Towards an Integrated Pedestrian Safety Assessment Method

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I. INTRODUCTION

While passive safety assessment is well established in regulation and consumer testing, active safety assessment has only emerged recently. An integrated safety system is one which consists of both active and passive safety devices. Assessment of these systems is in its infancy and is the subject of current research. The current challenge is to define a methodology which integrates active and passive assessments and takes into account the influence that the active safety system has on the boundary conditions for the passive safety system. The current study is focused on developing a methodology to assess integrated pedestrian systems. Some previous research work has been performed to develop methodologies to assess these systems but to date no methodology has been developed which integrates the active and passive assessments fully and takes into account the effect of the active safety system on the passive safety system boundary conditions. The current research work is described below and key features of it are summarised in table 1.

Euro NCAP assesses the protection offered for pedestrians with component tests at fixed test speed and impact angles [**1**] [**2**]. An assessment for active safety systems is currently under discussion. Test methods for active safety systems are proposed by, besides others, AEB [**3**] and vFSS [**4**]. A combined assessment cannot be the straight forward combination of both because the benefit of the active and passive system are measured in different units: e.g. impact speed reduction for active safety systems and injury criteria measurements for the passive safety system component test which can be related to injury risk of the tested body region.

A combined assessment method has been proposed by Schramm [**5**] and Roth and Stoll [**6**]. It makes use of separate active and passive safety tests at a reference speed (40 km/h) and calculates MAIS 2+[*1] injury risk reduction as a function of speed reduction and Euro NCAP pedestrian point score. This combined assessment is, however, not a fully integrated assessment. Active safety systems functionality is assumed to have no influence on the configuration of the passive safety tests, for example no change in impact area or angle is expected. This dependence has been demonstrated e.g. by Peng et al. [**7**]. Furthermore, expected benefits of the systems are added, which requires independence of the effectiveness of passive and active safety systems. This can not necessarily be assumed to be the case as two technologies might address the same type of injury as shown by Rosen et al. [**8**].

VeRPS [**9**] has been proposed as an assessment method which combines simulation and component tests. Simulation is used to determine impact points, speed, angle, etc. for the specific vehicle because it has been shown that car geometry and stiffness, besides others, influence these parameters. Component tests are used to measure impactor response and relate this to injury risk potential. This methodology could be extended into an integrated assessment. The impact speed at which the vehicle specific simulations are carried out could be altered and interaction between active and passive safety systems could be reflected in an altered passive safety test. However, a large number of simulations and tests would be expected to be required which may not be practicable.

Hamacher et al. [**10**] has developed an extension for the VeRPS-Index to include active safety technology. Impact speed reduction from a reference test speed and changes in passive safety boundary conditions are considered. For six different geometrical vehicle classes, to which the assessed vehicle has to be assigned, adjustment factors for head impact speed and angle are derived from multi-body simulation as the maximum

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1 AIS: Abbreviated Injury Scale, a standard measure for injury severity* [18**] *and MAIS: Maximum AIS, measure for overall injury severity using the maximum AIS of all injuries sustained. It reaches from 0 (uninjured) to 6 (currently not treatable).*

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values from several statures and impact locations. The likelihood of head impact at different positions is likewise calculated a priori for the vehicle class. Both, kinematic adjustment factors and impact probabilities are available for 4 different impact speeds as well as for an adult and child pedestrian. The resulting index value is an impact speed dependent probability weighted risk of AIS3+ head injury. A separate simplified leg injury index is proposed similarly. This methodology is an integrated assessment as boundary conditions for the passive safety assessment are adjusted based on the influence of active safety systems.

Recently, Hutchinson et al. [**11**] proposed an assessment highlighting the importance of considering not only one reference speed but all impact speeds. This is to avoid sub-optimization: A design optimal for a single reference speed might not be optimal over all impact speeds. The benefit measure used for illustration is AIS2+ injury risk. However, those authors believe that "a better option would be to take into account all levels of injury, with their different levels of seriousness, and arrive at an average 'cost'".

This short communication paper shows the principles and steps to be taken to develop an extensive and fully integrated pedestrian safety assessment method.

Table 1: Elements of existing pedestrian safety assessment methods relevant for a new integrated assessment

	Euro NCAP [**1**] [**2**]	AEB [**3**]	vFSS [**4**]	Schramm [**5**] Roth and Stoll [**6**]	VeRPS [**9**]	Hamacher et al. [**10**]	Hutchinson et al. [**11**]
Active safety tests	-	Warning and autonomous braking	Warning and autonomous braking	By simulation	-	Not specified (external tests protocol)	-
Test speed	-	Increasing from 10 km/h to no effect	40 km/h	Various	-	40 km/h	-
Test scenarios	-	3 daytime crossing	4 daytime crossing	Crossing & stationary)	-	Not specified	-
Outcome for each scenario	-	Impact speed reductions	Impact speed reduction	Impact speed reduction transformed to MAIS2+ injury reduction from global injury risk – impact speed curve	-	Impact speed reduction	-
Passive Safety tests	Component tests	-	-	Component tests	Component test	Component tests	Component test
Body regions tested	Child head, Adult head, Upper leg, Lower leg	-	-	As Euro NCAP	Head	Head and lower leg	Head
Test speed	40 km/h	-	-	As Euro NCAP	Impact point specific from simulation with 45 km/h impact	As Euro NCAP	40 km/h – calculation of test values for whole incidence speed distribution
Impact angles	Fixed	-	-	As Euro NCAP (no changes due to active safety)	Impact point specific	As Euro NCAP	As Euro NCAP (no changes due to active safety)
Impact area and point distribution	Fixed impact area. Uniform distribution within test area	-	-	As Euro NCAP (no changes due to active safety)	Vehicle specific by simulation (potentially changed by active safety)	As Euro NCAP	As Euro NCAP (no changes due to active safety)
Outcome	Point score (body region specific thresholds based on injury risk curves)	-	-	Point score transformed to MAIS 2+ risk reduction with injury-shift method	Risk reduction at chosen AIS level	Injury risk at AIS3+ level	Cost function from injury risk, example risk reduction at AIS2+ level
Integration	-	-	-	Addition of active and passive safety MAIS2+ reduction	As outlook: Change in impact speed for vehicle and impact point specific simulations.	Passive tests adjusted for head impact velocity and angle vehicle class specific, weighted by impact speed adjusted impact probabilities	As outlook: Change in incidence distribution.

II. METHODS

An integrated pedestrian safety assessment methodology is being developed within the European Commission 7th framework project AsPeCSS using a literature review, accident data analysis, computer simulation, hardware testing and validation against real-world data [**12**]. The main aim is to develop an assessment that is related to the benefit that the system will offer in real-world impacts in order to ensure that it is meaningful. Other objectives for the development of the assessment include:

- A fully integrated assessment is necessary to evaluate potentially relevant interactions of safety systems. The integrated assessment has to measure benefits of safety strategies which reduce impact speeds and reduce injury risk for given impact speeds. Some possibilities for an integrated assessment method have been shown by Hamacher et al. [**10**].
- The measure of benefit needs to be clearly defined and the rationales for the chosen measure motivated. The methodology needs to consider all the casualty's (AIS2+) injuries and not just the maximum AIS injury because it is the combination of all the injuries which determines the outcome for the casualty. Low AIS injuries can have a significant risk of long term consequences and can therefore be costly [**13**]. The derivation of a cost function for all injury levels and body regions for a European pedestrian population has not yet been attempted, however data for the USA exists in this detail [**14**]. The benefit needs to be expressed as a single number which is indicative of the overall benefit of the system. This will enable easy comparison of the assessments of safety systems with different strategies.
- A relevant range of impact speeds needs to be considered based on the description of Kullgren [**15**] of road traffic injuries and dependent on incidence rates and injury risk. This follows the approach of Hutchinson et al [**11**]. It was shown that pedestrian protection has a contribution at speeds beyond regulatory testing, with a fatality risk of 50% at 75 km/h [**16**]. A single test might encourage sub-optimization because the structure tested might not be developed to offer protection at higher speeds [**11**]. Similarly, the full potential at lower speeds might not be reached. Assessing protection offered at relevant speeds with the corresponding incidence rates will allow a global optimum for protection to be reached [**11**].
- Injuries sustained by all body regions and from ground impacts need to be considered. The benefit of improved protection for a specific body region might be offset by worse protection for another body region. Ground impact may reduce the effectiveness of passive safety measures similar to the way a not addressed accident scenario reduces effectiveness of active safety systems. Appropriate component tests (e.g. with headform and legform, but potentially also new tools to test currently "untestable" areas) will be identified.
- Both the impact area as well as impact point distribution need to be aligned with actual impact probabilities to assess vehicle structures according to the risk they impose to pedestrians. Impact probabilities of particular pedestrian body regions have been shown to depend, besides other variables, on impact speed e.g. [**7**] [**8**]. This influence needs to be explicitly modelled. For this, full human body model simulations will be carried out.
- Furthermore, the influence active safety intervention might have on impact kinematics needs to be analysed by full human body simulation and reflected in the methodology. Both have been incorporated in the method proposed by Hamacher et al. [**10**].
- The assessment methodology needs to be accurate and validated against real-world data, as well as simple and usable for vehicle assessment.

III. RESULTS

An outline assessment methodology has been developed. It consists of five steps as listed below (see figure 1).

1. Active safety testing: Exposure / velocity curve shift

Driver warning and autonomous emergency braking systems will be assessed with respect to their ability to reduce impact velocity. Changes to impact kinematics due to this intervention will be noted for passive safety testing. Analysis of accident data will be used to define representative test scenarios, similar to, but not necessarily equivalent to those developed by other projects such as AEB [**3**] or vFSS [**4**]. The test scenarios will be weighted corresponding to their contribution to injury occurrence. From each test scenario the typical speed reduction over the whole range of impact speeds will be derived, in a manner similar to [**3**]. Using this information, the exposure – velocity curves for the corresponding accident scenario will be adjusted to account for the effect of the active safety system.

2. Passive safety testing: Impactor measurement

Tests will be conducted at one or several speeds and impact angles to estimate impactor injury criteria measurements for the relevant vehicle speeds identified in step 1. For the headform impactor this will involve estimation of head impact velocity from pedestrian impact speed. As the number of tests will be limited, a model for speed dependency for each impactor might be needed. For head impactor testing, recent work proposed such a model [**11**] [**17**]. Impact points will be chosen according to the impact distribution of the pedestrian population. Both the boundaries of the test area as well as the distribution within need investigation. For the lateral direction, uniform point distribution will be assumed (as e.g.in [**10**]). For the longitudinal direction a potential shift of impact probabilities and impact kinematics with impact speed has to be considered, taking into account limited repeatability and reproducibility due to the complexity of vehicle to pedestrian accidents.

3. Calculation of injury: Injury risk

Injury criteria measurements from step 2 will be converted into an injury estimate for tested body regions using injury risk curves and velocity-exposure data from step 1. Available injury risk curves may need to be re-analysed to match with the pedestrian population exposed. Gender, age, stature, and impact velocity might be influential. Furthermore, injury risk curves need to be made available for all injury severity levels.

4. Calculation of cost: Socio-economic cost

Injury risks for tested body regions will be converted into costs for individual injuries. This could be done in one of two ways. Firstly, relevant costs could be established from European insurance and accident data. The largest contributors to cost are usually production loss and the valuation of lost quality of life, while medical treatment cost remains comparably low. Alternatively, US harm data [**14**] might be weighted towards European pedestrian causalities.

5. Vehicle assessment: Weighting and summing

In the last step, costs will be weighted to account for non-tested body regions and ground impact. These costs will be summed to give overall socio-economic cost of vehicle fitted with active and passive safety systems. This total cost will be subtracted from a baseline cost representing a typical vehicle to express the socio-economic cost in terms of a saving or benefit.

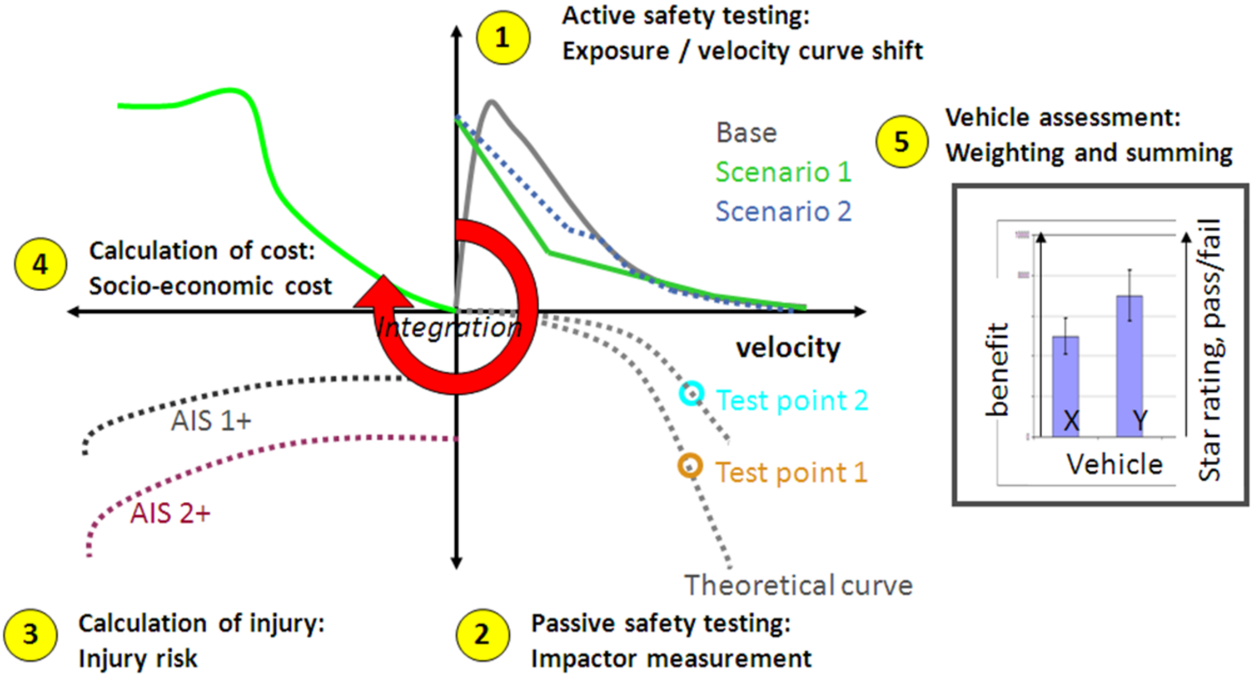

Figure 1: AsPeCSS methodology

IV. DISCUSSION AND CONCLUSIONS

This paper describes a concept for the assessment of an integrated pedestrian safety system. It includes the assessment of active and passive systems in an integrated manner and takes into account the effect that the active system has on the boundary conditions for the passive system. It is based on an estimate of the reduction of pedestrian injury that would be seen in the real-world and hence is meaningful. Further development will include validation and calibration against real world data, uncertainty assessment and possibly simplification for use by stakeholders such as Euro NCAP. In the future, hardware testing could be replaced by simulation to do more tests in a shorter time.

V. REFERENCES

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VI. ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (*FP7/2007-2013)* under grant agreement n° 285106.

The authors would like to thank all partners of the AsPeCSS project Task 1.3 for the fruitful discussions and valuable input to the development of this integrated pedestrian safety assessment method.