally, the grade of fulfillment of the requirements defines the ambient conditions and test parameters, i.e. whether a system is tested in closed position, in fully deployed position or dynamically. The active pedestrian protection test procedures have been implemented within the test protocol version 5.3 and are valid since January 2011.

## HEAVY VEHICLES

In 2011, the Euro NCAP working group on heavy vehicles finalized the development of a set of changes to the different protocols that were particularly related to the testing and assessment of M1 vehicles derived from commercial vehicles, with a gross vehicle weight between 2,5 and 3,5 tons and 8 or 9 seats. In terms of pedestrian safety, BASt investigated the main differences between passenger cars and heavy commercial vehicles and proposed to the working group a set of particular test parameters that were different to the ones related to the standard pedestrian tests (Zander 2010-1 and 2010-2). Essentially, as main differences, Euro NCAP concluded a uniform head impact angle of 50 degrees rearwards and of 20 degrees forward of the bonnet leading edge reference line. Besides, at impact points with a height of the bonnet leading edge reference line greater than 835 mm, no test with the upper legform impactor against the BLE was required. In terms of rating, a soft landing for heavy vehicles was introduced: while in 2011, a fulfilment rate of 25 percent was required for 5 stars balancing criteria, the requirements were identical between commercial vehicles and passenger cars for four and five stars vehicles in 2014.

After finalization of the pedestrian test procedures for 2015, the Euro NCAP working group on pedestrian safety discussed the applicability of the modified tests to commercial vehicles. Gehring et al. (2014) examined several heavy commercial vehicles in detail (see Figure 7) and found the general applicability of the pedestrian testing protocol also to heavy vehicles.



*Figure 7. Investigation on the applicability of pedestrian testing protocol to heavy vehicles.*

As in the meantime a head impact angle of 20 degrees for tests on or forward of the BLERL had already been introduced for passenger cars, the remaining main difference to the pedestrian testing protocol was the adult headform angle of 50 degrees instead of 65 degrees for the passenger cars. During the investigations, Gehring et al. also found some potential for improvement that was well applicable to the pedestrian testing protocol. For practical reasons they proposed for steeper parts of the outer contour of the vehicle to markup the grid using a horizontal instead of a vertical projection. This proposal was adopted by Euro NCAP for all areas forward of the BLERL where the angle of a line, connecting the BLE-RL and WAD 1000 on the vehicle's vertical longitudinal centerplane, is greater than 60 degrees to the ground reference level. For relevant gaps in the markup area, the outer contour of the vehicle is to be approximated with tape, whereas between the lower bumper reference line and the BLE, a wrap around is to be created.

Due to the fact that within the new upper legform test the impactor centreline is always aligned with WAD 775 and thus the grid point height is always below 835 mm, the test exemption that was valid for the first phase of the heavy vehicles protocol is not applicable anymore with the introduction of the new test.

## DISCUSSION

In the past five years, the work performed by the Euro NCAP pedestrian safety working group with input from the ad hoc working group on active pedestrian protection systems as well as the heavy vehicles working group was mainly focused on three topics related to pedestrian safety. The first topic concentrated on harmonization with the legal requirements. In this context, amongst other things, the headform impactors and impact areas as well as the lower performance limits were aligned with the impactors and with the pass/fail criterion for one third of the impact area detailed in Commission Regulation (EC) No. 631/2009.

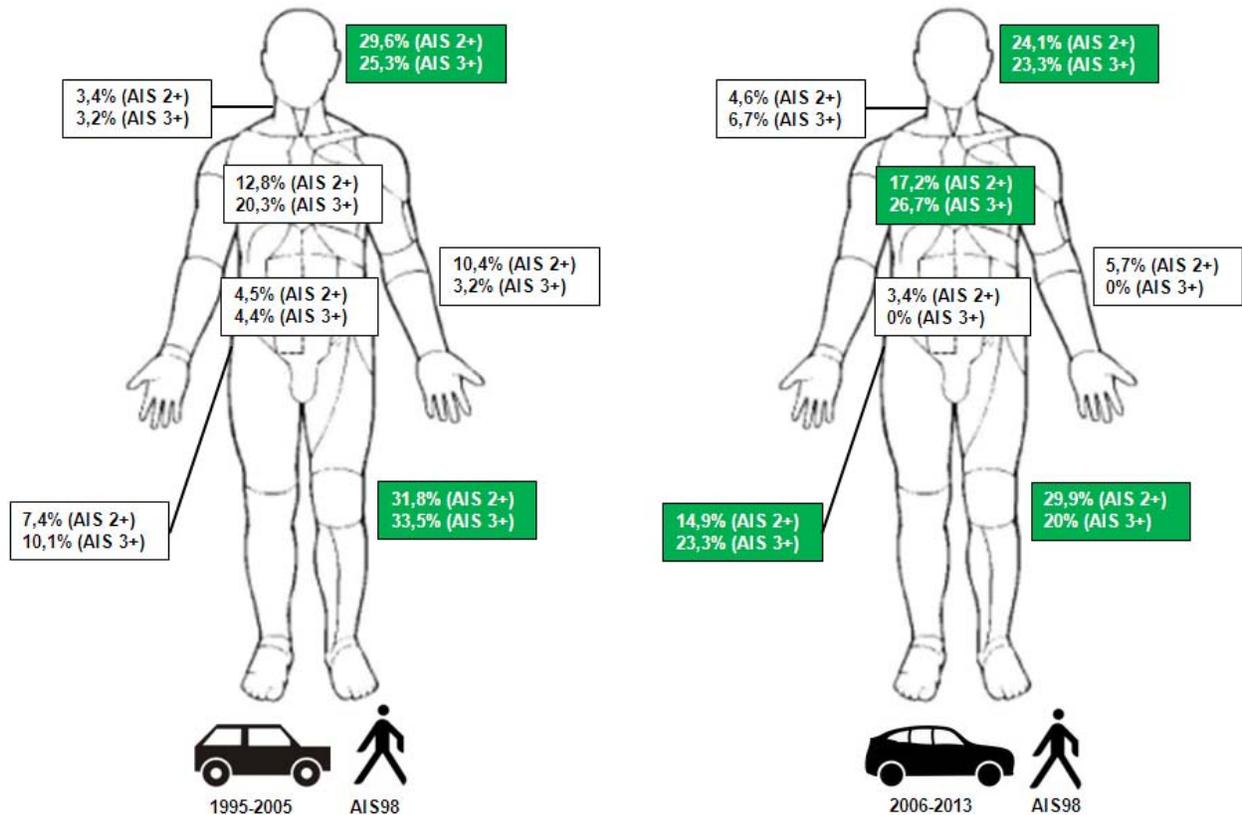
The second topic dealt with the objectification of the test procedures which was mainly done by introducing a high resolution grid over the entire front area to be assessed, resulting in detailed and homogeneous information in terms of the pedestrian safety performance. The grid approach has opened up the protocol to virtual testing predictions by vehicle manufacturers based on CAE. This way of combining physical testing and simulations is a first in consumer safety testing. The first two years of experience with the head grid method give evidence that the capability of predicting the safety performance is already at a high level. A study of the results of 70 vehicles tested and assessed according to the 2013 and 2014 protocols shows that the target of a correction factor between 0,75 and 1,25 was met in all but three cases. In most cases, the correction factor was significantly below the phase-in target of a deviation from the actual verification test results of no more than 25 percent. With the majority of cars having a positive correction factor above 1, the mean value was 1,05, meaning only a 5 percent underestimation by the given colour predictions, being well in line with the actual safety performance, proving the feasibility and applicability of the grid method using colour predictions.

Also testing active systems of passive pedestrian safety such as active bonnets is allowing human body model simulations as part of the evidence, what again is a new approach in the world of safety assessment and consumer testing.

The third topic was related to improved biomechanics of the test tools and procedures. With the introduction of the FlexPLI a biofidelic test tool with the capability of simulating the kinematic behaviour and human responses of the lower leg and knee area in an appropriate manner along with new injury criteria was introduced. Here, the first year of testing resulted in a majority of cars performing quite well in the lower leg area. A comparison of the 2013 and 2014 lower legform results gives evidence of the feasibility of the new test method using the FlexPLI. While in 2013 the 31 assessed vehicles resulted in an average of 5.7 points when tested with the EEVC WG 17 lower legform impactor, the mean value of the 39 vehicles tested in 2014 with FlexPLI and grid method was 5,9 points. In 2013, 87% of the vehicles scored full points in the lower legform area; in 2014, 76 % of vehicles had entire green bumper zones. None of the assessed vehicles scored less than 4.8 points.

The upper legform impactor remained, in principle, without further modification but with the focus on the injured body regions pelvis and femur rather than on the bonnet leading edge as injury causing part of the vehicle. To avoid crucial gaps in the assessment, the bonnet leading edge is covered by an additional test with the headform impactor, where necessary.

A fourth topic that has not yet been entirely covered by the work in the past years is the review of pedestrian injury patterns currently existing in real world accidents. Figure 8 depicts injury patterns occurring in vehicle to pedestrian collisions according to AIS98 code based on body parts (Zander et al., 2015):



**Figure 8. Injury patterns occurring in vehicle to pedestrian collisions according to AIS98 code based on body parts. The Figure shows the relations between the injury severity from AIS 2 (or AIS 3 respectively) to AIS6 (i.e. AIS2+ or AIS3+ respectively) in the particular body region and AIS2+ (AIS3+) injury severities of all body regions.**

The in-depth investigation of road accidents in Germany shows the relevance of AIS2+ and AIS3+ head and leg injuries (approximately 30% each) in particular for pedestrians involved in accidents with passenger cars registered between 1995 and 2005, i.e. in the time when the pedestrian impactors have been developed by the pedestrian safety working groups of the European Enhanced Vehicle-safety Committee (EEVC), but still before application of the Framework Directive 2003/102/EC as predecessor of Commission Regulation (EC) No. 631/2009. During accidents with passenger cars registered from 2006 onwards, i.e. after application of the Framework Directive, the distribution especially of the AIS3+ coded injuries has been shifted towards the body regions thorax and pelvis while the relevance for the head and leg remains more or less unchanged. From this study it can be concluded that on the one hand, a test procedure covering the pelvis area as now introduced by Euro NCAP is addressing the real world accident scenarios, but also that an additional thorax test could be expected to significantly reduce thoracic injuries on the other hand.

Another point that has not yet been addressed is the safety of cyclists being the second big group of vulnerable road users besides pedestrians. Euro NCAP is planning to cover cyclist safety as from 2018 onwards by means of active safety. However, like for pedestrians, a baseline passive safety level also for cyclists should be ensured, especially as active safety systems are expected to mitigate rather than avoid crashes in most cases. A current research project at BAST dealing with the development of passive test and assessment procedures for cyclists aims at implementing modifications to the current pedestrian procedures to adequately cover both groups of vulnerable road users.

Finally, in the light of demographical change the procedures to-be should also focus on elderly as vulnerable road users. The upcoming European SENIORS (Safety-ENhancing Innovations for Older Road userS) project settled under the European HORIZON 2020 framework programme will in particular address the passive safety of the elderly.

## CONCLUSIONS

The Euro NCAP pedestrian test and assessment protocols have been substantially updated and, where necessary, amended. Where possible, the procedures were harmonized with legislation. The assessment has gained objectivity by introducing grid procedures for all assessed body regions. The tools and test procedures have been modified to better reflect impact kinematics as well as the biomechanical response that can be observed in real world accidents. However, there is room for further improvement in terms of real world injuries and their coverage by the latest test and assessment procedures. The linearly guided upper legform impactor is lacking biofidelic behavior that should be reflected in terms of pedestrians' pelvis and femur. While knee and tibia injuries can be reliably predicted with the FlexPLI, the readings for the femur cannot be used mainly due to the lack of the torso mass of the pedestrian. Studies by Zander et al. (2011) have shown a good correlation between full scale dummy tests and tests with the FlexPLI with applied upper body mass (UBM); however, for an implementation within the existing test procedures the generated database needs to be extended by more vehicle frontends and human body simulations, i.e. further research is needed. In depth accident studies show a redistribution of pedestrian injury patterns towards thoracic and pelvic injuries that need to be addressed by new or improved impactors and test procedures. Furthermore, the procedures need to also cover cyclists as the second big group of vulnerable road users. Finally, pedestrian safety should also take care of the elderly being the most vulnerable road users. Results in this context can be expected from the upcoming European SENIORS project.

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