

**EUROPEAN COMMISSION  
DG RTD**

SEVENTH FRAMEWORK PROGRAMME

THEME 7

TRANSPORT - SST

SST.2011.RTD-1 GA No. 285106



**ASPECSS**

**Assessment methodologies for forward looking Integrated  
Pedestrian and further extension to Cyclists Safety**

Deliverable No.	AsPeCSS	
Deliverable Title	Final Publishable report	
Dissemination level	Public	
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Issue date	10/10/2014	

## Executive Summary

The overall purpose of the AsPeCSS project was to contribute towards improving the protection of vulnerable road users, in particular pedestrians and also cyclists, by developing harmonised test and assessment procedures for forward-looking integrated pedestrian safety systems.

Autonomous Emergency Braking (AEB) systems for pedestrians have been predicted to offer substantial benefit. On this basis, consumer rating programmes, e.g. Euro NCAP, are developing rating schemes to encourage fitment of these systems. One of the questions that need to be answered to do this fully is how the assessment of the speed reduction offered by the AEB can be integrated with the current assessment of the passive safety for mitigation of pedestrian injury. Ideally, this should be done on a benefit related basis.

This methodology has been proposed together with AEB test protocols and the standard Euro NCAP pedestrian passive safety test protocol as a test and assessment protocol for integrated pedestrian protection systems with pre-crash (AEB) braking. The methodology calculates the cost of pedestrian injury expected, assuming all pedestrians in the target population (i.e. pedestrians impacted by the front of a passenger car) are impacted by the car being assessed, taking into account the impact speed reduction offered by the car's AEB (if fitted) and the passive safety protection offered by the car's frontal structure. For rating purposes, this cost can be normalised by comparing it to the cost calculated for selected cars.

Furthermore, when developing the overall assessment methodology a first set of accident scenarios and associated test scenarios with weighting factors was first developed. A first estimation for accident scenarios was done taking advantage of previous work and additional information was needed using current data from Germany and the GB to identify severe crashes between passenger cars and pedestrians. To take results of previous projects into account and performing additional detailed analysis, available literature was reviewed and summarised into preliminary accident scenarios for AsPeCSS. Accident scenarios are categorizations of accidents happening in the real world. However, test scenarios are an abstraction of accident scenarios that can be reproduced in a test environment. Through several different factors the test scenarios and its weighting has been derived.

AsPeCSS has also worked on establishing specifications for test targets, test tools and test procedures used in AEB-P testing. Systems to address pedestrian accidents are more challenging from a technology point of view due to difficulties to predict pedestrian path, pedestrians are relatively small making it hard to detect and classify and majority of pedestrian accidents happen in cross-traffic situations. AsPeCSS has been pioneer in developing proposed testing procedures for testing AEB-P. Previously, the project determined boundary conditions, technical technologies and sensor limitations.

The differentiation whether an AEB system should automatically brake or not in a specific situation is difficult to grasp because no exact physical or mathematical formulation can be found for the typical and expected decision and brake activation process. Thus, the development of these procedures had been developed assessing in parallel the justification system responses.

The project has also studied pedestrian impactor testing and simulation for a representative selection of vehicles. These simulations and tests provide valuable information regarding the influence of the testing parameters on test results. The WAD, impact angle, impact speed and type of vehicle are correlated with Head Injury Criteria (HIC), forces, moments and elongations creating functions to provide the necessary information for developing the overall assessment methodology.

Summing up the main AsPeCSS results are summarized in the following list:

- Preliminary set of accident and test scenarios representing
- Test procedures and assessment of justified system responses
- Benefit based methodology for the overall assessment of pedestrian pre-crash systems, that allows balancing of passive safety performance against active safety performance.
- Test and assessment protocol for pedestrian pre-crash systems
- Injury curves for single vehicle points as function of vehicle impact speed and impact angle, for a wide range of vehicle types

AsPeCSS had accomplished huge impact in the advanced driving systems forums. The project has arranged several workshops with relevant stakeholders, has provided input to Euro NCAP working groups and has been present in numerous conferences and pedestrian events. Thus, we can say that AsPeCSS have boost pedestrian protection and provided significant basis for future developments and assessments in this area.

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# 1 Project context and Objectives

## 1.1 Project context

Road traffic accidents are a global problem causing approximately 1.2 million fatalities per year<sup>1</sup>. World-wide the largest group of road user fatalities is represented by pedestrians hit by motorised vehicles<sup>2,3</sup>. In the western world, typically 10% to 30% of all road accident fatalities are pedestrians<sup>4</sup>. In Europe<sup>5</sup>, pedestrians account for more than 19% of road fatalities in the EU-27. In some Member States, the proportion of pedestrian fatalities is as high as 38%. Furthermore, while advances in road safety have resulted in year on year reductions in annual fatalities for most vehicle occupants, vulnerable road users have not seen the same level of improvement.

### 1.1.1 Problem definition

Vulnerable road users can be defined as those road users **unprotected by an outside shield**, namely **pedestrians** and **two-wheelers**. These road users have a greater risk of injury in any collision with a vehicle. In view of the large research efforts currently in the field of powered two-wheelers this proposal will consider pedestrians and to a minor extend pedal cyclists, see section 1.2.1 background.

It is well known that most accidents with pedestrians are caused by the driver being in-alert or misinterpretation the situation<sup>6, 7, 8, 9</sup>. For that reason pedestrian detection systems coupled with driver warning and/or autonomous braking action are recommended to facilitate accident avoidance or reduction of the impact speed. Especially combined active and passive countermeasures that on one hand reduce impact speed and on the other hand protect the pedestrian upon impact (at low speeds) have a high potential to reduce fatalities and injuries<sup>10</sup>. As stated in the call text: *“Unprotected and un-motorized road users suffer the most severe consequences in collisions with vehicles due to the limits of the human body’s tolerance to crashes at a collision speed over 30 Km/h.”* Assuming that:

- 50 to 75% of pedestrian accidents are foreseeable, i.e. the pedestrian can be detected and the car braked before the impact<sup>11</sup>
- Forward looking integrated pedestrian safety systems can reduce impact speed by 15 to 20 km/h for pedestrians hit by the front of the car (as claimed by systems currently in the market)

and using the benefit methodology as developed for the European Commission<sup>12</sup>, it is estimated that integrated pedestrian safety systems could yield a significant reduction in the number of pedestrian road fatalities in Europe upon full penetration into the fleet.

Based on such findings various EU FP projects<sup>13</sup> started developing required pedestrian detection technologies which enabled the development of commercial systems that are now entering the market. However, their **actual deployment is limited**. The main reason is the lack of public awareness, which, to a very high extent is caused by

<sup>1</sup> World Health Organization, 2004. World Report on Road Traffic Injury Prevention. Geneva.

<sup>2</sup> Mohan, D., 2002. Traffic safety and health in Indian cities. J. Trans. Infrastructure 9, 79–94

<sup>3</sup> Odero, W., Garner, P., Zwi, A., 1997. Road traffic injuries in developing countries: a comprehensive review of epidemiological studies. Trop. Med. Intern. Health 2, 445–460.

<sup>4</sup> IRTAD, 2008 [homepage on the Internet]. International Road Traffic and Accident Database [cited 2008 July 7]. Available from: [www.irtad.net](http://www.irtad.net)

<sup>5</sup> World Health Organisation Global status report on road safety 2009

<sup>6</sup> TRACE, TRAffic Accident Causation in Europe, FP6-IST Project 027763

<sup>7</sup> M.C. Simon et. al., Intersection Road Accident Causation: A European View, Paper presenting results of the TRACE project, ESV Paper 09-0370

<sup>8</sup> PEDESTRIANS, Development of a comprehensive service of pedestrians protection by the definition of new test procedures more representative than the current ones IDIADA 2009

<sup>9</sup> Ron Pack, National Highway Traffic Safety Administration, Pre-Crash Sensing Countermeasures and Benefit, ESV paper 2005-0202

<sup>10</sup> INTEGRATED PEDESTRIAN COUNTERMEASURES” Rikard Fredriksson and E. Rosén1 IRCOBI Conference - Hanover (Germany) - September 2010

<sup>11</sup> Accident Research paper based on GIDAS analyses; vFSS project workshop Oct 2010

<sup>12</sup> Lawrence, et al., A study on the feasibility of measures relating to the protection of pedestrians and other vulnerable road users, 2006. Project Report UPR/VE/045/06 under Contract No. ENTR/05/17.01 to the European Commission

<sup>13</sup> EC co-funded projects such as: Save-U, Chameleon, APROSYS and PReVENT

the fact, that the benefits of such systems have not been quantified yet<sup>14</sup>. Moreover, it is difficult for the average vehicle or fleet owner to see, how investments in integrated pedestrian safety systems will pay off<sup>14</sup>. Therefore, **an essential step for the widespread introduction of integrated pedestrian safety systems is the development and implementation of procedures for their evaluation**<sup>15</sup>. As stated by various stakeholders like the eSafety forum wide deployed in the marketplace is required to realise their potential benefits<sup>15</sup>.

## 1.2 Overall project objectives

Advanced forward looking integration safety systems have a high potential to improve safety for this group of road users. These systems combine reduction of impact speed by driver warning and/or autonomous braking with protective devices upon impact.

Main goal of the AsPeCSS project was **to contribute to the protection of vulnerable road users by developing harmonized test and assessment procedures for integrated pedestrian safety systems**. that can be used for consumer rating and regulatory purposes. As such the project was meant to stimulate wide spread introduction of these systems that have high potential to improve safety of pedestrians and, in case adequate detection technology becomes available, also for pedal cyclists.

The outcome of the project will be a suite **of tests and assessment methods as input to future regulatory procedures and consumer rating protocols**. Implementation of such procedures / protocols will enforce widespread introduction of such systems in the vehicle fleet, resulting in a significant reduction of fatalities () and seriously injured () among these vulnerable road users.

The AsPeCSS consortium was strongly convinced that significant reductions in fatalities and injuries can be achieved by implementing the project findings and results in future regulatory and **consumer rating procedures for vehicle safety**. It is well known that consumer rating programmes have a strong influence on manufacturers to build vehicles that consistently achieve high ratings, thereby enforcing introduction of new safety systems that address real world needs into vehicles<sup>e.g. 16</sup>. Moreover, it will raise the public awareness of the benefits of these integrated safety systems by means of easy understandable rating systems.

### 1.2.1 Scientific and technological objectives of the project

On the basis of the above, the following scientific and technological objectives were defined:

- To develop harmonised and standardised procedures and related tools for the assessment of **forward looking integrated pedestrian safety systems**. Such harmonisation shall be provided at European level and will also target a broader scope worldwide. As part of this:
  - Develop a methodology for balancing direct active safety benefit, combined active-passive safety benefit, as well as direct passive safety benefit into one overall safety assessment (based on benefit estimations);
  - Develop methods and means to adapt passive safety test conditions for scenarios with preceding pre-crash action;
  - Develop test targets representing pedestrians for different sensor types
- To gain acceptance for future implementation of test and assessment tools in scientific, industrial, regulatory or consumer rating procedures by extensive evaluation and validation;
- To set the bases and prepare similar activities focusing on the test and assessment of integrated protection systems dedicated to cyclists.

With these objectives the AsPeCSS project was directly addressing priorities and actions set by the EC regarding the road safety strategy for 2011-2012<sup>17</sup>. *“In view of achieving the objective of creating a common road safety*

<sup>14</sup> PREVAL Project Presentation (see <http://www.prevent-ip.org/download/Events/20061008-2 ITS WC London/SS04/6-PreVAL.pdf>)

<sup>15</sup> eSafety Compendium Addendum 1 - December 2006

<sup>16</sup> The New Car Assessment Program Suggested Approaches for Future Program Enhancements, National Highway Traffic Safety Administration Department of Transportation, January 2007

<sup>17</sup> EC Communication COM (2010) Towards a European road safety area: policy orientations on road safety 2011-2020

area, the Commission proposes to target of halving the overall number of road deaths in the European Union by 2020 starting from 2010". In their actions towards reaching this goal, **the Commission indicated safety of vulnerable road users to be one of the three main priorities<sup>17</sup>**. On a more specific level **the use of modern technology, among which Anti Collision Warning or Pedestrian Recognition systems, should be promoted**. Accelerated deployment and broad market take-up of such safety enhancing applications needs to be supported in order for their full potential to be unleashed.

More specific the following activities and results are defined:

#### WP 1 – Methodology for balancing active and passive safety

- Define and evaluate a methodology for the overall assessment of pedestrian pre-crash systems, that allows balancing of passive safety performance against active safety performance.
- As part of the development of the methodology estimate benefits of the pre-crash braking part of forward looking integrated pedestrian safety systems. Extend estimate to include effect of improved passive / active safety systems.
- Provide additional data to check and weight the relevance of test scenarios for collision avoidance and mitigation testing to ensure that they are representative for Europe
- For cyclist pre-crash systems:
  - o Make recommendations for work necessary to adopt test scenarios and extend methodology developed for pedestrians to include cyclists
  - o Make initial estimate of additional potential benefits, based on information currently available.

D1.1 Report with Scenarios and weighting factors for pre-crash

D1.2 Report with the Initial benefit estimate for pedestrian pre-crash systems

D1.3 Report with the Benefit estimate for pedestrian pre-crash systems

D1.4 Proposal for test and assessment protocol for pedestrian pre-crash systems

D1.5 Benefit estimate for pre-crash cyclist systems and recommendations for necessary changes to pedestrian

#### WP 2 – Test Procedures for Preventive Pedestrian Safety Systems

- Define a technology-independent test procedure suitable for assessment of preventive pedestrian safety systems.
- The test procedure should be capable of assessing driver-in-the-loop and automatically intervening driver assistance systems utilized for pedestrian protection. The test result should reflect a representative, comprehensive effect of a total system in real life accident scenarios as determined in WP1.

D2.1A and D2.1B Test target specification document, including sensor response requirements

D2.2 Report describing the comparative survey of existing test protocols and test facilities

D2.3 Test target specification document, including sensor response requirements - Second version

D2.4 Report on Driver reaction models

D2.5 Test procedure including test target and misuse tests, based on test results

#### WP 3 – Injury assessment: data for construction of Injury risk curves<sup>2-4</sup> pages achievements

The main objective of this WP was to derive injury risk against impact speed curves from pedestrian impactor tests (including virtual) for a selection of vehicles representative of the vehicle fleet.

- Construct HBM simulations that reflect the accidentology and scenarios defined in WP1.
- Define impact conditions for testing according to all
- Generate all requested data to develop the injury risk functions, based on the biomechanical values from test and simulation data. To develop injury risk curves it will be necessary to perform tests to determine injury risk wherever a pedestrian head may impact, i.e. tests will have to be performed on points all over the car not just points chosen on a worse case basis.
- As part of the above establish pedestrian impact conditions for relevant accident scenarios and impact parameters as identified in WP1

D3.1 Pedestrian kinematics and specifications of new impact conditions for head- and legform impactors

D3.2 Data to develop injury risk curves: Simulations and Testing results.

D3.3 Risk curves for single vehicle points as function of vehicle impact speed, for a wide range of vehicles

#### WP 4 – Dissemination and exploitation

Overall objectives for the dissemination and exploitation work package are:

- To maximise the dissemination of results and to express them in terms that are readily understandable to stakeholders (e.g. governments, industry and suppliers) in order to accelerate the implementation of the research findings.
- To promote the dissemination of the project findings through presentations at the project workshops, scientific publications and preparing information for the project website.
- To facilitate technology transfer and accelerate dissemination of on-going research activities.
- To achieve an optimum knowledge management including appropriate handling of IPR's; implementation and exploitation of the obtained results;

D4.1 Project website, public and partner restricted part, project templates for reports, presentations and

D4.2 Dissemination database with relevant stakeholders, interest groups and their contact details

D4.3 Flyer publication with general project information for public project dissemination

D4.4 Dissemination and exploitation plan

D4.5 First Project Advisory Board meeting and public workshop

D4.6 Newsletters describing new developments and results from the project

D4.7 Update of Dissemination and exploitation plan

D4.8 Second Project Advisory Board meeting and public workshop

D4.9 Newsletters describing new developments and results from the project

D4.10 Technical publications listed and executive summary published on the public website

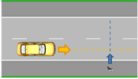


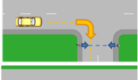

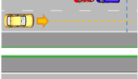

## 2 Main Science & Technological results and Foreground

### 2.1 WP 1 – Methodology for balancing active and passive safety

#### 2.1.1 Car-to-pedestrian accident data analysis

After a literature review of results of previous projects (APROSYS, AEB Test Group, vFSS) and further detailed accident data analysis, seven accident scenarios could be identified to be most representative for car-to-pedestrian crashes, see Table 1. These were compiled mainly by the analysis of German, British and French national accident data for different injury severity levels (slightly, seriously injured and killed pedestrians as well as regarding all pedestrian casualties) and light conditions ('day' and 'dark').

**Table 1: AsPeCSS Accident Scenarios 1-7**

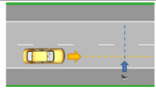




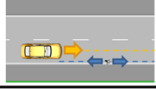
Drawing	ID	Accident Scenario Description
	1 A/B	Crossing straight road, nearside, no obstruction, day / dark
	2 A/B	Crossing straight road, offside, no obstruction, day / dark
	3 A/B	Crossing at junction, near- or offside, vehicle turning across traffic, day / dark
	4 A/B	Crossing at junction, near- or offside, vehicle not turning across traffic, day / dark
	5 A/B	Crossing straight road, nearside, obstruction, day / dark
	6 A/B	Crossing straight road, offside, obstruction, day / dark
	7 A/B	Along straight road, no obstruction, day / dark

The seven preliminary accident scenarios were confirmed to be relevant for Great Britain and Germany and weighting factors obtained. In view of these factors accident scenarios 3 and 4 were joined together.

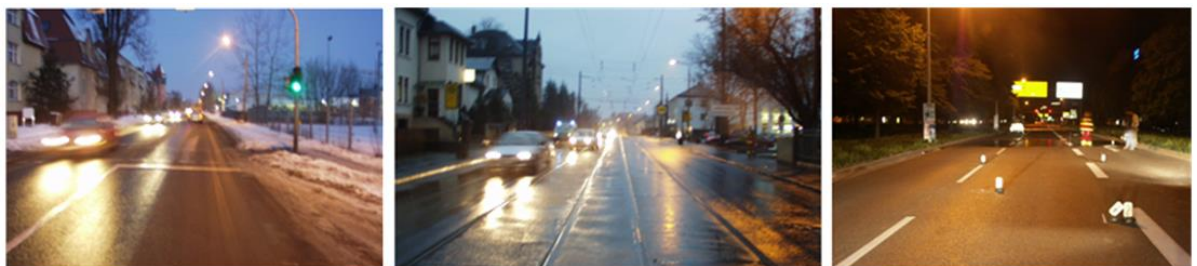
The final AsPeCSS accident scenarios with weighting factors for killed and seriously injured (KSI) pedestrian casualties are given for GB, Germany and the average for both in Table 2 and for fatally injured pedestrians (see D1.1 and according ESV2013 paper).



**Table 2: AsPeCSS' Accident Scenarios of car-to-pedestrian crashes in day and dark light conditions (national accident data from GB and Germany of years 2008-2010 regarding killed and seriously injured (KSI) pedestrians)**

Accident Scenarios	ID	Description	Light condition	Killed and Seriously Injured (KSI)		
				GB	Germany	Average
	1	Crossing a straight road from near-side; No obstruction	All (day/dark)	27 (16/11)	24 (14/10)	25 (15/10)
	2	Crossing a straight road from off-side; No obstruction	All (day/dark)	16 (8/8)	24 (11/13)	20 (8/12)
	3, 4	Crossing at a junction from the near- or off-side with vehicle turning or not across traffic	All (day/dark)	4 (4/0)	12 (6/6)	8 (5/3)
	5	Crossing a straight road from near-side; With obstruction	All (day/dark)	6 (4/2)	11 (9/2)	9 (7/2)
	6	Crossing a straight road from off-side; With obstruction	All (day/dark)	7 (5/2)	7 (5/2)	7 (5/2)
	7	Along the carriageway on a straight road; No obstruction	All (day/dark)	24 (14/10)	5 (2/3)	15 (8/7)
TOTAL			All (day/dark)	84 (51/33)	83 (47/36)	84 (48/36)

The analysis above shows that often collisions with a car in dark light conditions end up with serious injuries or death of the pedestrian. Figure 1 shows randomly chosen accident scenes at night from GIDAS. Since a majority of accidents occur in urban areas, there is almost never complete darkness, but always a diffuse illumination by streetlights, traffic lights, street furniture or similar reflections on the wet roadway and / or bright lights from the headlamps. These driver demanding light conditions often occur combined with obstructions and thus lead to a more complex situation.



Man (41) crosses from far-side – MAIS 2    Woman (51) crosses from near-side – MAIS 2    Man (20) crosses from near-side – MAIS 6

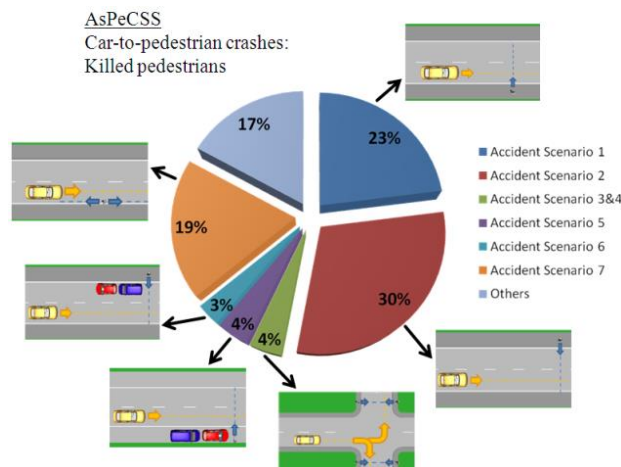


Man (27) crosses from near-side – MAIS 2    Woman (14) crosses from far-side – MAIS 2    Woman (51) crosses from near-side – MAIS 3

**Figure 1: GIDAS examples of car-to-pedestrian collisions on German roads at twilight, night, glare, rain, reflections and obstructions**

Figure 2 shows the weights of the accident scenarios (car-to-pedestrian crashes) limited to killed pedestrians using national data from GB and Germany. Highest weights were assigned to scenario 2 (30%; crossing straight

road, offside, no obstruction), followed by scenario 1 (23%; crossing straight road, nearside, no obstruction), scenario 7 (19%, along straight road, no obstruction) and others (17%).



**Figure 2: AsPeCSS Accident Scenarios – Overview of killed pedestrians in crashes with cars**

In summary, accident scenarios 1, 2 and 7 were found as the three highest weighted scenarios for car-to-pedestrian crash configurations (sum of weights concerning KSI is 60% and concerning fatalities is 72%) that may potentially be addressed by forward-looking integrated pedestrian safety systems. However, accident scenarios 3&4, 5 and 6 (KSI: 24%, Fatalities: 11%) also have a significant weighting as regards future active pedestrian protection systems. About 80% of the car-to-pedestrian crashes could be assigned to the seven AsPeCSS accident scenarios. Remaining percentages include other car-to-pedestrian crash configurations, such as while parking or reversing.

### 2.1.2 Development of methodology for overall system assessment (balancing passive / active safety)

The work in this task focused on the development of an overall methodology to assess integrated pedestrian safety systems considering results from previous tasks in WP1, results from WP2 and WP3 and thus that allows balancing of passive safety performance against active safety performance. One major question in background was how the assessment of the speed reduction offered by the AEB can be integrated with the current assessment of the passive vehicle safety for mitigation of pedestrian injury, e.g. in Euro NCAP. Ideally, it was concluded that this should be done on a benefit related basis. Further, a test and assessment protocol for pedestrian pre-crash systems was proposed. The results have been summarized in Deliverable 1.4.

The overall benefit based methodology has been proposed together with AEB test protocols and the standard Euro NCAP pedestrian passive safety test protocol (version 7.1.1) as a test and assessment protocol for integrated pedestrian protection systems with pre-crash (AEB) braking. The methodology calculates the cost of pedestrian injury expected, assuming all pedestrians in the target population (i.e. pedestrians impacted by the front of a passenger car) are impacted by the car being assessed, taking into account the impact speed reduction offered by the car's AEB (if fitted) and the passive safety protection offered by the car's frontal structure taking into account results from WP2 and WP3, respectively. For rating purposes, this cost can be normalised by comparing it to the cost calculated for selected cars.

The methodology developed consists of five main steps as described below and shown in Figure 3.

#### 1.) Active safety testing: Exposure - impact velocity curve shift

The active safety (Autonomous emergency braking (AEB)) part of the pedestrian protection system is assessed with respect to its ability to reduce impact velocity. The test scenarios are weighted according to their contribution to injury occurrence. From each test scenario the typical speed reduction over the whole range of casualty impact speeds is derived. Using this information, the exposure – impact velocity curve for the pedestrian casualty target population (i.e. pedestrians impacted by a car front) is adjusted to account for the impact speed reduction provided by the active safety system, see also results from Task 1.2.

#### 2.) Passive safety testing: Impactor measurement and extrapolation

Standard headform, upper and lower legform impactor tests (following the Euro NCAP version 6.0 or 7.1.1 protocol) combined with manufacturer simulated data, provide impactor results for most of the car's frontal area. This provides performance data on the areas likely to be hit by a pedestrian apart from areas with a high Wrap Around Distance (WAD) such as high on the windscreen and the windscreen header rail for the headform impactor. Tests are conducted at the standard speed which approximately represents a 40 km/h pedestrian impact. Injury criteria values recorded at the standard speed are extrapolated to all other speeds experienced by the pedestrian target population.

### 3.) Calculation of injury frequency

Impact probabilities for each area of the car's front are calculated for each impactor. Using these probabilities, injury criteria measurements from step 2, injury risk curves relating these measurements to the probability of injury, and the velocity – exposure data from step 1, injury risks for each AIS level are summed for tested body regions for all casualties in the target population to give injury frequency for tested body regions.

### 4.) Calculation of socio-economic cost

Injury frequencies for tested body regions are converted into costs using 'Harm type' cost information for the injuries considered, i.e. those related to the impactor injury criteria.

### 5.) Vehicle assessment: Weighting (calibration) and summing

The body region costs are weighted using calibration factors and summed to give the total cost of injury assuming that all pedestrians in the target population were involved in an accident with the car being assessed. This cost is also weighted using a calibration factor to account for factors such as injuries to body regions not assessed by the impactors and injuries caused by ground impact. This cost can be compared with the cost calculated for other selected cars to give a relative assessment of the car.

Calibration (weighting) factors were derived by comparing the costs calculated with those known from accident data. To do this, it was assumed that none of the cars involved in the accidents in the accident data sample had AEB fitted. Impactor test results were derived for a car with passive safety protection levels representative of those of the cars in the accident data sample.

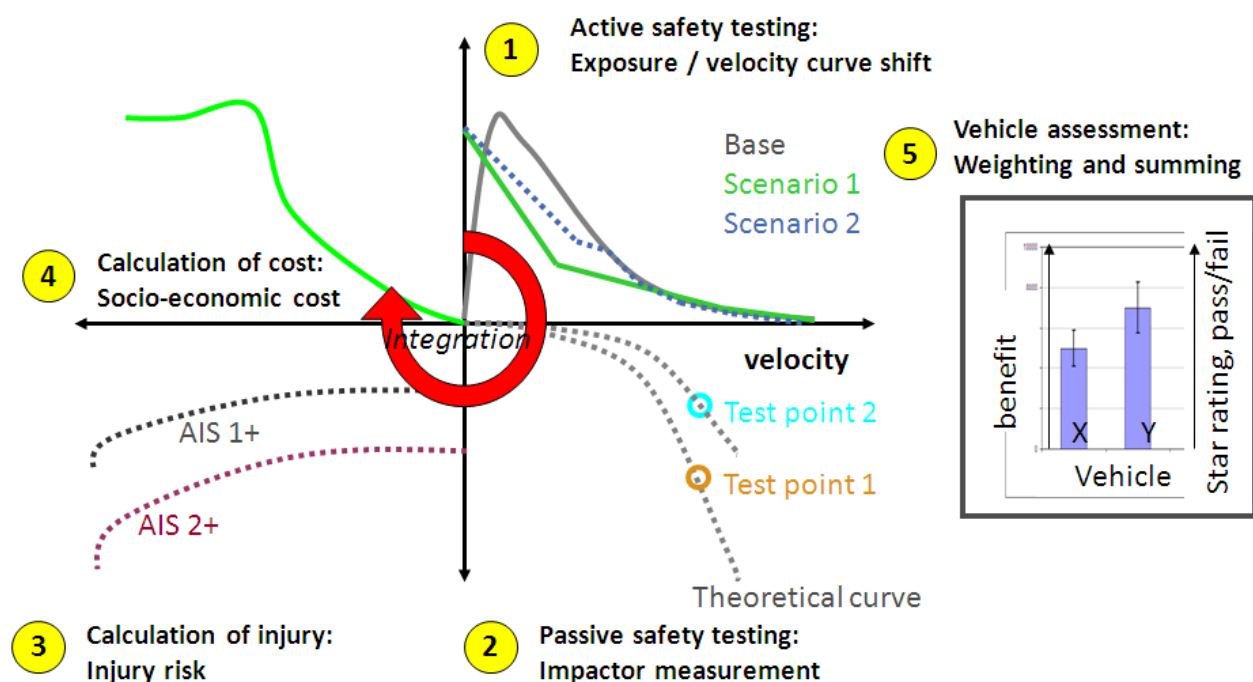


Figure 3: Main steps of methodology

Application of the methodology showed differences between the passive safety assessments of vehicles using this methodology and Euro NCAP. While the Euro NCAP ranking of good, average, and poor rated cars was reproduced with this methodology, the benefit of increasing from poor to average was larger than increasing by a similar Euro NCAP point score from average to good. This discrepancy was caused mainly by differences in the

head impact assessments which, in turn, were caused by the different amount of windscreen and A-pillar in the assessment area for the good, average and poor rated cars. The inclusion in the AsPeCSS methodology of discrimination in rating for severe head injury with HIC (head injury criterion) greater than 1,800 and weighting of the assessment area with wrap-around-distance, which are not included in the Euro NCAP assessment, caused this difference. This leads to the question of whether or not Euro NCAP should consider inclusion of these factors, which in principle make the methodology more benefit based. This AsPeCSS assessment methodology offers that opportunity and also emphasises how important assessment of the windscreen and A-pillar areas can be when they are located in an area of high impact probability. It should be noted that assessment of the windscreen and A-pillar areas is not included in the regulatory assessment of pedestrian protection.

For active safety, application of the methodology showed that the addition of an AEB system which has a performance representative of current systems, in terms of the assessment, is broadly equivalent to increasing passive safety from poor to average or average to good.

Simplifications in the AsPeCSS assessment methodology, namely to not take into account the speed reductions that active safety systems may deliver when the driver brakes partially and to assume that the speed reduction for the obstructed child scenario 75% impact condition is the same as for the obstructed child scenario 50% impact condition, turned out to have no major influence on the resulting benefit estimate. Neither did the choice of head injury risk curves.

Due to the availability of in-depth accident data from only two European countries, effectively, two versions of the assessment methodology, a German and a UK one have been developed. The German methodology is recommended for use in preference to the GB one as there are more data and they are believed to be more accurate. That is unless calibration specifically for GB is required, in which case the GB method may be better suited for the application.

There are two possible main approaches for use of this methodology within Euro NCAP. These are:

- Implement the methodology in its current form within Euro NCAP for the assessment of pedestrian protection.
- Use the methodology to help develop weighting factors for a simpler way to combine the assessments of active and passive pedestrian protection into an overall assessment of pedestrian protection.

The first approach is preferable to take into account the interactions between active and passive safety, namely the modeled shift of head impact location probabilities with car speed. This would truly be an integrated assessment. Using the second approach one could develop a rating that would be additive but not truly integrated.

The results using the German and GB versions of the assessment methodology for the hybrid vehicles are shown in Table 3 and Table 4 below, respectively. Results are shown in terms of total casualty costs assuming all cars in Germany or GB (depending on the version of the assessment used) were fitted with the system being assessed. Costs are nominally in Euros for the German version and Great Britain pounds for the GB version because the models were calibrated using the results of the benefit analyses for the respective.

**Table 3: For German version of methodology, assessment results in terms of total casualty cost for hybrid cars with good, average and poor Euro NCAP passive safety rating fitted with various AEB systems. Percentages show costs normalised to average passive safety performance with no AEB system fitted.**

AEB System	Passive Safety Level (Euro NCAP score rating)		
	Good (32.2)	Avg (22.6)	Poor (12.2)
No System	€674,833,590 (97.0%)	€695,655,066 (100.0%)	€943,722,432 (135.7%)
Current generation system model 2013+	€579,292,610 (83.3%)	€597,640,882 (85.9%)	€809,741,694 (116.4%)
Current generation system model 2013+ with additional impact locations and partial braking	€557,356,996 (80.1%)	€577,575,632 (83.0%)	€780,545,282 (112.2%)

AsPeCSS Vehicle C test / model results Ref: D2.5	€521,954,375 (75.0%)	€538,167,808 (77.4%)	€725,527,777 (104.3%)
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**Table 4: For GB version of methodology, assessment results in terms of total casualty cost for hybrid cars with good, average and poor Euro NCAP passive safety rating fitted with various AEB systems. Percentages show costs normalised to average passive safety performance with no AEB system fitted.**

AEB System	Passive Safety Level (Euro NCAP score rating)		
	Good (32.2)	Avg (22.6)	Poor (12.2)
No System	£905,987,923 (97.0%)	£934,143,898 (100.0%)	£1,253,150,292 (134.1%)
Current generation system model 2013+	£780,094,731 (83.5%)	£805,629,605 (86.2%)	£1,077,328,016 (115.3%)
Current generation system model 2013+ with additional impact locations and partial braking	£741,636,876 (79.4%)	£768,485,845 (82.3%)	£1,025,533,028 (109.8%)
AsPeCSS Vehicle C test / model results Ref: D2.5	£687,078,290 (73.6%)	£708,493,419 (75.8%)	£947,330,416 (101.4%)

### 2.1.3 Cyclist pre-crash systems

Within this task, car-to-bicyclist accidents have been investigated for the United Kingdom (UK) and the Netherlands. The main differences between car-to-bicyclist and car-to-pedestrian accidents have been pointed out and general test scenarios for bicyclist safety systems have been proposed. Additionally, RCS (radar cross section) measurements of bicyclist and pedestrian (dummies) have been conducted that can be used as baseline information for further development of a bicyclist dummy target. In a last step, the effectiveness of bicyclist helmets has been estimated based on UK data and the effectiveness of AEB systems addressing bicyclists and VRU airbags have been summarized based on literature. The results have been summarized in Deliverable 1.4.

With regard to accident scenarios it could be seen, that pedestrians are mainly injured crossing the road by a straight forward moving passenger car. A significant share of these pedestrians was obstructed and a significant share of fatal accidents occurred during dark light conditions. For bicyclist-to-car accidents, crossing accidents with both opponents traveling straight forward are also very common. Situations where the car hits the bicyclist while turning either to the right or to the left are however also very important to consider. Longitudinal accidents with both, car as well as bicyclists traveling in the same direction are quite common in the UK (and other EU countries), however less prominent in the Netherlands.

In comparison with pedestrians, it can be seen that pedestrians move relatively slow with velocities between roughly 3 km/h and 8 km/h, whereas bicyclists are much faster and can reach speeds of up to 50 km/h (race bike). Pedestrians always are “animated” as they need to move their legs and will most likely also move their arms while walking. A bicycle is able to move by itself once a certain speed is reached, hence the bicyclist might be sitting “statically” on the bicycle without any need to move during the pre-collision phase.

The size of a pedestrian can vary significantly depending on the age and stature of the pedestrian itself. The size of bicyclists of course also varies, however less significant as for pedestrians as bicyclists are sitting on their bicycle and the difference in sitting height is less prominent than differences in standing height. On the other hand, the posture of a bicyclist might differ more depending on the bicycle used compared to the usually quite simple upright and standing posture of a pedestrian. Where a standard Dutch city bike will put its occupant in an upright seating position, race bicycle users can be inclined into an almost lying position.

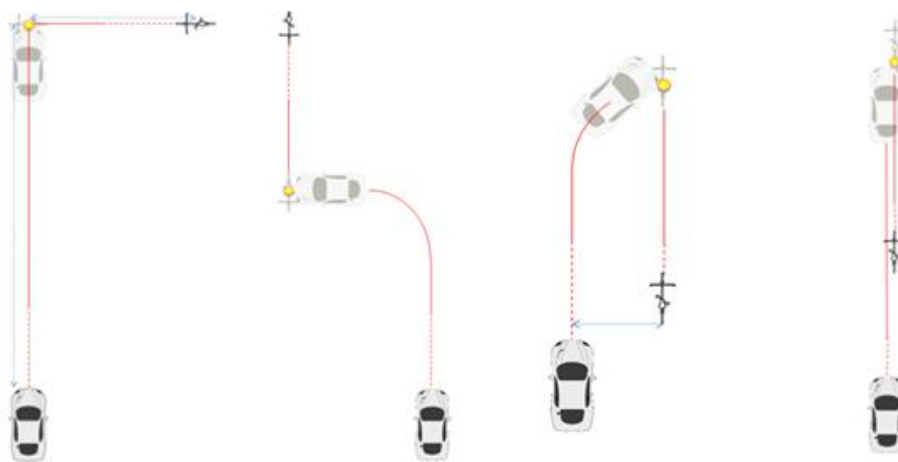


Where pedestrians hit their head on a car upon impact in most cases on the bonnet or the lower part of the windscreen, bicyclists tend to hit higher.

The task also came up with a proposal for test scenarios based on information not only available in the UK and the Netherlands, but also from countries as Germany or Sweden. The scenarios are defined based on accident configurations, not taking into account yet whether or not they might be addressable by current or near future safety systems to be implemented into passenger cars or currently available test tools. Further, it has to be noted that a significant amount of bicyclists get injured in accidents involving no other crash partner or involving a crash partner other than a passenger car. Such accidents are neglected for the scenario definition.

The following preliminary test scenarios were proposed for vehicle based active bicyclist safety systems (see Figure 4):

- 1.) City Crossing (car and bicycle moving straight forward)
- 2.) City turning left (car turning of the road to the left with bicyclist moving straight forward)
- 3.) City turning right (car turning of the road to the right with bicyclist moving straight forward)
- 4.) Inter-Urban Longitudinal (Car travelling straight forward hitting the bicyclist driving straight forward from behind)



**Figure 4: Preliminary bicyclist scenarios from left to right: City Crossing, City turning left, City turning right, Inter-Urban Longitudinal**

The importance of night testing and (partially) obstruction of the bicyclist needs further investigation.

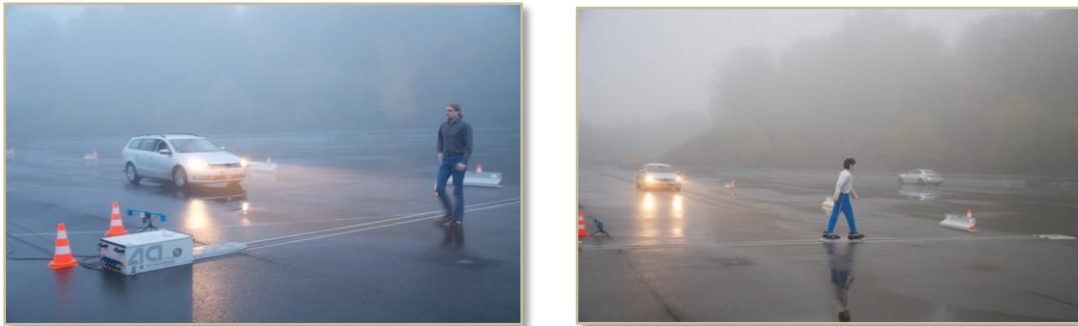
## 2.2 WP 2 – Test Procedures for Preventive Pedestrian Safety Systems

### 2.2.1 Dummy Development

During previous test sessions in 2012, “Dummy detect-ability” at BAST and “2nd Dummy Testing Workshop” in IDIADA, testability and robustness of the defined scenarios have been shown. The next step was to harmonize the dummy in between all relevant OEMs and Suppliers. The focus is to develop the dummy in his sensor detection properties in a way, that all relevant sensor technologies detect the dummy as a real pedestrian. Due to the fact, that camera and radar system are the available sensors for pedestrian detection, two workshops has been set up: a Radar Cross Section Workshop at BAST and a Contrast Workshop at Thatcham.

#### 2.2.1.1 Test event “Radar Cross Section Workshop” at BAST (12<sup>th</sup> -13<sup>th</sup> November 2013)

At this workshop, seven different Radar Systems from OEMs and Suppliers were involved to test the Dummy RCS (Radar Cross Section) in comparison to the RCS of a real Human. Tests with static and moving pedestrians and dummies have been done. There was an on-line evaluation possible, where a too high RCS of the dummy has been measured. Therefore, an RCS damping of the dummy feet was integrated and tested at day 2. The improved Dummy with the new RCS Specification was then detectable for all available radar systems.



**Figure 5: RCS Measurement Dummy vs. Real Human at BAST**

#### **2.2.1.2 Test Event “Contrast workshop” at Thatcham Airfield at 28<sup>th</sup> November 2013**

In Co-operation with the AEB Group, a second Workshop concerning the vision characteristics of the dummy was organized. At this workshop, eight different mono and stereo camera system has been involved. The aim was to do Measurements of pedestrian dummy according contrast and background to guarantee reproducibility of tests independent of the background of the test area. Different combinations of coloured clothes had been tested as well as different weather and lighting conditions. The result of the workshop was that the Dummy with the defined contrast specifications is detectable for all available video based systems, independent from the testing background.



**Figure 6: Adult dummy in front of a dark background (left) and adult dummy in front of a bright background**

### **2.2.2 Test Scenario Development**

#### **2.2.2.1 Accidentology and Boundary Conditions**

Test scenarios need to reflect real accident situations as good as possible. Since the accurate simulation of real accident situations in lab-testing is difficult and complex, characteristic parameters that have a significant impact on system performance have to be identified. Test scenarios then are defined using these characteristics.

For scenario definition, an accident kinematics model is developed using physical parameters like velocities, positions and starting times. In a first step, velocities are assumed to be constant, and in a second step, pedestrian detection timing and a brake logic were integrated. Using this model, the following parameters have been identified as most important for scenario definition:

- initial velocity of pedestrian and passenger car
- impact point of pedestrian on the car front
- start of pedestrian movement (timing) and total travel distance to impact point
- distance of obscuration (if applicable) to the passenger car path

In addition, the following aspects need to be taken into account:

- test scenarios should reflect realistic accident situations as good as possible,
- test scenarios should be able to simulate various accident scenarios and not only those occurring most frequently,
- test scenarios should take estimated abilities of current and near-future AEB systems as well as current test tools (e.g. repeatability, contrast, light conditions) into account.

#### **2.2.2.2 Base test scenarios and advanced test scenarios**

The developed AsPeCSS test scenarios were defined first for daylight conditions and were categorized with regard to view obstructions and pedestrian speed (Base Test Scenarios):

- Test scenario 1: Crossing Child, which runs out from behind an obstruction (distance 1 m between vehicle path and obstruction).
- Test scenarios 2 and 3: Crossing elderly (walking slowly) and adult (walking) without view obstruction.

The test scenarios 2 and 3 are supposed to be also tested in dark light conditions as soon as it is feasible to conduct these tests reproducibly. The classification of 'child', 'adult' and 'elderly' to the test scenarios was made based on the related assignment of personal data to the accident scenarios and reflects the size and walking speed of pedestrians.

Advanced test scenarios are considered to be developed in a later phase. Hereby, turning maneuvers as well as the scenario where the pedestrian is walking along a road on the near-side should be covered. This latter scenario is technically an 'unobstructed' scenario with a lateral pedestrian speed of zero. However, the longitudinal speed and movement of the pedestrian is relevant for the detectability for some sensors, especially radar. It is currently not yet possible to simulate this satisfyingly with available test tools (because the dummy can only travel between two bearings, and cannot be overrun).

### 2.2.2.3 AEB functionality and sensitivity

The evaluation of test scenarios regarding realistic AEB performance on one hand and regarding the necessary repeatability on the other hand requires a description of the sequence of events in an AEB system. An AEB system will constantly monitor driving situation, surroundings and objects in the front of the vehicle and continuously judge the probability of an accident. When a dangerous situation is detected, the system's algorithms will take the decision for an intervention and command the braking. Brake line pressure increases with a gradient that in general is limited by the brake pump performance. Brake deceleration will also increase proportionally until the maximum possible deceleration is reached. This deceleration then is maintained either to a standstill or to the moment of collision.

Requirements for the robustness of a test scenario to deviations of the test conditions need have a tremendous influence on the necessary test tools and with this of course on the expected test costs. For the definition of robustness, the speed reduction of an exemplary AEB system working as described in simple test scenarios is simulated. The exemplary system has the following characteristics:

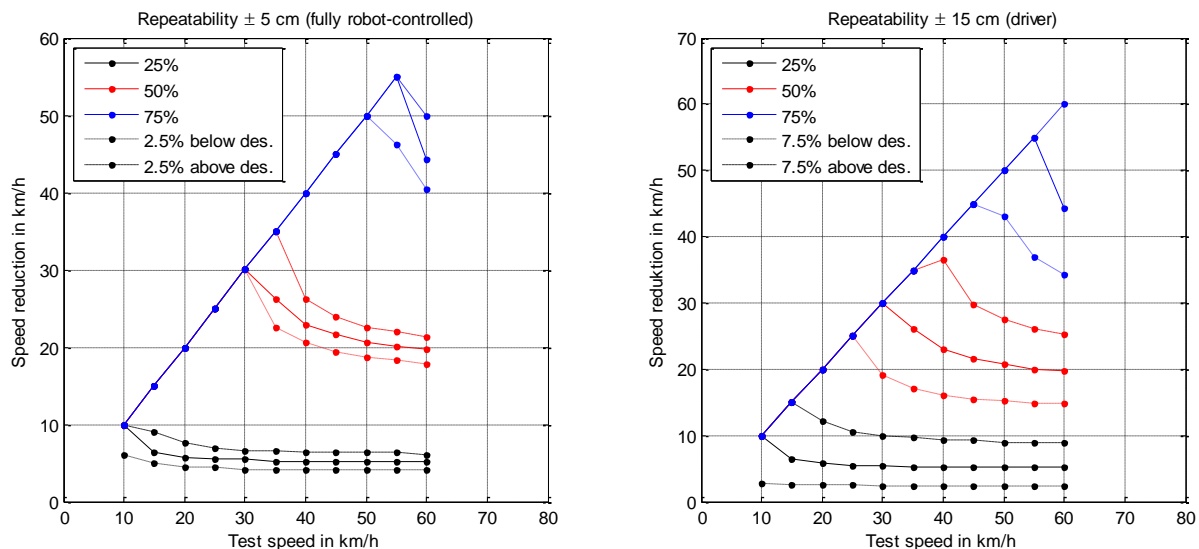
- it brakes as soon as the pedestrian enters the vehicle path,
- maximum deceleration shall be  $9 \text{ m/s}^2$ ,
- brake swell time shall be 500 ms (with linear increase of deceleration during the swell time),
- treatment of the pedestrian as a point.

In general, the criticality of a pedestrian will increase with decreasing lateral distance to the vehicle path. The lateral relative position between pedestrian and vehicle throughout the experiment is assumed to cumulate in the quantity impact point. Deviations of the speed reduction are expected for deviations of the impact point. Deviations of the impact point result from

- lateral shift of the path of the vehicle under test (independent from test speed),
- deviations in the travel speed of the vehicle under test (larger influence for smaller travel speed),
- deviations in dummy travel speed (larger influence for smaller vehicle travel speed),
- variations of pedestrian start of movement (dummy trigger timing).

Figure 7 shows consequences of typical impact point variations on the speed reduction for a simple simulation of a crossing pedestrian, walking at 5 km/h, with different nominal impact points.





**Figure 7: Simulation of speed reduction for several test speeds, based on the variation of the impact point of an unobscured walking adult (5 km/h). Solid lines correspond to the nominal point of impact, dashed lines correspond to the worst case variations of the impact point in both direction (as given).**

These results suggest that primary concern in a test setup must be to keep variation of impact points (in general all lateral deviations) limited within boundaries that allow still acceptable variations in measured speed reduction.

The required repeatability depends on the overall assessment of the system, including all weighting factors. The overall assessment for the simulated AEB system performance is given in **Error! Reference source not found.** without considering maximum speed reduction).

The results show that the expected rating variations are relevant especially for mitigation cases rather than for avoidance cases for the middle and high speeds.

The influence of variations on the overall assessment is in the region of  $\pm 5\%$ , depending on the nominal impact point. These are the worst cases. In reality, not all deviations have the same sign, and thus variations tend to compensate each other, which reduces the sensitivity significantly. However: it is still very likely that variations in assessment results are not neglectable.

Some methods for the reduction of sensitivity in this case could be

- implementation of a Grid approach: the vehicle manufacturer delivers own test results which need to be confirmed by test labs within a certain accuracy
- multiple test conduction
- multiple conduction of only those tests without full avoidance

Some of these methods increase the test burden and test cost as well.

**Table 5: Variation of overall assessment for the simulated speed reductions according to Figure 7, left case (2.5% deviations).**

Test speed	Available Pts	50% Walking Adult						75% Walking Adult						25% Walking Adult					
		SR	Pts	SR	Pts	SR	Pts	SR	Pts	SR	Pts	SR	Pts	SR	Pts	SR	Pts	SR	Pts
10	1	10	1,00	10	1,00	10	1,00	10	1,00	10	1,00	10	1,00	10	1,00	7	0,70		
15	1	15	1,00	15	1,00	15	1,00	15	1,00	15	1,00	15	1,00	9	0,60	7,5	0,50	6	0,40
20	1	20	1,00	20	1,00	20	1,00	20	1,00	20	1,00	20	1,00	8	0,40	7	0,35	6	0,30
25	2	25	2,00	25	2,00	25	2,00	25	2,00	25	2,00	25	2,00	8	0,64	7	0,56	6	0,48
30	2	30	2,00	30	2,00	30	2,00	30	2,00	30	2,00	30	2,00	8	0,53	7	0,47	6	0,40
35	3	35	3,00	26	2,23	23	1,97	35	3,00	35	3,00	35	3,00	8	0,69	7	0,60	6	0,51
40	3	26	1,95	23	1,73	21	1,58	40	3,00	40	3,00	40	3,00	8	0,60	7	0,53	6	0,45
45	3	24	1,60	22	1,47	19	1,27	45	3,00	45	3,00	45	3,00	8	0,53	7	0,47	6	0,40
50	2	23	0,92	21	0,84	18	0,72	50	2,00	50	2,00	50	2,00	8	0,32	7	0,28	6	0,24
55	1	22	0,40	20	0,36	18	0,33	55	1,00	55	1,00	46	0,84	8	0,15	7	0,13	6	0,11
60	1	21	0,35	20	0,33	18	0,30	50	0,83	44	0,73	40	0,67	7,5	0,13	7	0,12	6	0,10
Sum	20		15,22		13,96		13,16		19,83		19,73		19,50		5,58		4,99		4,09
Percent			76,10%		69,79%		65,80%		99,17%		98,67%		97,52%		27,91%		24,96%		20,47%

#### 2.2.2.4 Driving experiments and results

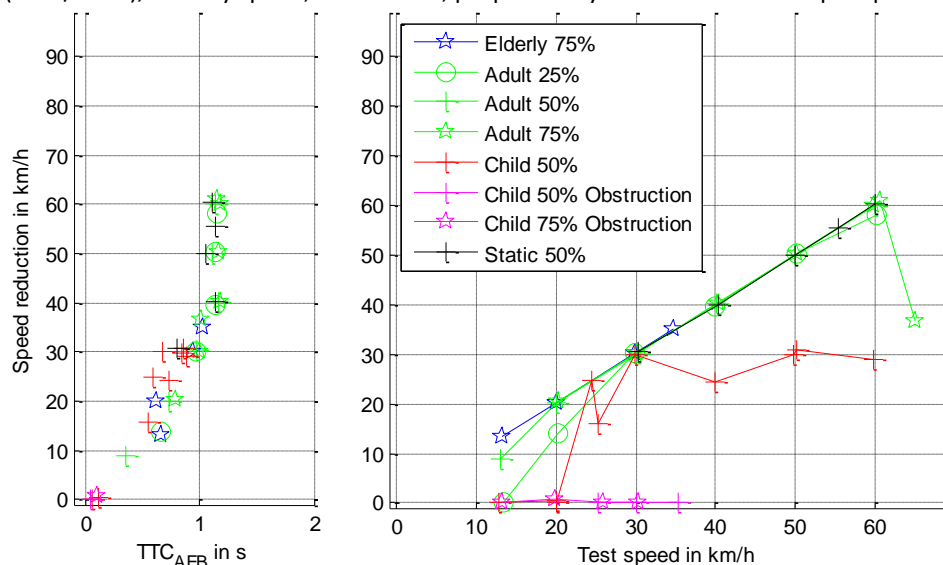
As mentioned in the introduction, pedestrian AEB is available in only four vehicle type series. Of each of those four series, a representative vehicle has been tested by ADAC. AsPeCSS also did tests for those vehicles in detail. Vehicles A and B were equipped with stereo camera, near infrared and RADAR, vehicle C was equipped with mono camera and RADAR, and vehicle D was equipped with mono camera only.

Vehicle A has been tested by BAST and IDIADA in detail, according to the AsPeCSS test scenarios. BAST used a platform-type dummy propulsion system, IDIADA used a gantry-type system. Some of the tests were done during night condition. Speed reduction and TTC of start of braking are available for evaluation.

All vehicles had been conducted speed reduction measurements with a comparable platform-type dummy propulsion system. A detailed description of test setup and results is available in [Rigling, 2013].

##### Detailed results for vehicle A

Figure 8 shows speed reductions and TTCs for start of braking for vehicle A, distinguished between dummy type (child/adult), dummy speed, obstruction, propulsion system and desired impact point.



**Figure 8: Speed reduction (right) and start of braking TTC (left) as function of test speed for vehicle A**

The test results for vehicle A show a large portion of the proposed test suite can be addressed already today. However, especially test cases with a speed ratio between dummy speed and vehicle speed approaching 1 and the resulting large angles between pedestrian and passenger car throughout the test lead to relatively low speed reductions. This is particularly true for tests with 10 km/h vehicle speed and 5 km/h dummy speed, as well as for 20 km/h vehicle speed and 8 km/h dummy speed.

A reason for this might be that the field of view of the vehicle sensor system is not sufficient to detect the pedestrian dummy from the start - the dummy will appear in the sensor range only during the experiment.

Another observation is the start of braking TTC and therefore also the achieved speed reduction do stay on the same level in running child experiments above 30 km/h. Sensor field of view is no explanation, since the demand decreases with increasing test speed. The time needed for decision making might exceed the time available in these cases.

The test scenarios with running child from behind an obscuration clearly show the limits for active safety: the child appears approximately 1.3 seconds before the impact (75%). This time is not sufficient for more than a few km/h speed reduction. For a 25% situation, the appearance time is approximately 0.7 seconds, which is even worse for AEB performance.

The test results suggest some potential for the running child scenario with 75% impact, but it seems that running child situations with 25% impact point might not be solvable in the mid and far future, and even mitigation does not seem to be possible.

Vehicle A does not seem to have problems with dark light conditions (night, dusk), and there seems to be no significant difference in results with regard to the propulsion system type.

The brake timing seems to stay constant from 40 km/h upwards. In fact, the remaining distance of the vehicle after standstill to the dummy line of movement decreases for these higher speeds. This suggests that the intended avoidance speed is 40 km/h, and all speed reductions above this speed do occur because of the

relatively high friction on one of the test tracks. Lower speed reductions for the gantry-type propulsion system therefore do not contradict the assumption that there is no influence of the type of the propulsion system; the friction of the test track might make the difference.

### Consequences

First of all, a holistic view with regard to possible AEB pedestrian performance for all vehicle segments might be possible in a few years time. For the time being, it seems that today's vehicles do not have problems with slow and readily visible adults, and there are observable differences between different vehicles.

The AsPeCSS child scenarios however do not allow a real differentiation between vehicles or AEB systems. In this aspect, ADAC scenarios with decreased dummy speed are better.

AsPeCSS scenarios with the obscured and running child do challenge all vehicles, only slight speed reductions are possible. This type of scenario combines the three challenges obscuration, high dummy speed, small dummy in one scenario.

In collaboration with other European initiatives, AsPeCSS developed the idea of distributing these difficulties into more than one scenario in order to be able to better assess and compare system performances.

The test scenarios have been improved based on the AsPeCSS test results and together with Euro NCAP for better comparability of vehicles, see Table 6. The dummy speed in the child scenario has been decreased to 5 km/h, and the different impact points (a fact that is quite important according to accident figures) will be tested with a walking, unobscured adult dummy. Higher as well as lower pedestrian walking speeds are transferred to a scenario with an adult dummy coming from the far side - the dummy will be readily visible long before the impact in this case.

**Table 6: Advanced test scenario definitions from AsPeCSS**

Scenario	Walking adult	Running adult	Walking adult	Walking adult	Walking child
<b>Pedestrian speed</b>	3 km/h	8 km/h	5 km/h	5 km/h	5 km/h
<b>Dummy type</b>	Adult	Adult	Adult	Adult	Child
<b>Dummy initial position</b>	Far side	Far side	Near side	Near side	Near side
<b>Vehicle speeds</b>	20-60 km/h	20-60 km/h	10-50 km/h	10-50 km/h	20-60 km/h
<b>Obscuration</b>	No	No	No	No	Yes
<b>Impact point</b>	50 % (Center)	50 % (Center)	25% (Nearside)	75% (Nearside)	50 % (Center)
<b>Weighting</b>	1	1	1	1	1

These scenarios have been tested with the 4 different state-of-the-art AEB Pedestrian systems as described above. The test results can be found in Deliverable 2.5. These test results from current vehicles show that some accident scenarios that have been reflected in AsPeCSS test scenarios are addressed already with current AEB systems, and the test tools do have potential to achieve the necessary repeatability.

The original test scenarios do not seem to show differences between different vehicles since they are either too easy or too difficult to deal with. For a better differentiation between vehicles, the challenges in the test suite (high dummy speed - dummy obscuration - different dummy impact points) are distributed between different scenarios, which is gained by the advanced test scenarios. Also, the advanced test scenarios are derived from accident analysis and therefore mirror the effectiveness of these systems in real world.

#### 2.2.2.5 Assessment of justification of system response

The differentiation whether an AEB system should automatically brake or not in a specific situation is difficult to grasp because no exact physical or mathematical formulation can be found for the typical and expected decision and brake activation process. Furthermore, traffic situations and their accompanying risk levels are perceived rather dissimilar by different individuals. While one person would judge a situation as harmless it could be seen already very critical for another one. This mainly depends on the experience and background everyone has made

so far in his “driving”-life and the personal risk sensation that may also vary over a large and rather unspecific range within the population.

There are, however, two crucial factors that can be well considered when classifying the AEB system behavior:

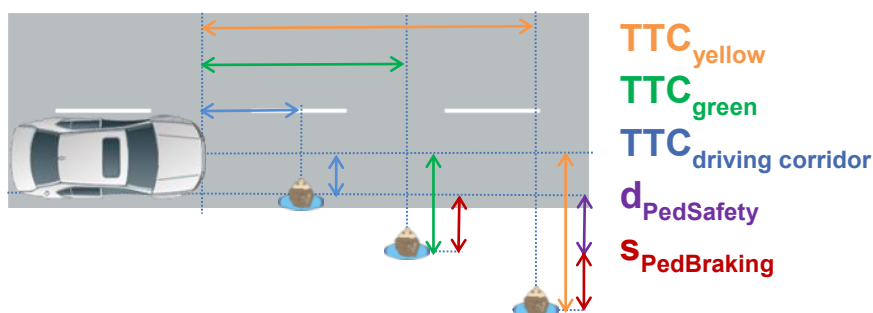
- i. A good trade-off between the desired system performance and the still acceptable unjustified system response occurrences;
- ii. A good generalization of the system reaction to avoid direct tweaking or locking on simple test situation or linear movement scenarios (that may easily extend the prediction horizon capability to a few seconds but never really happen in everyday traffic life).

In the following page a first draft proposal of such generalization check and tradeoff tests is shown.

From an economical viewpoint it is much better to extend the existing test scenarios and use the same test equipment and methodology instead of defining completely new test setups from the scratch (see Figure 11).

The AsPeCSS consortium finally came to the conclusion that an extended design approach for the so-called quality or trade-off tests is sufficient both on a technical and economical basis.

For the performance assessment and rating of these trade-off tests different areas in front of the vehicle were defined in which system reaction like a braking intervention can be still tolerated or not, respectively. These areas are defined by using the TTC zones, as marked in Figure 13.



**Figure 9: TTC zones used as assessment and rating criterion for the trade-off test scenarios**

The measurement variable TTC was already introduced and described in chapter 2.2 and is the perfect indicator for rating the quality of the trade-off test scenarios. With the introduction of different TTC zones the system design can be much better accommodated with respect to the desired behavior that can go from very conservative to highly pro-active. Indeed, there is no unique value or reaction scheme that is appropriate for a given situation while any parametric change would be totally off target. The  $TTC_{driving\ corridor}$  is the lower bound where system reaction is mandatory to happen, the  $TTC_{green}$  zone opens variations in timing to act earlier with the help of anticipation and the end of the  $TTC_{yellow}$  area marks the region where prediction already starts to become rather unsure and intervention strategies are often too early in time.

The TTC zones are derived by the motion capability of a pedestrian and classified in Figure 14 accordingly.

$TTC_{intervention} < TTC_{green}$	$TTC_{green} < TTC_{intervention} < TTC_{yellow}$	$TTC_{intervention} > TTC_{yellow}$
pedestrian is not able to come to a complete stop before entering the driving corridor	pedestrian is able to stop between the beginning of the driving corridor and an additional safety distance to the driving corridor	Safety system is prematurely triggered and the unsure intervention is still unsubstantiated and typically not tolerated by the user

**Figure 10: The different TTC zones for rating the trade-off tests**

The question whether trade-off test scenarios should be introduced or added to the already existing standard EuroNCAP tests is not finally answered. In 2013 EuroNCAP staff members were of the opinion that it is within the liability of the OEMs to guarantee a good generalization of the safety system performance to real traffic scenes and not only tweaked to the current test scenarios in force. However, if it becomes obvious that the system

performance obtained in the EuroNCAP tests cannot be (completely) transferred to a suitability everyday use, further appropriate measures and additional generalization capability tests may be introduced in the future.

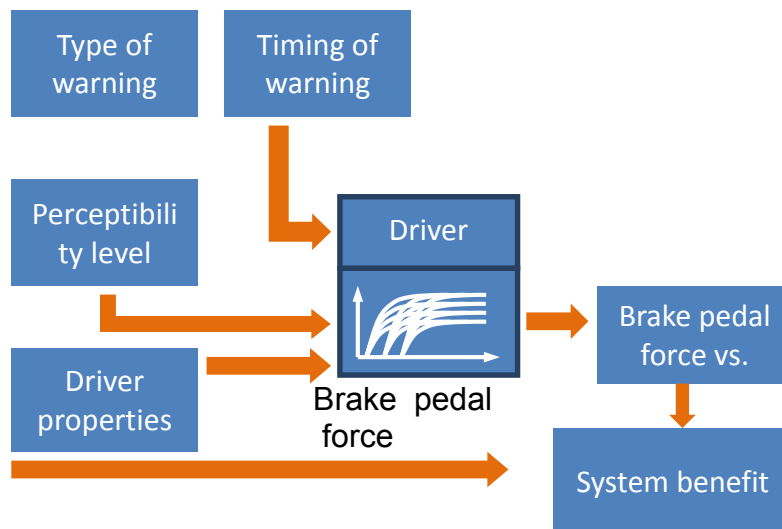
#### 2.2.2.6 Driver Model

The Aim of 2.2 is to develop a driver and pedestrian reaction models suitable for assessing the effectiveness of pedestrian protection systems.

Scope:

- Models applicable for a representative range of physical and mental human skills including age-specific capabilities
- Spectrum of driver reaction to warnings, braking support or automatic intervention, including controllability will be quantified

A Driver Model was defined as followed:



A parameter set for this driver model has been generated. Ongoing task is to verify this driver model by a simulator study.

#### Findings of the simulator study

The main results of the Simulator study are:

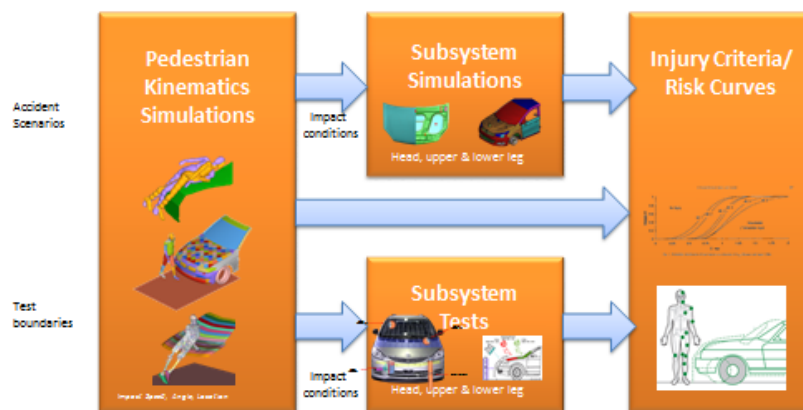
- Warning has significant influence on driver's reaction time
- Trend toward significance of TTC on driver's reaction time
- No significant influence of warning and TTC on gain and maximum braking force
- Drivers that react late apply higher braking force
- Warning has mostly influence in critical situations!

### 2.3 WP 3 – Injury assessment: data for construction of Injury risk curves2-4 pages achievements

WP3 conducted a main part of the simulation and testing activities needed to generate input data required for the construction of the injury risk functions by WP1.

The impactor test conditions used in regulatory and Euro NCAP testing were chosen to represent pedestrian impacts at approximately 40 km/h. AsPeCSS aims to define injury criteria curves to assess a wider range of impact conditions, including different impact speeds, effect of vehicles representative of current European fleet and a number of other impact parameters.

A three step approach was used to obtain this insight.



**Figure 11: 3 step approach to obtain injury criteria curves based on tests and simulations**

### Step 1: Pedestrian kinematics simulations

The goal of step 1 was to provide information about the **impact conditions for impactor simulations and tests by using human body model (HBM) simulation**. Based on prioritized accident scenarios provided within AsPeCSS, the conditions for relevant HBM simulations were identified; To handle the large amount of possible parameters to investigate and to leverage the advantages from the available simulation models, the investigation was split up in two.

Firstly a **trend study** was conducted with 18 **simplified vehicle models** (from previous FP7 project Aprosys), 4 different pedestrian sizes, different pedestrian stances and orientations, with an impact speed range from 20 to 80kph. This resulted in the parameter trends and the ones with the highest influence on impact conditions.

Subsequently, other partners conducted a second study with more **detailed pedestrian and vehicle models** in order to confirm the results from the trend study and to evaluate the effect of other parameters, such as braking and pitching. The output from these simulations was to determine the conditions for appropriate head and upper legform impactor tests, to be executed in step 2.

Once all simulation studies were available, the results were harmonized to evaluate the **headform** impactor setup for different pedestrian sizes as a function of impact speed; this includes impact location, velocity and impact angle.

The output of the trend study provided an overall understanding of the parameter variation, but suffered from some systematic effects induced by modeling simplifications. The detailed studies, on the other hand, provided more accurately results with a less general validity due to the limited number of vehicle models used. Results from the detailed studies were used to correct results from the trend study, and the resulting corridors were found to be in reasonable agreement to experimental data from recent literature.



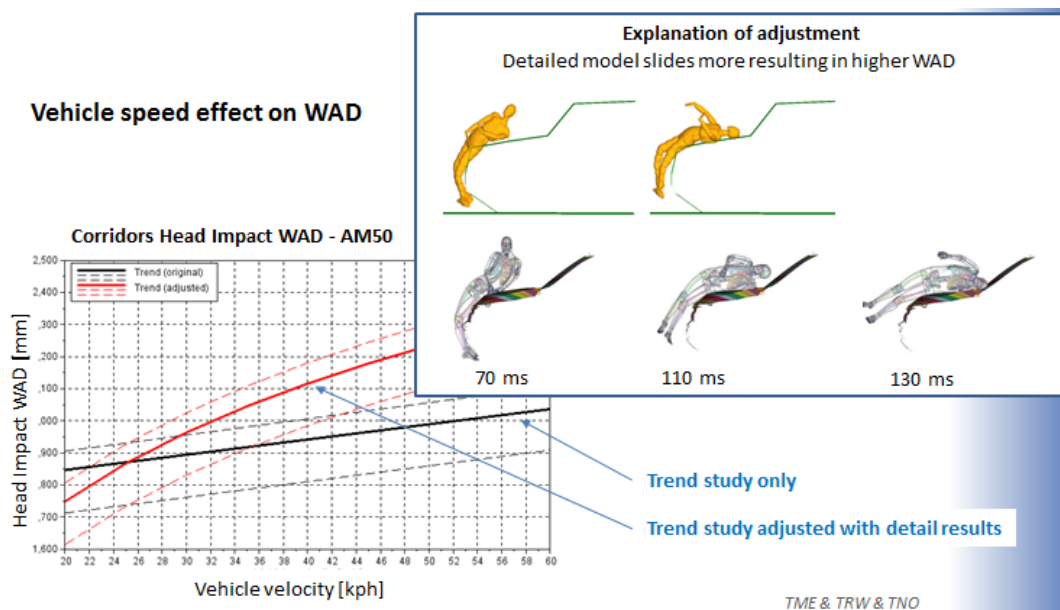


Figure 12: One example of harmonization of results trend study with simplified model and detailed model

For **upper legform** impact conditions, the output of simulations with detailed models was used to investigate the best setup for an equivalent testing based on a guided EEVC impactor. The load on the pedestrian femur is increasing during the accident, and this is combined with the kinematics of the leg. The proposed approach sets the impact angle as the one where the leg suffered from maximum load and the impact velocity as the one of femur point with maximum load at the time of its contact to vehicle body.

### Step2: Subsystem simulations and tests

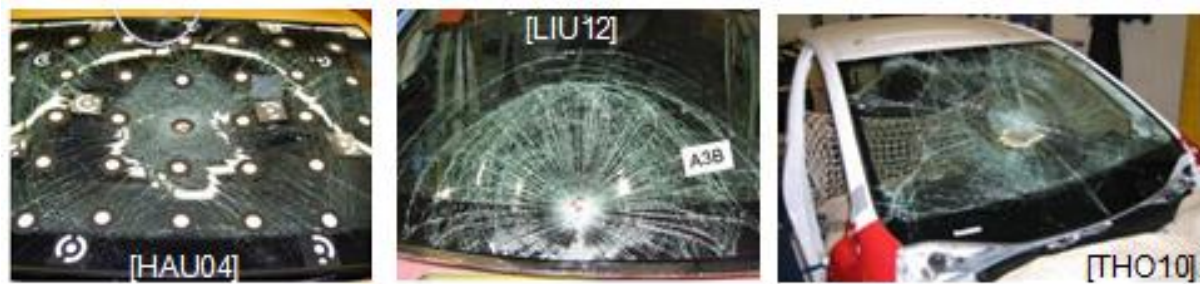
The human body model simulation activities carried out in step 1 generated data to set up impactor tests (virtual and experimental) for step 2. The aim of step 1 was to collect data to construct impact probability curves in terms of pedestrian height and Wrap Around Distance (WAD) and relationships between impactor speed and injury criteria. For this purpose a total of 1168 virtual tests and 120 physical tests have been carried out.

Before running tests, an **analysis of the Euro NCAP results** for the head impact was performed. Since Euro NCAP tested pedestrian protection for more than 15 years, the study provided a state-of-the-art in the pedestrian protection of the most representative cars in Europe. In the case of windscreen impacts, the tensile stress of glass is a scattered component depended property. Thus, an extensive review of the results on this area in Euro NCAP were analysed to increase the reliability of the test results (see figure 3).



Figure 13: Euro NCAP review study results

Beside the analysis of head impacts on the bonnet and a-pillars the windscreen area is a more complex and unknown area. In this study an **overview of open issues** in injury evaluation of the **head impact against windscreens** is given.



**Figure 14: 3 cases of head impact on windcreens for Euro NCAP tests**

The step 1 resulted in **virtual and physical tests** carried out by different partners. The test matrix was defined taking into account the trends extracted and the test set-up available in the project consortium. **Different impactors** (adult headform, child headform, upper leg and lower leg) were used for testing in **different car types** including Large Family Cars, Small Family Cars, Supermini, Sports Cars, SUV's and Large MPV's.

In the analysis a distinction is made between physical and virtual test, impactor type and car type, resulting in identification of several trends and conclusions. For all body regions, car types and methodology of the test (physical or virtual), **impact speed was found as the most relevant variable**. Additionally, the influence of other parameters such as the impact angle in the case of the headform impactor influencing the HIC depends on the impact speed with higher influence at a higher impact speed.

Furthermore, more specific situations were also studied and analysed, like the **Pedestrian Protection Airbag**. The effect of this system on the HIC outcome was studied through virtual and physical tests finding a reduction up to 86% of HIC in the case the head impacts the A-Pillar.

Also, a **sensitivity analysis** for the use of the **Upper Body Mass (UBM)** in the lower legform impactor was carried out. This upper body mass was confirmed to have an important influence, in simulation as well as testing, especially in case of the femur bending moments, but also on the ligament elongations and the tibia bending moments. As for other influential parameters analysed, the effect of the upper body mass on the signals in many cases is depending on the impact speed. Though further research is needed in this field, the comparatively lower rotation of the UBM equipped impactor in that area already shows a more humanlike behaviour and thus could help increasing the testability of areas currently excluded from European as well as worldwide legislation on pedestrian safety.

Finally, the collaborative work performed provided the necessary results to identify the **most significant factors** relevant to the biomechanical outcome of each impactor.

### **Step 3: Injury criteria and risk curves**

In the third step the results obtained from impactor testing and simulations conducted in step 2 were further analyzed, on top of work already done in step 3. For this analysis, the single datasets were merged for as far as possible to investigate overall relationships and correlations. This resulted in a proposal of relations of the main injury criteria to be used in the overall impact analysis in AsPeCSS. (see figure 6). The conversion from injury criteria into risk curves was part of the impact analysis and are therefore not part of the third step.



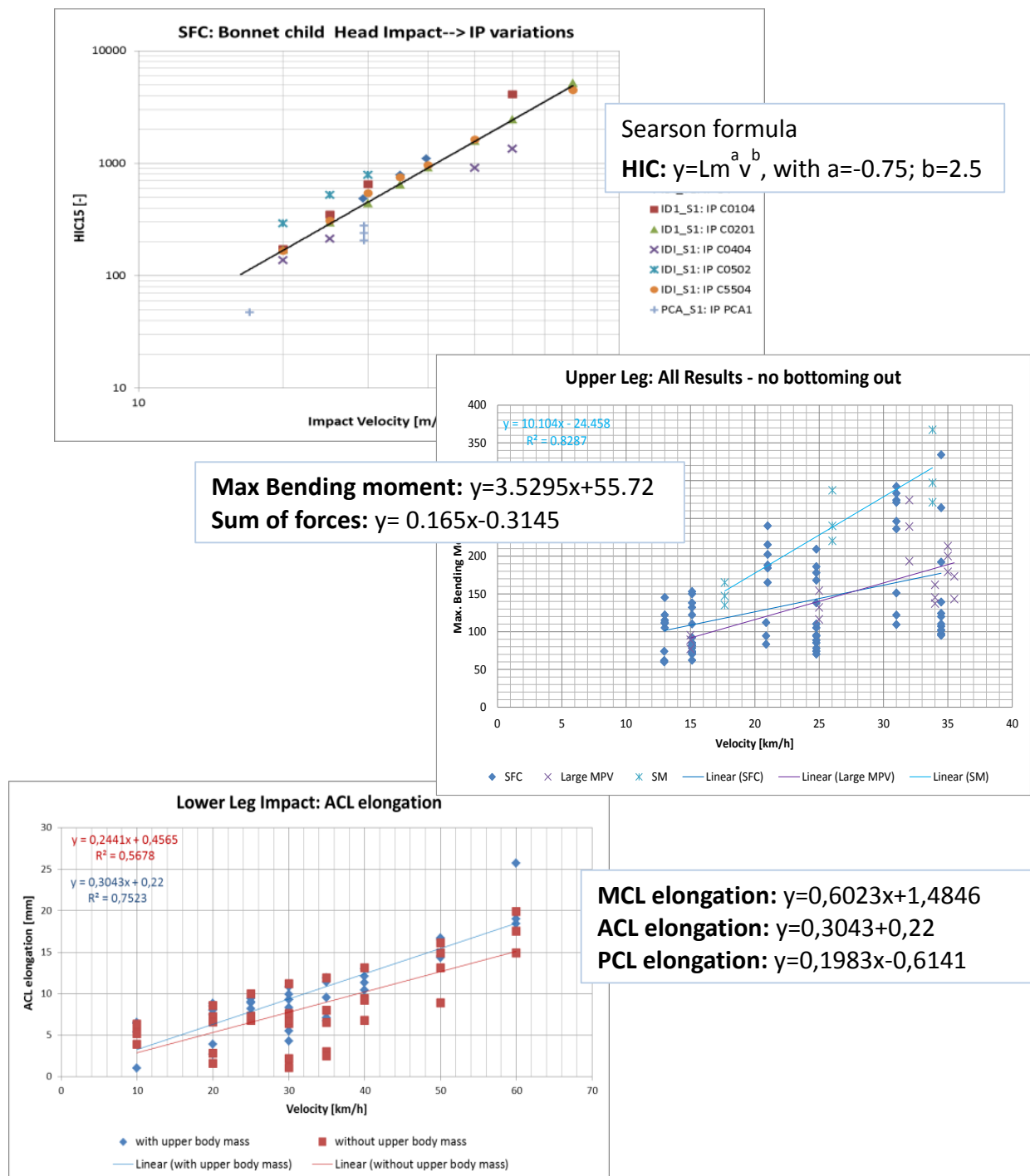


Figure 15: Injury criteria curves with their derived formulae to be used in the overall impact methodology

## 2.4 WP 4 – Dissemination and exploitation

Activities in WP4 – Dissemination and exploitation are running well in the first period. Many activities in this WP are performed in the first 18 months. Although some slight changes to the original workplan, all activities has been done and even more.

The public website was setup in the beginning of the project and afterwards maintained and updated on a frequent basis, including Logo creation and used for all type of templates:

- » General AsPeCSS presentation is available on the website. This presentation is maintained on a regular basis and used for external communications (like for instance the recent workshop held at TRL March 2013).
- » Flyer was released, sent to all contact on dissemination database and published on public website
- » First newsletter was released, mainly on the first test event and was sent to all contact on dissemination database and published on public website
- » Second newsletter was released, with information regarding the first results of active and passive safety part as well as the first draft of assessment methodology
- » Dissemination plan created and the deliverable D4.4 – Dissemination and exploitation plan released and submitted.

#### 2.4.1 External dissemination actions

The external dissemination activities performed in the ASPECSS project are listed below. Since, the outcome of the ASPECSS project is of relevance to a wide European network and even worldwide, there were several dissemination activities organised to inform these relevant stakeholders. And a wide acceptance of the proposed test procedures needs to be achieved, the stakeholders were invited to share their thoughts and results with the ASPECSS consortium.

##### Platform to harmonise assessment methods and tools

The Harmonisation platforms as setup in the ASSESS project are further continued to streamline the information exchange towards the stakeholders.

For HP2 three meetings were held (Feb 2012 BMW, May 2012 ADAC, September 2012 aligned with ActiveTest event). In addition 3 telecalls were held to discuss the reporting. Draft report on dummy specifications delivered to Euro NCAP November 2012. This report is integrated in the AsPeCSS Deliverable D2.1. In a workshop organised March 2013 at TRL all projects were called together to discuss results and findings on accidentology (scenarios), pre crash test set-up and test experience as well as assessment methodology. Representatives from Euro NCAP joined this meeting.

##### Technical workshops

- 1<sup>st</sup> AsPeCSS Workshop / Advisory Board meeting, September 2012, Autoliv, Sweden
- 2<sup>nd</sup> AsPeCSS Workshop /Advisory Board Meeting, March 2013, TRL, UK
- 3<sup>rd</sup> AsPeCSS Workshop, March 2014, TNO NL
- Technical Workshop Scenario specification, October 2012, IDIADA Spain
- Technical Workshop Contrast Test Target, October 2013, Thatcham, UK
- Technical Workshop Test target specification details, October 2013, BAST, Germany
- IRCOBI 2013 - AsPeCSS Workshop
- BAST-NTHSA Meeting,

##### Final event, July 1<sup>st</sup> 2014, BAST, Bergisch Gladbach, Germany

At the BAST the 1<sup>st</sup> of July the final event was organised by BAST, UNR and IDIADA at the premises of the BAST in Bergisch Gladbach, Germany. .

- » 70 guests attended the final event
- » Presentation of final results, available on the website
- » Panel discussion and key note speakers from Euro NCAP (Andre Seeck – BAST), OEM perspective (Klaus Kompass – BMW) and Japan (Kenichi Ando – NTSEL) .
- » Test driving demonstrator
- » Posters presentations

Overall the final event was a great success.



### 3 Impact - Estimate benefit of pre-crash braking part of integrated pedestrian safety systems

An initial estimate of the potential benefits of pedestrian integrated pedestrian safety systems based on field (accident) data was determined. It has to be noted that the benefit given by the pre-crash braking part of the system was considered mainly because it was believed that a large proportion of the benefit offered by these systems will be delivered by this system part. Since testing data was rarely available in a early project phase to be included in the method that was developed, only a theoretic estimation could be calculated with few additions of real test data. First results were shown in Deliverable 1.2. However, this deliverable was rejected later since the topic was captured in Deliverable 1.3 which included methodological corrections as well as data actualizations and thus reports final results of Task 1.2 and served as input for Task 1.3.

A major step within this task was to compare the impact speed distributions for pedestrian casualties hit by a car derived for the GB and German analyses performed (see D1.3). It was seen that there are far more casualties (mainly slight) at the lower speeds for the German distribution compared to the GB distribution. However, it has to be noted that no conclusion can be made from these impact speed distributions to the individual initial driving speeds (for each crash) and hence the drivers' braking behaviour. In Deliverable 1.3 possible reasons for that were discussed. On the basis of the likely bias in the OTS (GB) database and the fact that the national data showed a similar distribution of casualty injury severity, the authors believe that the shape of the German impact speed distribution is closer to the real-world than the GB one, both for Germany and GB. Therefore, the authors recommend that for future work in the project for which data representative of Europe is needed, for impact speed distributions, the German data alone was recommended to be used and no attempt to combine the GB and German data was made any further.

A further substantial step within Task 1.2 was the development of injury risk curves (IRC) for both Great Britain and Germany (as substitute for Europe) using appropriate accident data for each country. The accident data used to derive the curves did not contain any uninjured casualties because data for these casualties were not available. As a result of this, it had to be remembered that the IRC developed have errors and do not reflect real-world risk precisely. Logistic regression was used to generate IRC for both countries, however different statistical methods which suited the source data were used for weighting. The results are compared in Figure 16.

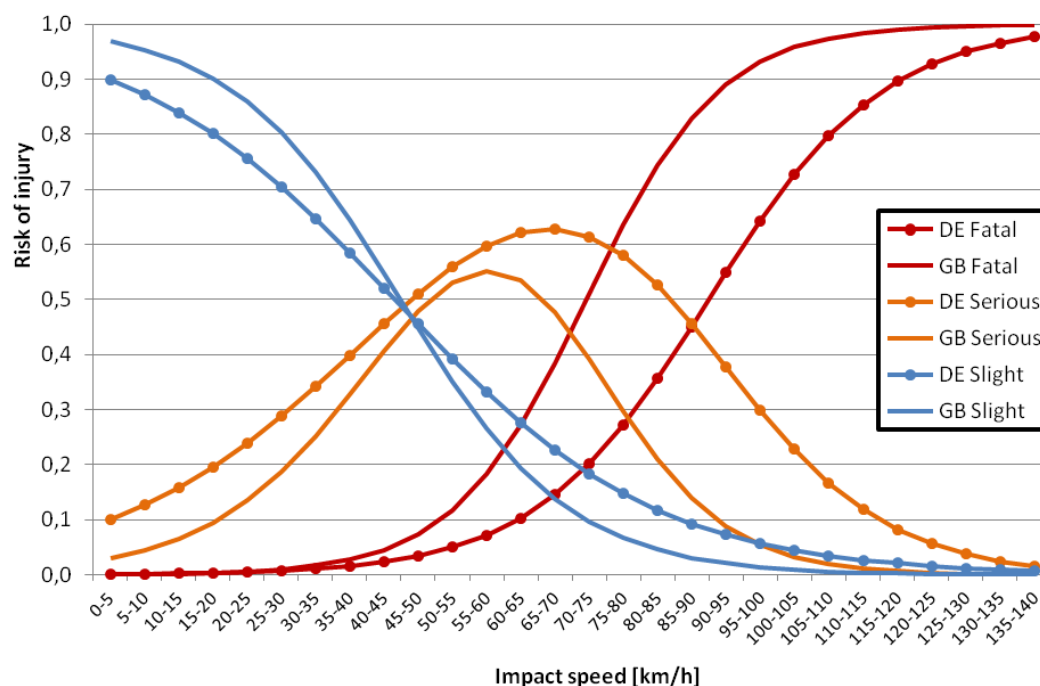


Figure 16: Comparison of Great Britain and German injury risk curves

Significant differences were seen between the fatal injury risk curves for GB and Germany, with the GB curve indicating a higher risk of a fatal injury for a given impact speed. Also, significant differences are seen between the slight injury curves for GB and Germany. A notable one is the higher risk of slight injury at higher speeds for Germany compared to GB. However, this makes sense because there is a lower risk of a fatal injury at higher speeds for the German curves. Likely contributory factors to these differences are:

- The OTS (GB) impact speed distribution has a lower proportion of slightly injured (and serious to some extent) casualties at lower speeds. This will tend to cause the calculation of a fatal injury risk curve with a higher risk of a fatality at lower speeds.
- A second contributory factor could be the differences in the definitions of slightly, seriously and fatally injured which are not exactly the same for GB and Germany. However, the slight and serious curves are most likely to be affected by this because the fatal injury definitions are not that different.

These developed curves have been compared with literature, e.g. paper by Rosén and Sander<sup>18</sup>. It could be seen that the curve derived for Germany within AsPeCSS differs to the GB curve and the curve developed by Rosén and Sander, in particular at speeds above approximately 50 km/h. These differences are due mainly to the cases selected to derive the risk curves. Rosén and Sander filtered the GIDAS cases to exclude sideswiped pedestrians, whereas in AsPeCSS this was not done and which appeared to be an important discussion item. Also, another significant difference was the way that the data set was weighted to the German national data. To investigate the sensitivity of these factors, two additional fatal risk curves were calculated for Germany to be comparable with the results seen in the literature. It was seen that the AsPeCSS curve calculated from a data set with side swipe cases removed is close to the Rosén and Sander curve which highlights that inclusion of side-swipe cases is the main cause of the difference between the AsPeCSS and the Rosén and Sander fatal injury risk curves. Finally, it was decided to use the original German injury risk curves developed by AsPeCSS for the benefit analysis rather than ones more similar to those developed by Rosén and Sander on the basis that all of the curves match within the confidence limits and using the original curve made scaling to the national data more straight forward.

Benefit estimates were finally calculated for GB and Germany for the introduction of AEB systems for pedestrians for three AEB system performance levels representative of current and future systems. As well as nominal calculations, sensitivity calculations were also performed to examine the range of the nominal benefit estimated. The benefits estimated are substantial and are shown in Table 7.

**Table 7: Summary of benefits estimated for the three representative pedestrian AEB systems. The results of the nominal calculations are shown in bold with the benefit expressed as % of all pedestrian road accident casualties shown in brackets. Below this, the range of each benefit estimate given by the sensitivity calculations is shown in brackets and non-bold type.**

<b>GB</b>					
<b>System (Baseline calculation)</b>	<b>Benefit compared to 'no AEB system'</b>				
	<b>Fatal</b>	<b>Serious</b>	<b>Slight</b>	<b>Avoided</b>	<b>Value £(m)</b>
Current generation 2013+	<b>31(6.2%)</b> (13-61)	<b>234(4.2%)</b> (97-441)	<b>463(2.2%)</b> (107-873)	<b>728</b> (218-1,375)	<b>£119</b> (£49-£229)
Second generation 2018+	<b>69(14.1%)</b> (31-102)	<b>495(8.8%)</b> (224-766)	<b>747(3.6%)</b> (319-1,550)	<b>1,311</b> (574-2,418)	<b>£255</b> (£115-£394)
Reference limit 2023+	<b>98 (19.9%)</b> (45-123)	<b>762 (13.6%)</b> (341-981)	<b>1,532 (7.3%)</b> (634-2,513)	<b>2,392</b> (1,019-3,616)	<b>£385</b> (£172-£501)
<b>Germany</b>					

<sup>18</sup> E. Rosén and U. Sander, "Pedestrian fatality risk as a function of car impact speed," Accident Analysis and Prevention, vol. 41, pp. 536-542, 2009.



System (Baseline calculation)	Benefit compared to 'no AEB system'				
	Fatal	Serious	Slight	Avoided	Value €(m)
Current generation 2013+	<b>17(2.9%)</b>	<b>374(4.6%)</b>	<b>1,034(4.4%)</b>	<b>1,424</b>	<b>€63</b>
	(7-36)	(137-792)	(331-2,381)	(474-3,208)	(€24-€135)
Second generation 2018+	<b>39(6.7%)</b>	<b>788(9.7%)</b>	<b>2,006(8.6%)</b>	<b>2,833</b>	<b>€136</b>
	(16-60)	(310-1,271)	(681-3,191)	(1,006-4,522)	(€54-€218)
Reference limit 2023+	<b>57 (9.9%)</b>	<b>1,281 (15.8%)</b>	<b>3,455 (14.8%)</b>	<b>4,792</b>	<b>€216</b>
	(23-73)	(497-1,673)	(1,250-4,598)	(1,771-6,344)	(€85-€282)

The benefits estimated for GB and Germany were scaled to give an estimate of the benefit for Europe. These benefits expressed as monetary values were of the order of billions and are shown in Table 8 below.

**Table 8: Benefit of representative pedestrian AEB system for EU27 excluding Bulgaria and Lithuania estimated by scaling GB and German benefit estimates expressed as monetary values.**

Pedestrian AEB system	Monetary value (€ Billion, i.e. €*10 <sup>9</sup> )					
	GB			Germany		
	Pessimistic	Nominal	Optimistic	Pessimistic	Nominal	Optimistic
Current generation 2013+	€ 0.46	€ 1.09	€ 2.11	€ 0.31	€ 0.82	€ 1.77
Second generation 2018+	€ 1.07	€ 2.38	€ 3.61	€ 0.70	€ 1.78	€ 2.84
Reference limit 2023+	€ 1.59	€ 3.51	€ 4.50	€ 1.10	€ 2.81	€ 3.66

In addition, Task 1.2 (together with parts of Task 1.3 and WP2 activities) developed and reported assessment methodologies for the braking part of forward looking integrated pedestrian safety systems in Deliverable 1.3 for use in consumer rating programmes, in particular Euro NCAP.

Two potential methodologies have been developed for the assessment of the Automatic Emergency Braking (AEB) part of forward looking integrated pedestrian safety systems for use in Euro NCAP. Assessment methodology I is based on the approach used by Euro NCAP for assessment of AEB systems for vehicle-to-vehicle impact, whereas assessment methodology II is based on the approach used for the benefit analysis performed in Task 1.3. Overall, the methodologies give similar ratings for the limited number of vehicles/systems assessed. However, there are some differences between them, such that assessment methodology I considers killed and seriously injured pedestrians only, whereas assessment methodology II considers all injured pedestrians (the assessment methodology is detailed in the section 2.1.2)

## 4 Website and contact details

### 4.1 Website

The project public website has been set up for the general public and can be found at the web address: [www.aspecss-project.eu](http://www.aspecss-project.eu).

The website provides general information on the project objectives and the work to be performed as well as details of the project partners, and contact details for the project coordinator. It includes a password protected section with access restricted to partners only. The website will be accessible for 4 years after the project is closed. Public deliverable reports and other open project documentation will be available via the website to the public during this period. Confidential reports will remain available to partners via the restricted part.



### 4.2 Contact persons

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## 5 List of Project Participants

Participant no.	Participant organisation name		Country
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2	AUTOLIV DEVELOPMENT AB	AUTO	Sweden
3	Bundesanstalt für Strassenwesen	BAST	Germany
4	Bayerische Motoren Werke AG	BMW	Germany
5	Robert Bosch GmbH	BOSCH	Germany
6	Humanetics Europe GmbH	HUMAN	Germany
7	Peugeot Citroën Automobiles SA	PCA	France
8	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek TNO	TNO	The Netherlands
9	Toyota Motor Europe	TOYOTA	Belgium
10	TRL Limited	TRL	UK
11	TRW Automotive	TRW	Germany
12	Uniresearch BV	UNR	The Netherlands
13	IKA - Rheinisch-Westfaelische Technische Hochschule Aachen	IKA	Germany