THE HEAVY GOODS VEHICLE AGGRESSIVITY INDEX

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ABSTRACT

The provision of protection for vulnerable road users (pedestrians and pedal cyclists) is not a new concept for vehicle design. Directives 2003/102/EC [1] and 2005/66/EC [2] assess the "structural aggressivity" of passenger cars and front protection systems ("bullbars") with respect to the protection of pedestrians. Adopting these directives for assessing heavy goods vehicles (HGVs) would be straight-forward. However, assessing the "structural aggressivity" only, will fail to address a relatively large number of fatalities, particularly those that occur at low-speeds.

This manuscript describes the development of the test procedures and assessment criteria for the Heavy Vehicle Aggressivity Index (HVAI). The procedure and criteria are derived based on the study of real world accidents. The proposed procedure integrates numerical simulation and physical testing methods.

The HVAI aims to reduce the number or severity of vulnerable road user (pedestrian and pedal cyclist) casualties from accidents involving HGVs by providing guidance to manufacturers/designers of such vehicles.

The HVAI consists of three parts, assessing the field of view of the driver (active HVAI), the direct contact between the casualty and the vehicle structure (structural HVAI) and the risk of the casualty being over run by the HGV (run-over HVAI). Each of these sub-indexes returns a value between 0 and 10. The three parts ensure that a wide range of accident scenarios are addressed.

Keywords: Vulnerable Road Users, Pedestrian, Bicyclist, Heavy Goods Vehicles, Trucks

INTRODUCTION

The Heavy Vehicle Agressivity Index (HVAI) aims to improve the protection offered to pedestrians and pedal cyclists – often referred as vulnerable road users in impacts with HGVs. The HVAI is a set of test procedures for the assessment of the protection afforded to vulnerable road users (VRU) by heavy goods vehicles (HGV). The HVAI aims to encourage HGV manufacturers and designers to develop more pedestrian and cyclist friendly vehicles in order to reduce the number or severity of VRU casualties from accidents involving HGVs.

METHOD

The HVAI consists of three parts assessing the performance of the design in relation to the following areas (see Figure 1):

- Active Index: The ability for the accident to be avoided though good visibility and/or active safety systems.

- Structural Index: Direct contact between the casualty and the vehicle structure,
- Run-over Index: Risk of the casualty being run over by the HGV.

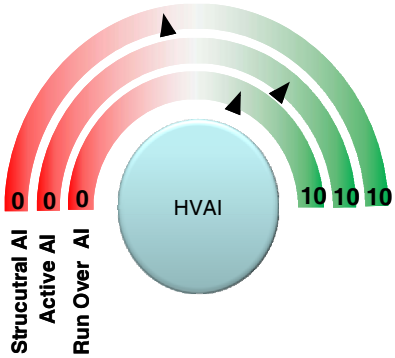

Figure 1. Presentation of the HVAI.

Each individual part of the HVAI is assessed on a scale from 0 to 10 with the score increasing with improved protection of the VRU.

Active Index

The accident analysis revealed numerous accidents at low impact speeds [3]. Passive safety measures will have limited effect on very low speed accidents because of the kinematics involved. These accidents are addressed by the active AI. The index evaluates the field of view of a 50th percentile driver, separated into a primary area of interest (in the close surroundings of the vehicle) and a secondary area of interest (>5m away from the right front edge of the HGV).

The active part of the HVAI is a methodology for comparison of cab designs of HGVs over 7.5t with respect to the driver's field of view. It is a proposal for comparing the driver's field of view by considering four basic components:

- areas only seen directly;
- areas only seen through the various mandatory mirrors;
- areas which can be seen directly and at least through one mirror;
- blind spots /areas not visible at any time.

The development of this assessment procedure is based on geometrical relations in 2D blueprints of the commercial vehicles and cabs. In addition, the mandatory mirror view areas around the vehicle were used. The assessment could be carried out using 3D-CAD and/or ergonomics software packages.

The current proposal is restricted to the assessment of cab-over-engine HGVs and includes only the primary structures affecting the visible area (edge of glazing and mirrors). Obstructions due to the dashboard or the steering wheel were not considered.

The test procedure defines two areas of interest in which measurements will be taken. These are the primary area of interest (PAI) and the secondary area of interest (SAI) as shown in Figure 2.

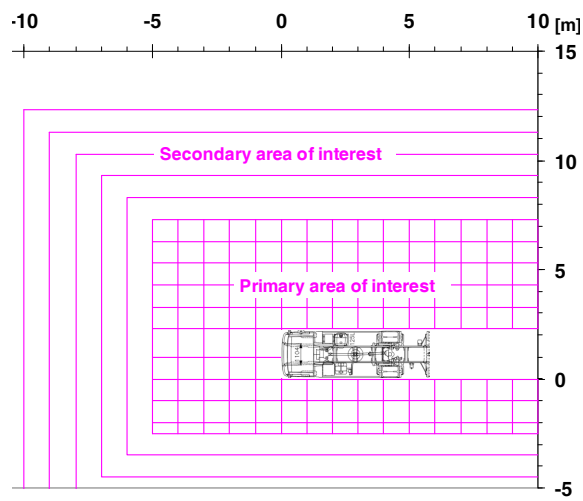

Figure 2. Definition of primary and secondary areas of interest.

<u>Direct field of view</u>

The direct field of view is that which can be seen by the driver without the use of visual aids such as mirrors or cameras. The direct field of view is often measured by marking the boundary of the visible area on the ground plane either physically or numerically by the use of CAD/ergonomics software. For the purpose of this proposed assessment protocol, the direct field of view is measured at a height of 1.6m from the ground. 1.6m is an estimate of the vertical position of the centre of the head of a walking 50th percentile person and will ensure that a pedestrian of this stature will be seen when standing in the visible area. However there are also other statures of VRU that could be considered for future development of this procedure, for example 5th percentile females, cyclists or child pedestrians.

Figure 3 shows an example of the direct field of view. Blind spots that result from the main structure of the cab are shown in red, whilst blind spots associated with other structures such as the mirrors are shown in blue. The assessment is based upon the monocular vision of a 50th percentile male driver sitting in a normal driving position.

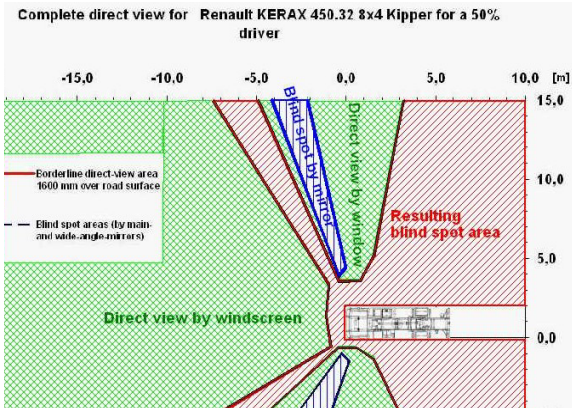

Figure 3. Direct field of view.

Indirect field of view

The indirect field of view is that which can be seen by the driver through the mirrors (or other features such as video cameras). Current legislation requires that the indirect field of view is measured on the ground plane. This can allow small objects within the prescribed area to be seen, however, it may not necessarily be possible to identify what the object is. To allow the driver to correctly identify a VRU, it is proposed that the indirect field of view is assessed at a distance of 0.5m from the ground plane. This should allow at least the lower half of a pedestrian's leg or half a bicycle wheel to be identified in the mirrors. The proposed assessment of indirect view does not include the Class II (main exterior mirrors) because they are not considered influential for current VRU accident scenarios. However, they are included for the purpose of assessing the direct field of view because they form an obstruction to the direct field of view. Figure 4 shows an example of the indirect field of view. The proposed index promotes an indirect field of view that exceeds existing regulations.

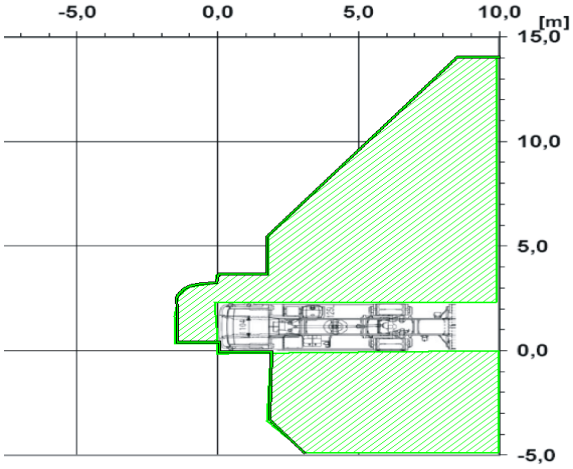

Figure 4. Indirect field of view.

Valuation of visible areas and blind spots

The areas defined above are combined as shown in Figure 5 and the following areas are calculated for both the PAI and SAI:

- Blind spots;
- Mirror view only;
- Direct view only; and
- Combined mirror and direct view.

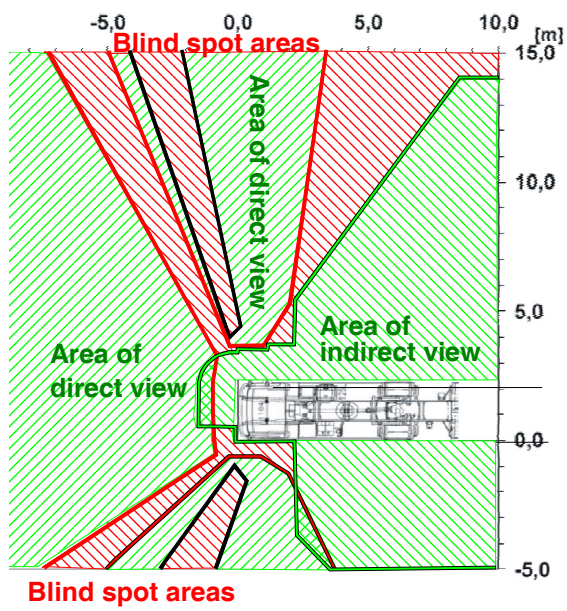

Figure 5. Diagram combining direct and indirect fields of view and blind spots.

To allow for the relative importance of the different view areas with respect to the safety of VRU, weighting factors were applied:

- Blind spots in the PAI were considered more relevant than those in the SAI because of the close proximity to the vehicle. These were therefore upgraded by 20% by applying a weighting factor;
- It is often more difficult to correctly identify an object in a mirror than through the windshield (direct view). Therefore areas that were only visible in mirrors were downgraded by 20%;
    - Mirror views in the SAI were downgraded a further 20% because the mirror views at that distance are even more difficult to interpret.
- Where the direct and indirect views overlap there is an increased probability that the driver will be able to correctly identify the VRU, for example if part of the head is visible through the window and part of the leg is in the view given by a mirror. However, because this area is also

part of the direct view, a neutral weighting is applied.

PAI Example

As example, the PAI around the truck has a total visible area of 123m² (see Table 1). The visible area of the PAI is divided in the areas of direct view (49m²) and in areas of mirror view (55m²). An area of 14m² can be seen both directly and in-directly (in the mirrors). The blind spot areas have a value of 5m². The value of direct view and overlapped view are un-weighted and will not be changed, remaining at 49m² + 14m² respectively. The value for the mirror view will decrease 20% from 55m² to 44m² and the value of the blind spot areas will increase 20% from 5m² to 6m². Consequently, the sum of the weighted areas of the PAI will decrease from 123m² to 113m². The direct view and overlap view areas will account for 43% and 12% of the total weighted area. The mirror view area is 39% (and 12% overlap) and the blind spot areas account for 5% in the PAI.

Table 1.
Example of calculated and weighted areas, PAI.

	Primary Area of Interest		
	Weighting Factor	Area ([m²])[%]	Weighted Area ([m²]) [%]
Blind spots	1.2	(5) 4	(6) 5
Mirror view	0.8	(55) 45	(44) 39
Overlap direct -mirror	1.0	(14) 11	(14) 12
Direct view area	1.0	(49) 40	(49) 43
Total		(123) 100	(113) 100

SAI Example

The SAI around the truck is usually about 60% larger than the PAI and has in our example a total amount of 195m² (see Table 2). The weighted value of direct view will not be changed and remains at 131m². The value of mirror view will decrease from 45m² by 20% to account for it being the indirect view and by a further 20% because it is the SAI (as described earlier) to 35m² (including 16m² overlap). The value of the blind spot areas on the other hand remain at 19m². Hence the sum of the areas of the SAI will decrease to 184m². The direct view area and overlap area will account for 71% and 9% of the weighted area. The mirror view area is 19% (incl. 9% overlap) and the blind spot areas 10% in the SAI.

Table 2.
Example of calculated and weighted areas, SAI.

	Secondary Area of Interest		
	Weighting Factor	Area ([m²])[%]	Weighted Area ([m²])[%]
Blind spots	1.0	(19) 10	(19) 10
Mirror view	0.64	(29) 15	(19) 10
Overlap direct- mirror	1.0	(16) 8	(16) 9
Direct view area	1.0	(131) 67	(131) 71
Total		(195) 100	(185) 100

Modifiers

Even when the design of HGV enables the driver to see almost every detail around the vehicle, there will remain some specific situations when the VRU is not visible, particularly when in very close proximity to the HGV:

- VRU is standing just in front of the HGV;
- VRU is just to the nearside of the HGV; or
- VRU is walking towards the HGV roughly behind the B-pillar.

Modifier points are awarded to vehicles where the following criteria apply:

1. Step one is to evaluate if there is an overlap area of direct view and indirect view by one of the mirrors in the PAI around the vehicle. For example, this overlap could be found between the area covered by the direct view and the area covered by the wide-angle-mirror on the nearside. This criterion is fulfilled, if there is an overlap of at least 100mm, in which case a modifier of 3 will be awarded;
2. The second criterion is applied if the first criterion is fulfilled. This criterion focuses on the overlap of the direct view out of the nearside window and the proximity mirror area. The criterion is fulfilled, if there is an overlap of at least 100mm between the interior borderline of the direct view through the nearside window and the exterior borderline of the proximity mirror view. In this case the modifier number increases to a maximum of 6.
3. This criterion focuses on the overlap of the direct view out of the side window and the wide angle mirror area in the PAI on the nearside of the vehicle. The criterion is fulfilled, if there is a point were the overlap of the rear borderline of the direct view through the right window and the frontal borderline of the right wide angle-mirror-

view. If this is the case, the modifier number increases to a value of up to 10.

Overall score for Active HVAI

Figure 6 shows an example of the presentation of the results of the assessment. The outer circle shows results for the SAI, the inner circle is the PAI and the number in the centre refers to the modifier score.

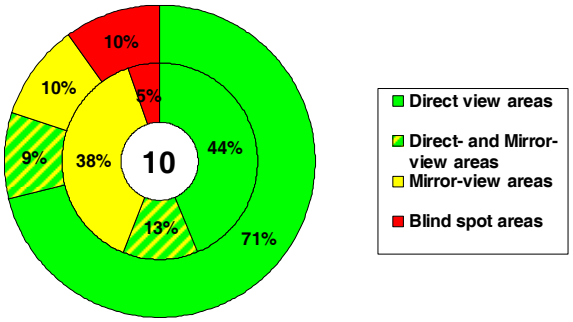

Figure 6. Example presentation of assessment results.

There are three important values required to assess the overall field of view (direct view, mirror view and blind spots). For each area of interest, the direct view and blind spots were benchmarked against 10 existing HGV designs. Benchmarking two of the three values was considered sufficient since the mirror view would be the remainder of the total (i.e. mirror view = 100% - direct view – blind spots). The results of the benchmarking are shown in Table 3.

Table 3.
Benchmarking of direct view and blind spots.

PAI	Direct View	Blind Spot	SAI	Direct View	Blind Spot
10	58%	4,0%	10	80,0%	9,0%
9	55,5%	5,5%	9	77,5%	10,5%
8	53,0%	7,0%	8	75,0%	12,0%
7	50,5%	8,5%	7	72,5%	13,5%
6	48,0%	10,0%	6	70,0%	15,0%
5	45,5%	11,5%	5	67,5%	16,5%
4	43,0%	13,0%	4	65,0%	18,0%
3	40,5%	14,5%	3	62,5%	19,5%
2	38,0%	16,0%	2	60,0%	21,0%
1	35,5%	17,5%	1	57,5%	22,5%

This allowed a score from 0 to 10 to be applied to each of the four parts (direct view PAI, blind spot PAI, direct view SAI and blind spot PAI). These four values are then combined with the modifier score and averaged to give the Active HVAI score out of 10 as shown by the example in Table 4.

Table 4.
Example of overall Active AI score.

	Single Rating	Overall Rating
Modifier	10	
Direct view PAI	9	
Blind spot PAI	9	8.8
Direct view SAI	8	
Blind spot SAI	8	

Structural Index

Test procedures for the assessment of the structural interaction between passenger cars and pedestrians already exist, both, for type approval purposes and for use in consumer assessment ratings of vehicles. These existing protocols have been used as a basis for the development of a test procedure for the assessment of the protection for VRU in impacts with HGVs [4].

The structural aggressivity index defines two impact zones (adult and child) with 6 areas per zone and 4 regions per area. One region within each area is tested by propelling adult and child headforms (as defined by EEVC WG 17) horizontally at 11.1m/s. Up to 15 tests per vehicle are conducted to assess the structural response. Up to 2 credit-points are assigned to each test area.

Vehicle preparation and marking

The protocol specifies the marking out of the front of the vehicle into two zones, one an adult zone, and the other a child zone. The adult zone is the area where the head of an adult pedestrian is likely to hit and the child zone is the equivalent area for a child pedestrian. The marking procedure includes allowances for changes in ride height of the vehicle and defines the “corner” of the vehicle. The lower boundary of the test zone is defined with the vehicle at its maximum ride height, and the upper boundary with the vehicle at its minimum ride height. The heights of the boundaries are defined based on anthropometric data [5]. Figure 7 shows the marking of the two test zones.

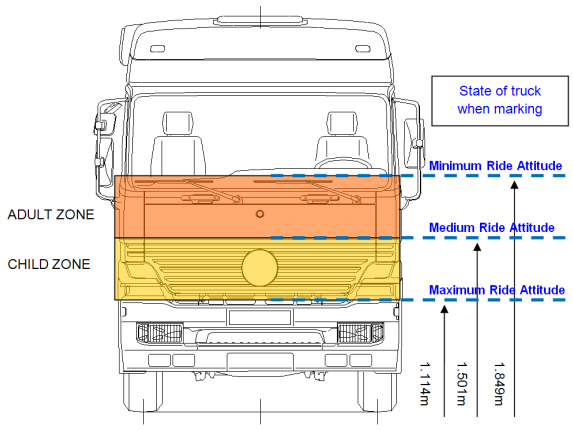

Figure 7. Marking out of test zones accounting for ride height of vehicle.

This approach has been developed based on flat-fronted vehicles, which are the most common HGV design currently in use in Europe. The protocol provides an alternative approach for marking vehicles that are not flat fronted, which allows the wrap-around kinematics to be considered.

Both the child and adult test zones are divided horizontally into six areas. Each area is then sub-divided into quarters and labelled as shown in Figure 8.

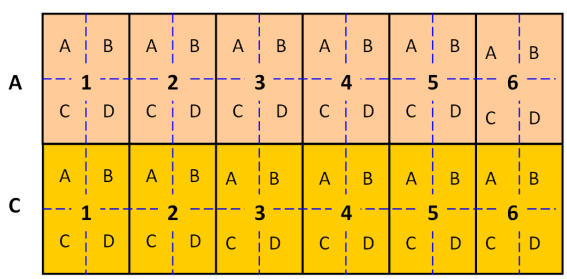

Figure 8. Labelling of test zones.

Impact points

The test points are selected by the test engineer from the testing organisation (as is the case in EuroNCAP pedestrian testing of passenger cars). At least one point must be selected from each test zone (A1, A2…..C5, C6). The test point selected should be expected to be the most injurious within that zone. In some cases, multiple test zones can cover the same structure, which is expected to have equivalent performance (e.g. the windscreen). Where this occurs, the protocol allows for only one test to be performed, with the same result translated to the second (and third etc) test zone.

The vehicle manufacturer may specify up to three additional tests (one per test zone), allowing for a total maximum of 15 tests.

Testing

The testing is carried out with air, spring or hydraulically propelled headforms. The protocol provides details on how to position the headform. The headform is propelled at the vehicle in the x-direction (nominally this is normal to the surface). However, alternative set-up requirements are described where the geometry of the HGV could affect the dynamics of the head impact due to wrap-around kinematics [4].

The testing is carried out using adult headforms for area A and child headforms for area C (Figure 8). The test speed used is 11.1± 0.2m/s selected based on analysis of accident data that showed approximately 50% of fatalities occur at impact speeds up to 40-45km/h [3].

Assessment criteria

The 15ms Head Injury Criteria (HIC_{15}) is used for the assessment of the structural aggressivity. For each test location, up to two points can be awarded, based on the performance criteria shown in Table 5. The scores for each test zone are combined to give a total of up to 24. This is then linearly scaled to a maximum score of 10.

Table 5.
Performance criteria.

HIC	Points	Colour Rating
0 < HIC < 1000	2	Green
1000 < HIC < 1350	1	Yellow
1350 < HIC	0	Red

If additional points are tested (up to 3 extra points), the score for each test location within a zone is weighted to the test zone. For example, if two tests are conducted in zone A6 (Figure 8), with one impact location scoring 1 point and the other scoring 2 points, then the overall score for the area is (0.5x1)+(0.5x2) = 1.5.

Example

Figure 9 shows an example of the test locations selected and the associated HIC_{15} category (left) and the scores attributed to each test zone (right).

The left hand figure shows a total of 15 test points. The additional points selected are highlighted with a black border. Also two of the twelve selected points were not tested because there was no expected benefit. These two points are in the adult zone on the

left and right A-pillars. These two points have been assigned a score of 0, because the anticipated headform response is HIC_{15}>1350.

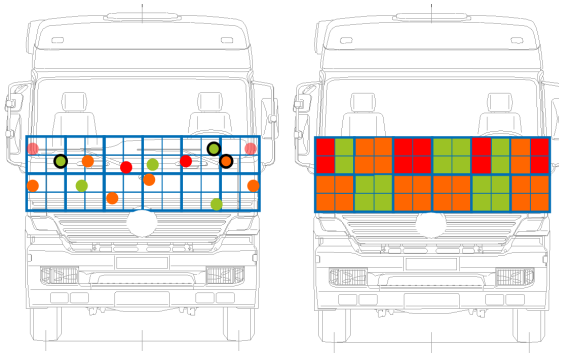

Figure 9. Example of test locations and results (left) and scoring (right).

The figure on the right shows how the overall score is derived. Where an additional test point has been included (for example in zone A1) half of the test zone is rated red and half green. Zone A5 is also rated half red and half green because of the second test point within the zone. The zone A6 was also tested twice, but this zone was rated half amber and half red. The overall score for this vehicle is calculated as shown in Table 6.

Table 6.
Calculating the overall score.

	Zone	Score
ADULT	A1	0x0.5 + 2x0.5
	A2	1
	A3	0
	A4	2
	A5	0x0.5 + 2x0.5
	A6	1x0.5 + 0x0.5
	Adult Total	*5.5*
CHILD	C1	1
	C2	2
	C3	1
	C4	1
	C5	2
	C6	1
	Child Total	*8*
	Overall Score	(13.5 / 30 x 10=) 4.5

Run-over Index

A virtual testing procedure based on multi-body simulation techniques is used to assess the risk of the VRU being run-over. The HGV is approximated by rigid facet surfaces. A human pedestrian model with and without bicycle is used. In total 21 simulations have to be carried out, covering two accident scenarios (turning and going straight), two road users (bicyclist and pedestrian) and seven impact areas, depending on the scenario (two on the front and five on side).

The rationale for developing a virtual test procedure is discussed later in the paper.
For the development of the proposed assessment procedure, the following basic objectives were considered: The procedure should remain simple therefore uniform contact characteristics (those of the pedestrian) are assigned to the vehicle, allowing CAD data to be transferred easily. To aid comparison, only one code, one human model and one type/mode of bicycle is currently proposed.

To help achieve these development objectives, the following steps were taken:

- Standard input-decks were developed and used. Only the data describing the outer shape of the specific HGV has to be provided.
- In order to keep the simulation simple, active safety systems were not considered. However, deployable systems can be included in this assessment in the deployed position (deployment of the system will need to be evaluated by additional testing not yet defined).
- The MADYMO multi-body solver was chosen as the common simulation tool, because MADYMO offers a broad variety of pedestrian human models validated with respect to initial impact kinematics. The HGV is represented as a rigid facet model in MADYMO;
- For the purpose of this study, rigid HGVs have been used to demonstrate the assessment procedure. The assessment of HGVs with trailers is also possible but more difficult, because only a certain combination of truck and trailer can be tested. Therefore, it is proposed that a standard trailer should be used.

Accident scenarios and impact locations

To assess the risk of the VRU being run over, a range of accident scenarios were identified from literature and accident data. The outcome of this analysis was the definition of impact locations on the HGV as shown in Figure 10 (for the side) and Figure 11 (for the front).

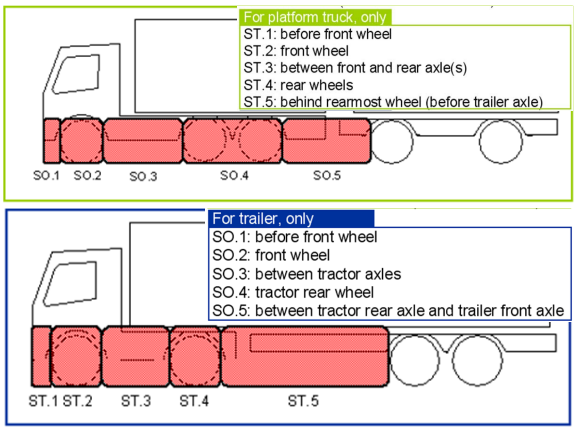

Figure 10. Definitions of impact sub-areas - Side.

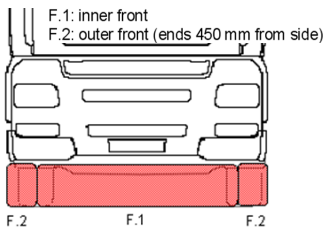

Figure 11. Definitions of impact sub-areas - Front.

The accident scenarios were combined with the relevant impact locations on the HGV. The final simulation matrix for assessing the risk of run over encompasses 21 simulations (Table 7).

Table 7.
Simulation matrix for run-over assessment procedure.

No.	Impact Location	Accident Scenario	Orientation of VRU
1	F.1	HGV turning vs. pedestrian	45°
2	F.2		45°
3	SO.1/ ST.1		0°
4	SO.2/ ST.2		0°
5	SO.3/ ST.3		0°
6	SO.4/ ST.4		0°
7	SO.5/ ST.5		0°
8	F.1	HGV turning vs. cyclist	45°
9	F.2		45°
10	SO.1/ ST.1		45°
11	SO.2/ ST.2		45°
12	F.2		0°
13	SO.1/ ST.1		0°
14	SO.2/ ST.2		0°
15	SO.3/ ST.3		0°
16	SO.4/ ST.4		0°
17	SO.5/ ST.5		0°
18	F.1	Forward driving HGV vs. pedestrian	90°
19	F.2		90°
20	F.1	Forward driving HGV vs. cyclist	90°
21	F.2		90°

For the purpose of weighting the impact locations in relation to the frequency of their involvement in real world accidents, it was necessary to combine the impact locations (the data from accidentology do not allow for distinguishing the impact locations to that degree). The sub-areas defined in Figure 10 and Figure 11 are combined into the main areas shown in Figure 12. For one main area to pass the assessment, the associated sub-areas must show that run-over is prevented. The association between the main areas and the sub-areas are shown in Figure 12 and Table 9.

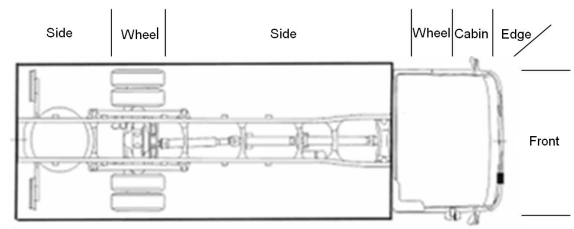

Figure 12. Definition of main impact areas.

Table 8.
Relationships between areas & sub-areas, Part A

Sub area	Front	Turning Edge	Cabin	Wheel	Side
F.1	X				
F.2	X	X			
SO.1/ ST.1		X	X		
SO.2/ ST.2				X	
SO.3/ ST.3					(X)*
SO.4/ ST.4				(X)*	
SO.5/ ST.5					(X)*

(X)* Not relevant for the sub scenario with the HGV turning and the bicyclist on a separate lane

Table 9.
Relationships between areas & sub-areas, Part B

Sub area	Forward driving Front	Edge
F.1	X	
F.2	X	X

Determining risk of run over

The output from the simulations is an assessment of whether or not the VRU is run over by the HGV. For that purpose, run-over is defined in two ways (see Figure 13 and Figure 14). The two definitions of run over are:

- The VRU is run over if one of the body regions coloured red is in contact with a wheel of the HGV (Figure 13); or
- The centre of gravity of the head or the hip is within the critical area defined (Figure 14)

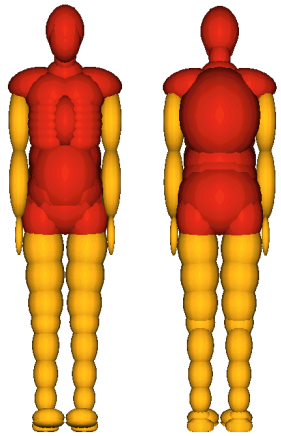

Figure 13. Body regions that must not contact wheels (shown in red).

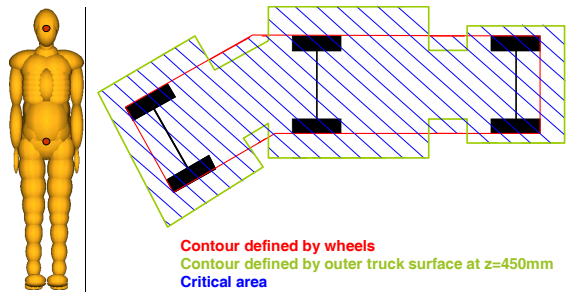

Figure 14. Definition of critical area under HGV.

If the VRU is not run over, there are a number of possible outcomes from the impact. Three types of outcome were defined:

- "Fixing" - the VRU is not run over and subsequently none of the red coloured body regions are involved in the secondary impact with the ground;
- "Isolating" - the VRU is not run over and subsequently the red coloured body regions are involved in the secondary impact with the ground and the HGV;
- "Moving away" – the VRU is not run over and is deflected away from the HGV by the primary impact.

The risk of injury associated with each of these different outcomes can be different. Fixing is considered to result in a lower risk of injury than isolating because the VRU is not pushed over the ground. Moving away is considered to result in a high risk similar to that associated with isolating, because of the uncertainty in relation to the direction and velocity of the secondary impact. The following risk factors are applied depending on the type of protection after the initial impact:

- Fixing = 1
- Isolating = 0.7
- Moving away = 0.7

Weighting factors

The literature and accident analysis has shown the variation in the frequency of the impact scenarios/locations. To allow for the distribution of real world accidents, the scores are weighted as shown in Figure 15 - based on the main areas defined in Figure 12.

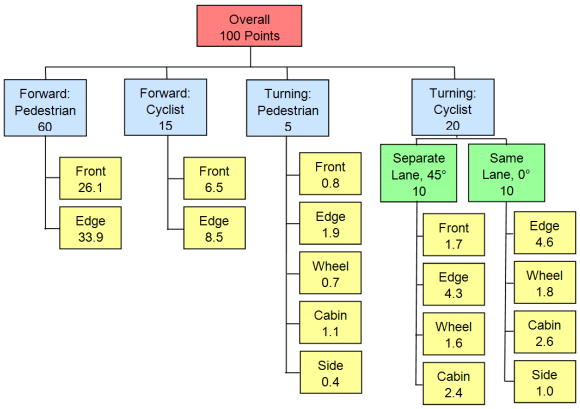

Figure 15. Weighting factors for each accident scenario.

Example

The following figures show a comparison between a flat fronted HGV and an HGV fitted with a "nosecone" [6]. Figure 16 and Figure 17 show simulations where the nosecone prevents run-over, while the flat front does not. Figure 18 and Figure 19 show a scenario where none of the designs prevents run-over. More examples can be found in APROSYS WP2.1 report [7].

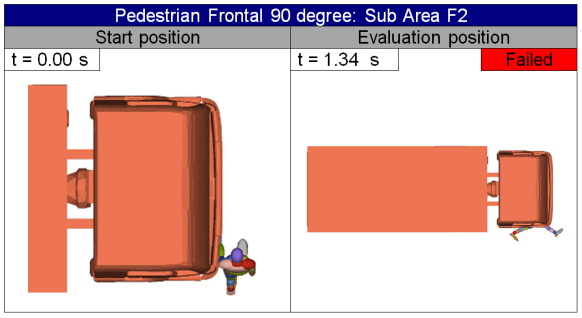

Figure 16. Flat front simulation result: Pedestrian frontal 90 degree - Sub Area F2.

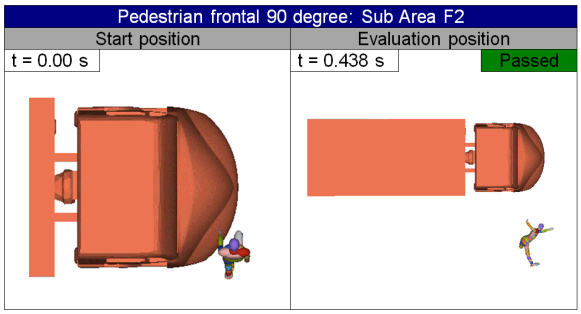

Figure 17. Nosecone simulation result: Pedestrian frontal 90 degree - Sub Area F2.

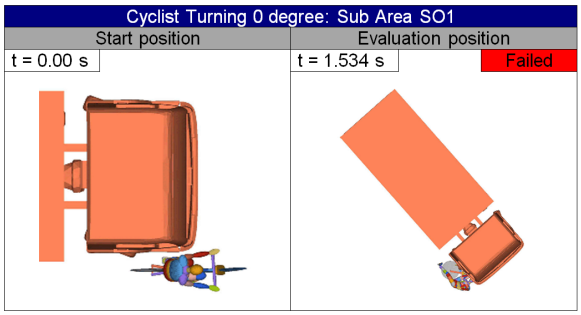

Figure 18. Flat front simulation result: Cyclist with HGV turning 0 degree – sub-area SO1.

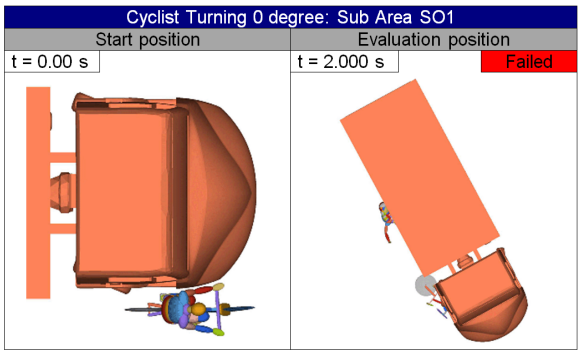

Figure 19. Nosecone simulation result: Cyclist with HGV turning 0 degree – sub-area SO1.

The outcomes from the simulations in terms of run over/not run over and the injury risk associated with the post impact kinematics are entered into a calculation spreadsheet. The spreadsheet returns a score between 0 and 10.
To continue the example of the nose-cone HGV: While the conventional flat front vehicle scores 0.3 points out of 10, the nose-cone HGV reaches 5.5 points.

DISCUSSION

Assessing the protection of VRU is not new to vehicle engineering. Directives 2003/102/EC [1] and 2005/66/EC [2] assess the "structural aggressivity" of passenger cars and front protection systems ("bullbars"). Revisions of these directives to come, will consider active collision avoidance systems, too. For HGV legislations addressing the protection of VRU are related to the sideguards and the geometry of the front of the HGV in relation to protrusions. Comparable directives to 2003/102/EC and 2005/66/EC do not exist for HGV. Adopting these directives for assessing HGVs would be straight-forward. However, assessing the "structural aggressivity" only, will fail to address a large number of low-speed fatalities that result from accidents involving HGVs [3].

The HVAI, developed by APROSYS, addresses these low-speed accidents by assessing the field of view around the vehicle and the risk of the VRU being run-over. Analysis of accident data has shown that a "structural index" has to concentrate on the front of the vehicle (including the vehicle's corners). The pedestrian is most frequently impacting the HGV front (64 to 75 % [3], [8, 9], [10]). For cyclists, the co-driver side is also highly relevant. However, where the impact is with the side of the HGV, the relative speeds between cyclists and HGV are lower and there is a greater risk of the cyclist being caught/run over by the HGV[8] and therefore this scenario is covered by the run-over index.

In APROSYS [11] major accident scenarios were defined. Table 10 cross-references each part of the AI with the accident scenarios that are most relevant to it (more stars represents closer correlation between the sub-index and the accident scenario).

Table 10.
Heavy Goods Vehicle Aggressivity Index versus accident scenarios

Scenario	Active AI	RunOver AI	Structural AI
1.1 (Turning)	★★★	★★★	
1.2 (Turning)	★★★	★★★	
2.1 (Overtaking, frontal impact)			★★★
2.2 (Overtaking, lateral impact)	★	★	
3.1 (Crossing, pulling away)	★★★	★★★	
3.2 (Crossing)			★★★
4 (Autobahn)			★

Figure 20 shows the accumulated percentage of fatal HGV-pedestrian accidents versus impact speed. The red bars highlight the impact speed range that is

addressed by each of the sub-indexes. It can be concluded, that the HVAI covers a significant range of HGV-VRU accidents and fatalities.

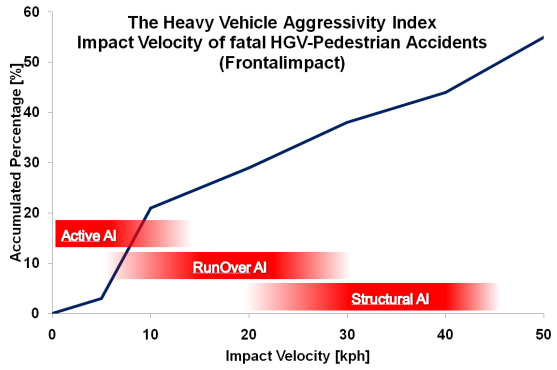

Figure 20. Heavy Goods Vehicle Aggressivity Index versus impact speed.

Presenting the three aspects of the HVAI separately allows the vehicle design to be assessed with respect to each individual component of the AI. Combining the three parts into one overall rating was discussed, however it was decided that presenting the individual results would be easier to understand (have more meaning) and enable designers/engineers to identify which aspects of the vehicle design to focus on in relation to the protection of VRU. A single overall score might distort the vehicle's performance.
The current index is a starting point and should be used as the basis to motivate further discussions and developments in the field of VRU protection of HGV.

Active Index

Vehicle blind spots and the driver's field of view from the cab of HGVs are often cited as contributory factors in a range of accident scenarios. The most recent changes in legislation requiring the fitment of close proximity mirrors to the front and nearside of the vehicle, have been intended to help reduce the number of casualties that are attributed to blind spot accidents. However, legislation provides a minimum performance requirement and does not account for the overlap of direct and indirect views. VRU are a group of casualties that are often severely or fatally injured in accidents caused by a driver's blind spot impaired field of view. Examples of accidents involving VRU casualties are those where the HGV is turning to the nearside and collide with a pedal cyclist or where the HGV is held up in stop-start traffic and a pedestrian crosses close to the front of the vehicle. This active AI aims to identify and encourage vehicle designs that can help to reduce the number of VRU casualties through improved visibility or the use of active safety systems.

The active index promotes areas that are covered by both direct and in-direct view consecutively, through the use of modifiers. The driver's view to the co-driver's side with its dangerous blind spot areas has a strong influence/effect.
By applying weighting factors improvements to the direct field of view are promoted. Of course, improved vision can be provided by mirrors as well,however, mirrors have a number of drawbacks:

- Mirrors need to be correctly set and adjusted to provide the view that is required by legislation:
- The number of mirrors fixed to current HGV makes it hard for the driver to correctly use these mirrors:
- Identification of objects in the mirrors is sometimes hard, as only parts of the VRU are shown (e.g. the legs of a cyclist).

The calculated values for the vehicles analysed while developing this methodology ranged from 2.4 to 9.2. From the 14 vehicles analysed, 10 of the vehicles reach only an index value between 2.4 and 4.0. Comparison of the active index result with the height of the lower edge of the windscreen from the ground showed some correlation, particularly for the lower scoring vehicles. There are already some designs on the market which achieve a good result for the active index despite a very high lower edge of the windscreen and vice versa. Therefore the lower edge of the windscreen is not the only factor that influences the visibility.

Further development of the active AI should consider the following issues:

- Evaluation of electronic vision aids is not implemented yet. Currently there are a number of such system under development, e.g. by Hino Motors [12] or Volvo [13], that overcome some of the limitations of mirrors.
- The current version of the active AI considers mandatory mirror areas only. However, mirror systems may exceed the requirements set by legislation. Also the new class VI mirror was not considered, yet.
- Obstructions caused by internal structures such the steering wheel and dashboard were not considered.

Run-over Index

For the development of the protocol assessing the run over aggressivity of HGVs several basic requirements were considered. The main objective was to offer a quantitative value representing the ability of an HGV to prevent the VRU from being run over when hit by a HGV. The assessment value has to reflect the influence of a broad variety of possible design modifications whilst ensuring that the biofidelity of the VRU is appropriately represented.

A number of approaches can be used to assess the risk for VRU being run over:

- experimental test;
- directive requiring simply measurable attributes (e.g. geometry or strength);
- combination of experimental testing combined with numerical simulation; or
- test procedure based mainly on numerical simulation.

Each of these approaches was assessed for their advantages and disadvantages against a range of criteria [7].

At the start of the project it was acknowledged that any proposed assessment protocol should be developed with minimal costs associated with any testing. Clearly, that aim was contradictory to experimental testing for assessing the risk of run-over due to potential damage to the dummies and HGV. Also, reproducibility and costly test set-ups of such experiments are an issue. For a test procedure that is based on numerical simulation, the effort is acceptable with respect to time effort and costs.
Also, virtual models of the VRU already exist while the development of experimental dummies for HGV vs VRU accidents would still require an extensive effort.

In parallel to the run-over index a new HGV front shape was developed, reducing the risk for run-over. This "nose cone" (see Figure 21) was tested at 20 and 30kph. In both tests, the pedestrian was deflected to the side and a run-over was prevented (see Figure 22).

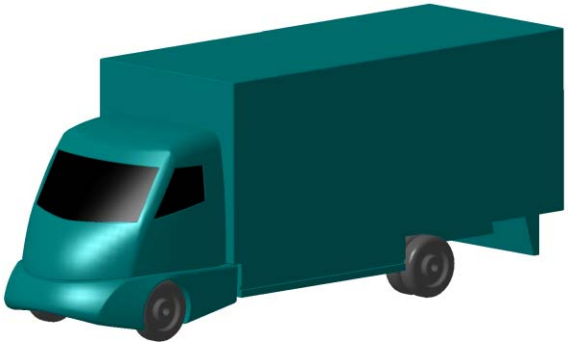

Figure 21. Nose cone

Figure 22. Experimental testing of nose cone

Structural Index

The current proposal has been based on head impacts with the HGV, particularly because it is one of the most frequently injured body regions and there are test tools currently existing for evaluating those impacts. Future developments of the structural index could include the development and inclusion of new test tools, for example to assess impacts with the thorax of the VRU.

Currently the structural AI is addressing the primary contact only (the contact with the truck front). However, numerical studies and experiments [14] have shown the severity of the secondary impact makes it a highly relevant aspect for future consideration. Studies of the "nose cone" [6] indicated not only a reduced likelihood for run-over, but also a reduced severity of the secondary impact (prevent forward-projection of pedestrian).

Existing test methods for passenger cars are continually under development, such as the research into rotational acceleration as an assessment method.

The future development of the structural index should be based on the lessons learned from existing test methods.

CONCLUSIONS

Legislation relating to the protection of VRU in impacts with HGVs is very limited, currently only covering the fitment of sideguards and geometric requirements for structures on the front of the HGV in relation to protrusions.

A set of assessment criteria to assess the risk posed by HGVs to pedestrian and cyclists were developed by APROSYS WP2.1. The index is a combination of physical and virtual testing. Each sub-index is returning a value between 0 and 10.

The active AI evaluates the field of view of 50th percentile driver. Weighting factors are applied to promote improvements to the direct field of view Modifiers are applied to promote the overlap of direct and in-direct fields of view within the PAI.

The run-over AI is based on multi-body simulation techniques using 21 simulation set-ups

The structural AI defines two impact zones (adult, child). Up to 15 tests per truck are conducted to assess the structural response using EEVC WG 17 headform impactors.

A separate score is reported for each of the three sub-indices, which prevents the masking of important design features within a single score. The presentation of the individual scores also shows the assessment in a way which is considered to be easy to read and understand (see Figure 1).

The HVAI could be developed for future legislation/consumer testing or could be used by manufacturers during the development of future vehicle designs. The current index is a starting point and should be used as the basis to motivate further discussions and developments in that field.

LIMITATIONS

Where available, accident data was used to define the so-called weighting factors. In case of the run-over index the weighting factors are based on accident data. However, in other cases, (e.g. Active Index) arbitrary weighting values were applied- based on experience from accident researchers and expert opinion.

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