Final report for the work on *"Heavy Vehicles" (SP 2)*

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APROSYS SP 2

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Publishable summary

This **report** summarizes the work of APROSYS **SP2**. APROSYS **SP2** was a subproject within an **Integrated Project** funded by the European commission during the period from 2004 to 2009. This subproject addressed accidents involving heavy goods vehicles.

In 2001 the European Commission set the ambitious aim of halving the number of road fatalities by 2010. Starting in 2004 APROSYS constitutes one of the measures initiated by the European Commission meeting this aim. At this time accidentology studies indicated, that the risk of being fatally injured varies significantly for different types of road users. The rate for killed or seriouly injured casualties in HGV-VRU (Heavy Goods Vehicle against Vulnerable Road User (pedestrians and cyclists)) accidents is extremley high and 7 to 10 times more frequent than in PC-VRU (Passenger Car against Heavy Goods Vehicle) accidents.

Based on these figures different types of road users and accident types were proposed to be investigated in APROSYS. In APROSYS **SP2** "Heavy vehicles" specifically two scenarios have been addressed:

1. Pedestrians and cyclists hit by trucks and
2. Cars hitting the side of a truck.

Based on these accident constellations APROSYS **SP2** pursued the following aims:

1. The development and validation of evaluation methods.
2. The development of **advanced protection systems** – considering exclusively passive safety measures.

APROSYS **SP2** developed:

1. The Heavy Vehicle Aggressivity Index.
2. New **protection systems** for vulnerable road users involved in heavy goods vehicle collisions.
3. New **protection systems** for passenger car occupants, when being involved in a side **underrun** accident.
4. Testing procedure for side **underrun protection** devices (SUPD) of heavy goods vehicles.

The Heavy Vehicle Aggressivity Index is a rating system and test-methodology for assessing the aggressivity of heavy goods vehicles in relation to vulnerable road users. The proposed index consists of three parts, assessing the performance of the design in relation to the following matters of subject:

- Direct contact between the casualty and the HGV front-end – referred as "Structural

Aggressivity Index";

- Risk for ending up under the HGV – referred as "Run-over Aggressivity Index"; and
- Driver's field of vision, evaluating the ability to avoide an accident by maximising the direct and indirect view– referred as "Active Aggressivity Index".

A goal was to demonstrate systems, which significantly mitigate the consequences of HGV-VRU accidents and to define their future exploitation. Two concepts were selected for amore thorough investigation in a virtual and experimental testing. These concepts were:

- Nose-cone; and
- Safety-bar.

The Nose-Cone concept aims to deflect the vulnerable road user and therefore avoid an over-run. The Safety-Bar as add-on device addresses the after-market and the individual needs of truck drivers to style their vehicles.

For side underrun protection devices (SUPD) a quasi-static testing procedure has been developed. The main objective here was to come up with advanced protections systems for accidents where a passenger car impacts the side of a heavy goods vehicle. A promising side underrun protection device, which is included in a pallet box, was demonstrated successfully in experimental studies. Again, the future exploitation of the developed systems are discussed.

Two accident scenarios for European roads were identified:

1. Accidents with the passenger car impacting the side of a trailer at a velocity of 65kph perpendicularly; and
2. Sliding/swiping collisions with closing speeds of 120kph.

All SUPD concepts for state-of-the-art truck architectures resulted in add-on solutions. Because these add-on solutions add weight to the trucks, recommendations based on a road map for "greener truck safety" were given.

The future truck needs an **integrated** concept for active and passive systems. The integration of passive systems will provide other benefits such as a streamlined designs with reduced fuel consumption. An all-around underrun protection can be realised by using a platform for trucks and trailers based on a smart space-frame architecture, where passive safety systems like rear, side and front underrun protection devices are **integrated** – and not just added.

Acknowledgement

Following participants contributed to this deliverable **report**.

Company	Representative	Chapters
TUG	J. Gugler	All
TUG	F. Feist	All

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1 Introduction

Apart from the technical and statistical background, this chapter summarizes the aims of APROSYS **SP2** in detail. It also highlights the links to other sub-projects within the **integrated project** APROSYS.

1.1 Background, state of the art

The proposal for the **project** APROSYS was filed in 2004. APROSYS was initiated as one of the answers for the European Commission for reducing the fatalities in road traffic accidents by 50% from 2000 to 2010. At this time accident data showed that car occupants represent the majority of fatalities in Europe. In 1998, there was a total of 42.699 transport related fatalities, of which 24.218 were car occupants. The distribution for different classes of road users is shown in Figure 1 for 1998 (1).

Figure 1 Distribution of road user fatalities in Europe among different classes of road users - 1998

Excluding car occupants the most important categories among road-traffic fatalities are motorcyclists, pedestrians and cyclists (sequence in the order of relevance). Included in the category "others" are, e.g. truck occupants, drivers of agricultural vehicles and bus and coach occupants. The latter category is estimated for about 150 fatalities a year. The total number of registered non-fatal casualties is estimated to 1.3 million annually in Europe and around 3.5 million if the non-routinely reported casualties are included. No equivalent distribution data of injuries for the various classes of road users are available but, it will be assumed here that injury frequency is roughly similarly distributed, although the type of injuries significantly varies among the different road user classes. The total annual costs of traffic related trauma in Europe is estimated to be 160 billion Euro (1).

The rate for killed or seriouly injured casualties in HGV-VRU accidents is extremley high and 7 to 10 times more frequent than in PC-VRU accidents (2).

Based on mentioned accident data, it has been decided to focus the work of APROSYS primarily on the 4 major classes of road users indicated above: car occupants, motorcyclists, pedestrians and cyclists.

More detailed accident data indicate that within the above classes of road users the following accident types are of particular importance (with the highest injury and fatality reduction potential):

- Car-car front and side impacts (taking into account compatibility issues),
- **Cars to trucks,**
- Pedestrians and cyclists impacted by the front of a car,
- **Pedestrian and cyclists impacted by trucks,**
- Motor cycle accidents with cars and with infrastructure.

The above priorities have been used as a starting point for the definition of the scientific and technological objectives of APROSYS. Focusing on heavy vehicles two accident configurations related to heavy goods vehicles (HGV), that have not been addressed adequately so far, are covered. These are:

- Pedestrian and cyclists hit by the side or front of a heavy goods vehicle, and
- Passenger cars impacting the side of heavy goods vehicles.

By legislation (ECE-R 73, respectively directive 89/297/EEC) a lateral **protection** in the area between the axles of a heavy goods vehicle to avoid a run-over of a vulnerable road user is required. This only covers the side of the heavy goods vehicle. The lateral **protection** has to withstand a test-force of 1.000 N. Clearly, this test force might be sufficient for cyclists and pedestrians, but not for passenger cars or motorcyclists.

Regulation ECE-R 61 and Directive 92/114/EEC are related to „[…] the external projections forward of the cab's rear panel of motor vehicles of category N." These constitute a standard for the shape of vehicles. Cabs shall not exhibit sharp external projections on the external surface in order to reduce the risk or the severity of injuries and to prevent parts likely to catch vulnerable road users.

Apart from these directives and regulations, no other passive safety measures for vulnerable road user are required by legislation **protection**, so far.

An active safety measure to avoid accidents between heavy goods vehicles and vulnerable road users are the mandatory mirror **systems** and **systems** for indirect view. The minimal field of vision by mirror-class (class II, III, IV, V, VI) are regulated by directives 2003/97/EC and 2007/38/EC.

For passenger car requirements to the **protection** of VRU (pedestrian safety) exist. Regulation 78/2009 (formerly directives 2003/102/EC, 2005/66/EC, and 2004/90/EC) and NCAP testing led to considerable improvements to pedestrian **protection** in passenger cars. There are no requirements to heavy goods vehicles to mitigate the consequences of impacts by e.g. improved structural interaction or advanced run-over prevention.

Another topic is the underrun of a passenger car under a heavy goods vehicle. There are directives in force to mitigate the consequences of front and rear underrun (Directive 2000/40/EC, ECE-R 93, ECE-R 58). Related to side underrun of passenger cars into heavy goods vehicles no performance criteria are available.

1.2 Aims

The aims of this sub **project** are to mitigate the consequences of accidents where a VRU is hit by a heavy goods vehicle and where a passenger car is impacting the side of a heavy goods vehicle, potentially resulting in a side underrun.

The first aim of this sub **project** was the development and validation of a set of evaluation methods, assessing the level of protection afforded by HGV to VRU. Furthermore, APROSYS **SP2** reached for the development of advanced protection systems for injury reduction of pedestrians and pedal cyclists impacted by heavy goods vehicles.

The second aim was the development and validation of a test method for side underrun protection devices (SUPD). Again APROSYS strived for the development of an advanced protection systems considering compatibility strategies for injury reduction of car occupants involved in a side-underrun.

1.3 Methodologies

The APROSYS **SP2** "Heavy Trucks" was divided into two workpackages and different tasks:

1. Workpackage 2.1 Advanced vulnerable road user protection systems
    a. Task 2.1.1: Development of HV Aggressivity Index
    b. Task 2.1.2: Pedestrian/Cyclist friendly frontal and side design strategies and concepts

    c. Task 2.1.3: Development of advanced protective systems based on cost benefit analysis
    d. Task 2.1.4: Guidelines for assessment criteria for HV **integrated** safety test methods
    e. Task 2.1.5: Advanced protection experimental module

f. Task 2.1.6 A Demonstration of truck front design improvements for VRUs focusing on structural interaction

g. Task 2.1.6 B Demonstration of truck front design improvement for VRUs focusing on run-over prevention and active safety

h. Task 2.1.7 Guidelines for **integrated** design and evaluation of **advanced** vulnerable road user **protection systems**

2. Workpackage 2.2 Enhanced opponent vehicle occupant **protection systems**

a. Task 2.2.1: Development of increased car to heavy vehicle compatibility

b. Task 2.2.2: Oblique, side and rear end impact under-run design strategies and concepts

c. Task 2.2.3: Development of **advanced** side, oblique and rear end under-run protective system based on cost benefit analyses

d. Task 2.2.4 Demonstration of truck side design improvements

e. Task 2.2.5 Guideline on development, integration and certification of Enhanced Opponent Vehicle occupant **protection systems**

In both workpackages the starting was the collection of in-depth accident data as well as an update of statistical data and the provision of an interpretation of these data.

WP 2.1 **Advanced** vulnerable road user **protection systems**

Having reviewed national accident databases and the literature, the most frequent accident scenarios were defined. These scenarios were used for deriving evaluation and performance criteria. For enhanced vulnerable road user **protection** the so-called Heavy Vehicle Aggressivity Index (HVAI) was defined. In parallel, different **protection** principles were evaluated by experts against real world accidents and their potential for improving the situation of the VRU. According to this initial evaluation the most beneficial **protection** principals were found to be an improved front geometry able to deflect the VRU (and therefore reducing the risk for run-over) as well as softening the front structure.

These two principles were developed focusing only on one part of the HVAI. For the changed front geometry only the run-over evaluation of the HVAI was taken into account. For the compliant front structure only the structural evaluation was used. So an isolated optimization in APROSYS **SP2** was performed.

Several **advanced protection systems** were designed and optimized by means of simulations. In order to do so the standing HUMOS II model was provided by APROSYS SP5 “Biomechanics”. The virtual analyses have been performed with the generic truck model developed by APROSYS SP7 and with truck models provided by OEM. Finally two designs were found bringing significant improvements to VRU **protection**. These two are:

- Safety-Bar: A retrofittable, energy absorbing Safety-Bar front-end;

- Nose-Cone frontal design.

During the design of the demonstrator the HVAI was refined. The Nose-Cone design was evaluated by means of the run-over aggressivity index, which is a virtual testing method proposed in the HVAI. The Safety-Bar was evaluated with hemisphere impactor testing – as proposed by in the structural aggressivity index.

Demonstrators have been constructed and evaluated in experiments. Final demonstrations were performed in a full scale test. In order to demonstrate the performance of the Nose-Cone tests at 20 and 30 kph were performed with a dummy. During these tests the pedestrian dummy was deflected to the side of the truck and a run over was avoided.

The performance of the Safety-Bar was demonstrated in several experiments, where a HIII 50_{th} pedestrian dummy was impacted at 30kph. Analysis of the Safety-Bar concept with **advanced** injury criteria and brain models were performed in collaboration with APROSYS SP5.

Initially it was planned to integrate the concept of an energy-absorbing front-end and the Nose-Cone. In response to discussion with industry, additional benefits of the Nose-Cone design were evaluated. Wind tunnel tests were performed with truck models having a conventional front-end design and with models having an **integrated** Nose-Cone design.

Finally a road map for greener truck safety was put forward providing a guideline for implementation of the APROSYS' results.

2.2 Enhanced opponent vehicle occupant **protection systems**

Based on the accidentology two scenarios for side **underrun** accidents were defined. These scenarios are not only different w.r.t. impact speed and angle of approach, but also regarding the prevailing accident location. Therefore, the scenarios were called urban and rural scenarios.

Then, an intermediate milestone was defined estimating the costs and benefits of enhanced side **underrun protection**. This analysis showed a reasonable number of fatalities to be saved (3) – comparable to those of rear **underrun** accidents.

In a brainstorming session numerous **underrun protection** principles were synthesized. These principles have been analyzed towards their efficiency in real world cases by experts. This initial benefit analysis identified two principles to be picked up for a more thorough analysis and for designing a prototype:

1. Rear **underrun protection** device to the side
2. Energy absorbing pallet box for semitrailer

During the design phase performance criteria were defined and a quasi-static test procedure was developed. One of the new approaches (where the spare wheel is **integrated** in the side **underrun protection** device) was filed for patent. For the virtual design and analysis a trailer model was developed based on inputs from the industrial partner.

The energy absorbing pallet box was built up for demonstration. Experimental testing with default and **advanced** pallet boxes proofed the performance of the pallet box in avoiding side **underrun**

The final cost benefit analysis showed a small margin for adding side **underrun protection** devices. A redesign of the truck and trailer frame integrating an all-around **underrun protection** will be a cost and weight neutral solution.

1.4 Partners involved and cooperation

In work package 2.1 "**Advanced** vulnerable road user **protection systems**" the partners contributed to and cooperated in tasks as follows:

- Task 2.1.1: Development of HV Aggressivity Index (TUG, RWTH, CRF, Bolton, CIC, Dekra, Skoda, TRL)
- Task 2.1.2: Pedestrian/Cyclist friendly frontal and side design strategies and concepts (TUG, RWTH, CRF, Bolton, Dekra, Polito, Schmitz-Cargobull, TRL)
- Task 2.1.3: Development of **advanced** protective **systems** based on cost benefit analysis (TUG, RWTH, CRF, Bolton, Dekra, GDV, IDIADA, Altair, Polito, Skoda, TRL)
- Task 2.1.4: Guidelines for assessment criteria for HV **integrated** safety test methods (TUG, RWTH, CRF, Bolton, Dekra, GDV, IDIADA, Altair, Polito, Skoda, TRL)

- Task 2.1.5: **Advanced protection** experimental module (TUG, RWTH, Bolton, GDV, Altair, DC)
- Task 2.1.6 A Demonstration of truck front design improvements for VRUs focusing on structural interaction (Polito, TUG, IDIADA, FhG, CRF)
- Task 2.1.6 B Demonstration of truck front design improvement for VRUs focusing on run-over prevention and active safety (RWTH, DEKRA, BOLTON, FhG)
- Task 2.1.7 Guidelines for **integrated** design and evaluation of **advanced** vulnerable road user **protection systems** (RWTH, CRF, Polito, Daimler, Altair)

There were several teams focusing on the development of the heavy vehicle aggressivity index, accident investigation and scenarios, virtual design, performance criteria, test methods and lab testing. The HVAI was mainly developed by TUG, RWTH, IDIADA, CRF and Dekra. Numerical simulations of the **advanced protection** principles were carried out by CRF, TUG; RWTH and Polito. Altair implemented the HVAI in the DOE software Adviser. The definition of accident scenarios and the cost-benefit estimations were done by TRL, GDV, Dekra and TUG. Bolton and RWTH led the design of the Nose-Cone prototype. Experimental testing of the Nose-Cone was performed by Dekra. TUG and Polito built the Safety-Bar prototype and performed the experimental testing. The workshops were done in cooperation with the partners and led by Dekra and TUG. External inputs from other projects were relayed by TRL and TNO. Daimler provided inputs and feedback from industry. IFAM supported by providing design principles and suggesting advanced energy absorbing materials. Setting-up the final guidelines and performing the wind-tunnel testing was done by TUG and RWTH. For the virtual design CRF, ALTAIR, TUG and RWTH cooperated to come to the final demonstrator design. A main driver for WP2.1 was the work package leader RWTH.

In work package 2.2 “Enhanced opponent vehicle occupant protection systems” contributed to and cooperated in tasks as follows:

- Task 2.2.1: Development of increased car to heavy vehicle compatibility (CRF, TUG, Dekra, GDV, IFAM, Idiada, Altair, Skoda, TNO, TRL)
- Task 2.2.2: Oblique, side and rear end impact under-run design strategies and concepts (CRF, TUG, Dekra, GDV, IFAM, Idiada, Altair, Schmitz-Cargobull, TNO, TRL)
- Task 2.2.3: Development of advanced side, oblique and rear end under-run protective system based on cost benefit analyses (TUG, Dekra, IFAM, Altair, Schmitz-Cargobull, TNO, CRF)
- Task 2.2.4 Demonstration of truck side design improvements (IDIADA, Schmitz-Cargobull, TUG, TRL, FhG)
- Task 2.2.5 Guideline on development, integration and certification of Enhanced Opponent Vehicle occupant protection systems (TNO, Schmitz-Cargobull, Altair)

Similar to task 2.1 the start of the activities was an in-depth accident analysis performed by GDV, IDIADA, DEKRA, TRL and TUG. Corridors for potential protection areas were derived by TNO. The defined accident scenarios were used to find underrun prevention strategies coordinated by IFAM. Based on this TUG, CRF and Altair started to design virtual prototypes. CRF developed together with SCB a trailer model for finite element analysis. In parallel performance criteria and evaluation methods were developed by TUG, TRL, CRF and TNO. IFAM supported by proposing advanced energy absorbing materials to be used. The demonstrators were designed by TUG and SCB. Pre-testing was done by TUG and the full scale testing by IDIADA. The workshop was organized by IDIADA and TUG. The final guidelines were written by TNO, SCB. Inputs from other projects were provided by TRL and TNO.

Schmitz-Cargobull provided a complete trailer for full scale testing of the demonstrators.

In SP 2 the following main links have been established with other SPs:

Connected SP	Received by SP 2	Provided by SP 2

SP 7 "Virtual Testing"	Generic Truck Model HVAI Evaluation Tool	Inputs to Adviser evaluation tool
SP 5 "Biomechanics"	HUMOS Model Advanced Head Injury Criteria and Evaluation Tool (Head Model)	Testing data for injury prediction
SP 3 "Pedestrian and Pedal Cyclist Accidents"	Testing methods and developments for harmonisation	Testing methods and developments for harmonisation
SP 8 "Training"	Workshop organisation	Inputs to Workshops

The following partners were involved in APROSYS **SP2**:

Partner name	Abbreviation	WP contributed to
Technical University Graz – Vehicle Safety Institute	TUG	2.1, 2.2
Rheinisch-Westfälisch Technische Hochschule Aachen; RWTH-IKA	RWTH	2.1
Centre Ricerche Fiat	CRF	2.1, 2.2
University of Bolton	Bolton	2.1
Dekra	Dekra	2.1, 2.2
Gesamtverband Versicherungswirtschaft	GDV	2.1, 2.2
Fraunhofer Gesellschaft	IFAM	2.2
Idiada Automotive Technology	Idiada	2.2
Altair	Altair	2.2
Schmitz-Cargobull	SCB	2.2
Netherlands Organisation for Applied Research	TNO	2.2
Politecnico di Torino	Polito	2.1
Skoda Vyzkum	Skoda	2.1
Daimler AG	Daimler	2.1
TRL Limited	TRL	2.1, 2.2

2 Description of the main SP results

This chapter describes the main results achieved in the APROSYS SP 2. The results were obtained by the partners listed in chapter 1.4 “Partners involved and cooperation” where also the collaborations with other APROSYS subprojects is reported.

Conclusions and further use of the results can be found in chapter 4 “Discussion and Conclusion” as well as in chapter 5 “Recommendations ”.

2.1 Heavy Vehicle Aggressivity Index

APROSYS **SP2** developed an aggressivity index for heavy goods vehicles (HVAI – Heavy Vehicle Aggressivity Index), allowing the assessment of **protection** offered to vulnerable road users (4-6). The proposed index consists of three parts, assessing the performance of the design in relation to the following areas:

- Direct contact between the casualty and the vehicle structure – structural index (7);
- Risk of the casualty being run over by the HGV – run-over index (8); and
- The ability for the accident to be avoided though good visibility and/or active safety **systems** – active index (9).

A combination of physical testing and numerical simulation has been proposed. Where appropriate proven methods that are already accepted by the automotive industry have been adopted and modified to make them appropriate for assessment of HGVs (5).

Physical measurements have been selected for assessing the primary impact. The structural aggressivity index defines two impact zones (adult, child) with 6 areas per zone and 4 regions per area (Figure 2). A WG 17 adult and child headform is propelled horizontally at 11m/s towards one region per area. Up to 15 tests per truck are conducted to assess the structural response (Figure 3).

Figure 2 Test zones for impactor testing (adult and child zone)

Figure 3 Experimental testing device (WG 17 headform) for structural index evaluation

Numerical simulations are proposed to assess the risk of run-over. A human pedestrian model with and without bicycle is used. In total 21 simulations are run, covering two accident scenarios (turning, going straight), two road users (bicyclist, pedestrian) and seven impact areas (see

Figure 5) depending on the scenario (two on the front and five on side) (Figure 4). Run over in the numerical simulation is defined by the torso, the pelvis and/or the head contacting the tire and/or by the head and/or pelvis coming to rest within a predefined "critical area" (Figure 5).

Figure 4 Virtual testing for run-over assessment (Standard vs. modified truck)

Figure 5 Definition of Impact Areas VRU-HGV

The driver's field of view has been assessed using a combination of physical measurements and calculations (Figure 6). The index evaluates the field of view of a 50th percentile driver, distinguishing between 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).

Figure 6 Example for assessing the active safety (field of view measurement)

By introducing designs with a low aggressivity index some 300-500 lives can be saved on European roads each year (10).

The HVAI aims to encourage heavy goods vehicle (HGV) manufacturers / designers to develop vehicles that can reduce the number or severity of vulnerable road user (VRU) casualties from accidents involving HGVs. It can also be applied by regulatory bodies to set certain standards (index levels). The overall score of a vehicle is shown in the HVAI graph in Figure 7.

Figure 7 Overall assessment and index levels (0 = poor, 10 = excellent)

It is recommended that the proposal is disseminated across Europe and that further development/discussions be taken up by an appropriate expert working group. Attention should be paid to active driver assistance systems and an appropriate assessment should be implemented in an updated HVAI.

2.2 New protection systems for vulnerable road users in heavy goods vehicle collisions

In this main result two advanced protections systems for heavy goods vehicles were developed to mitigate the consequences of impacts with vulnerable road users. These designs are derived and optimized by application of the Heavy Vehicle Aggressivity Index and its test methods (11-17).

The goal of these activities was to demonstrate systems, which significantly reduce the consequences of these impacts and define their future exploitation.

Based on the findings in statistical and in-depth accident analyses numerous concepts were suggested (11). These concepts were reviewed in terms of their expected efficiency (benefits) and associated costs (12). The reviewed concepts were applied to the cases in the APROSYS accident collection and their benefit for each individual case rated by an expert panel. Finally, two

concepts were selected for further investigations and for being built up as a demonstrator (16). These concepts were:

- Nose-Cone
- Safety-Bar

The Nose-Cone concept aims to deflect the vulnerable road user and avoid an over-run by the heavy goods vehicle. This is an **integrated** concept that requires a comprehensive redesign of the truck cabin (Figure 8).

Figure 8 Greener & Safer truck (Nose-Cone design)

Based on the heavy vehicle aggressivity index the demonstrations of an optimized geometry showed the improved post impact kinematics of a pedestrian-HGV collision. The pedestrian is deflected and so a life threatening run-over is avoided (Figure 9).

Figure 9 Simulation and Testing of a Nose-Cone design

The Safety-Bar is an add-on part for trucks, which aims to reduce the aggressivity of the front structure of the cabin by mitigating the severity of the primary impact (Figure 10).

Figure 10 Safety-Bar as a styling feature and vulnerable road user protection device

The Safety-Bar as add-on device addresses the after-market and the individual needs of truck drivers to style their vehicles.

Passive safety measures in the field of heavy goods vehicles are not the first topic for OEMs and hauliers. Currently the primary interests are the reduction of fuel consumption and emissions (18). A future streamline truck design can address both, enhanced passive safety and decreased fuel consumption. These benefits were shown by wind tunnel tests, comparing a conventional truck and a truck having the Nose-Cone **integrated** (17) – see Figure 11.

Figure 11 Wind tunnel testing of conventional and Nose-Cone truck

Depending on the impact velocity, three mechanisms for enhanced vulnerable road user safety were identified (17):

1. Lower impact velocity range: Enhanced field of view will reduce accidents with vulnerable road users.
2. Middle impact velocity range: At impact velocities below 30kph, approx. 80% of the vulnerable road users end up under the heavy goods vehicle. Deflecting the pedestrian to the side prevents run-over. The Nose-Cone concept is a promising concept reducing fatalities due to run-over. Numerical simulations indicated also a less severe secondary contact with the road, when hit by a Nose-Cone goods vehicle.
3. Upper impact velocity range: At impact velocities exceeding 20-30kph, the severity of the primary impact needs to be reduced. The Safety-Bar is reducing the load on the vulnerable road user during impacts with the cabin. This results in a reduced injury risk to the head and to other body regions.

The Nose-Cone design offers benefits going far beyond enhanced vulnerable road user **protection**:

- reduced fuel consumption,
- enlarged drivers working place,
- additional space for font-**underrun protection** devices (FUPD) and
- improved direct view for the truck driver.

Experimental testing suggested that the Nose-Cone design could reduce the drag coefficient by 10-20%. These additional benefits will promote the integration of a design similar to that of the

Nose-Cone (Figure 12).

Figure 12 Drag coefficients for truck models (box-trucks with spoilers)

The introduction of a Nose-Cone concept is conflicting with the current truck-length regulation. A revision of weight and dimension regulations is essential for enhanced partner-**protection** in HGV. It is suggested to allow for extra length and weight when the vehicle is equipped with safety features for improved partner-**protection**. The decision for a safer truck has to be promoted by tax-benefits or regulation enforcements. The introduction of a Nose-Cone design will also be driven by haulers asking for reduced fuel consumption.

The idea of the Safety-Bar can be taken up by after-market suppliers, providing low-cost styling features combined with improved safety for vulnerable road users.

2.3 New protection systems & testing procedure for side underrun protection of heavy goods vehicles for passenger cars

In several research projects the front and read **underrun protection** of HGV have already been analysed (e.g. VC Compat). For the result presented here, **protection systems** as well as testing procedures for performance evaluation of side **underrun** have been developed. The main objective here was to develop **advanced** protections **systems** for heavy goods vehicles in case of accidents where a passenger car is running into the side of a heavy goods vehicle and to demonstrate **systems** and define there future exploitation (Figure 13).

Figure 13 Overview of accident scenario

These objectives were addressed by defining the most common accident configurations (19-21). Among heavy goods vehicle side impact accidents, two scenarios for European roads were identified. These two are:

1. Accidents with the passenger car impacting the side of a trailer at a velocity of 65kph (75th percentile value) perpendicularly (Figure 14)
2. Sliding/swiping collisions with closing speeds of 120kph (75th percentile value) (Figure 15)

Accident Place:
Intersection

Critical Areas

V_{PC}=65 kph

V_{HGV}=40 kph

Figure 14 Urban Scenario

Accident Place:
Junction

Critical Areas

V_{HGV}=45 kph

V_{PC}=75 kph

Figure 15 Rural Scenario

Based on these scenarios numerous concepts of side **underrun protection** devices (SUPD) were originated in brainstorm sessions; some of them roughly developed and evaluated (22). Bearing in mind the above-mentioned scenarios, the cost-benefit estimation of concepts resulted in three main candidates for a demonstrator (23):

- Front **underrun** protective device adapted to the side of the HGV
- Deflection device: Guard-rail-like device around the truck/trailer
- Crashworthy pallet box for trailers

The performance of these concepts with respect to side **underrun** prevention and deflection capabilities were analysed in a numerical environment, using the generic car models developed within APROSYS SP7 (24). In parallel a quasi-static testing procedure for side-**underrun protection** devices was developed (25).

All three concepts provided the necessary level **protection** and met the requirements set by the quasi-static testing procedure – see Figure 16.

Figure 16 Virtual testing of crashworthy palletbox (3 impactors loaded at 90kN each)

In the testing procedure three rectangular rams are loading the side **underrun protection** device with a total of 270 kN. The maximum intrusion must not exceed 400mm (see Figure 16). For the final demonstration the crashworthy pallet box was designed and tested under real world conditions (26) – see Figure 17.

Figure 17 Full scale testing of crashworthy pallet box vs. conventional pallet box

All these devices were designed as add-ons or adaptations for conventional trucks or trailers (ladder frame design with two longitudinal beams). Therefore additional weight (reducing the payload) and/or additional costs are arising and influencing the cost-benefit ratio negatively. A substantial change of the truck/trailer body design towards an **advanced** frame concept will lead to a cost-efficient integration of an (all-around) **underrun protection** and other benefits, like a decreased drag coefficient.

3 Links to other projects

This chapter lists briefly which results have been used or shared with other **project**, workshops, working groups (EEVC, ISO), etc..

For heavy truck safety and the specifically addressed topics vulnerable road user safety and side **underrun protection** not too many links are to be found. Related research was addressed in the following contexts:

Other projects:

- VC-COMPAT (EC **project**): results from VC-Compat regarding performance criteria, accidentoloy and scenarios have been used and transferred from rear and front **underrun protection** to side **underrun**
- Safety (EC **project**): comparing accidentology and scenarios.
- TRL study for EC on rear **underrun**: Inputs from TRL were given from a study performed by TRL for the EC. APROSYS **SP2** could find similar force levels and evaluation methods for side **underrun protection** as the TRL study for rear **underrun**.
- LUTB Prevon: This French national **project** by “Lyon Urban Truck & Bus” started in 2007 focusing on the further development of passive pedestrian **protection** on trucks uses the outcomes of APROSYS **SP2**. This **project** involves Renault Truck as OEM. The data from **SP2** where shared with this **project**.
- DEKRA: **Project** started in Germany and Austria, where markings on parking lots, gas stations and repair stations are provided helping the truck driver correctly adjusting the mirrors.

Working groups:

- EEVC Working Group 17, relating to pedestrian **protection**. The work of WG 17, however, is focusing on pedestrian **protection** in passenger cars.
- EEVC Working Group 14, relating to **underrun**, in particular front-**underrun**. Currently, the working group is inactive.

The topics vulnerable road users and side impact related to heavy vehicles were addressed on an European level the first time in an RTD **project**. No other initiatives could be found. Former projects analyzed front and rear impact of cars into heavy vehicles.

The most relevant **project** was the VC-COMPAT **project** funded by the European commission. Accident data published by VC-COMPAT was analysed and formed an important input to the accidentology of APROSYS **SP2**. APROSYS **SP2** and VC-COMPAT came to similar force levels for the performance criteria of side **underrun** protective devices. Also the test method is similar defined as a quasi-static procedure.

The APROSYS data will be shared with the French national **project** "LUTB Prevon".

For side **underrun** data will shared with a consortium aiming for the development of a new urban truck platform using a space frame concept made of aluminium to avoid **underrun**.

4 Discussion and Conclusion

APROSYS subproject 2 has fully addressed its original objectives, which were stated in chapter 1. The chapter summarizes how this was done and what were the main achievements of APROSYS SP 2. This chapter also indicates what has to be done to take the results further. Limitations found during APROSYS are discussed. Furthermore, for the society as well the partners potential benefits are indicated.

4.1 Heavy Vehicle Aggressivity Index & New protection systems & testing procedure for side underrun protection of HGVs for passenger cars

The heavy vehicle aggressivity index is one outcome to drive the development towards a vulnerable road user friendly design of heavy vehicles. With its three individual evaluations (run-over, structural and active) the index is ready to be used to evaluate heavy goods vehicles. No major experimental testing is necessary. Only component testing of the vehicle front has to be done. The remaining two evaluations are based on plain virtual testing methods and geometrical measurements.

Numerical analysis showed that the run-over of a vulnerable road user can be avoided with an optimized design in approx. 80% of the cases covered by the defined evaluation scenarios. An energy absorbing front structure can decrease the consequences of the first impact significantly (e.g. HIC minus 70%). All those critical situations can be avoided if blind spots are minimised and the direct view is maximised. Therefore the active-aggressivity index evaluates the direct and indirect view area around the heavy goods vehicle.

The application of the index during design of new vehicles is useful in order to avoid impacts with vulnerable road users or at least mitigate the consequences of these accidents.

Both demonstrators were added to a truck – and have not been **integrated**. These parts result in additional weight and additional vehicle length. Therefore it is essential to combine vulnerable road user protection with other benefits (like decreased drag coefficient and fuel consumption) in order to introduce the passive safety measures proposed by APROSYS SP 2 successfully.

In the recent years active safety systems started to be introduced in heavy goods vehicles e.g. pedestrian detection, video systems, a.s.o.. These systems can be highly cost efficient and support the driver to avoid a collision. Nevertheless impacts will continue to occur.

Most benefits of passive systems can be gained if they can be **integrated** in the design providing other primary benefits (eg. less fuel consumption) and secondary benefits (eg. vulnerable road user protection). Therefore the benefits of streamline-designs were studied. They show decreased fuel consumption and passive safety benefits as well. Some of these designs are already presented on motor shows, but cannot be seen on the roads yet.

These streamline-designs show some extra length, which reduces the freight volume. This is a main issue for not introducing these designs. Monetary or user benefits have to be allowed for these new designs. E.g. if a certain vulnerable road user protection is **integrated** in the design, extra length can be used for the truck (an extra 0.4m are recommended). A smart design could then use only some 0.2m for the protection and the remaining 0.2m for additional freight volume or engine-package volume.

Based on the current traffic situation about 200-400 lives can be saved in Europe, if improved passive vulnerable road user protection is introduced in heavy goods vehicles.

The APROSYS **SP2** partners benefit from a better knowledge on vulnerable road user protection. This will be provided to the European society. Specific support from APROSYS **SP2** currently is given to an initiative providing a tool helping the truck driver correctly adjusting all six mirrors on a truck. This will help protecting vulnerable road users, by applying the exterior mirrors as intended by directive 2007/38/EC.

For the industrial partner a support for new designs is given by APROSYS **SP2** results.

4.2 New protection systems & testing procedure for side underrun protection of heavy goods vehicles for passenger cars

The developed side underrun protection devices and the testing procedure can contribute to save some 100 lives of fatally injured car occupants impacting the side of a truck or trailer annually in the EU-25.

The design of side underrun protection devices showed up the possibilities and the challenges. It showed also the application of virtual testing and the use of computer-aided engineering for the truck/trailer development.

All protective devices are add-on parts which lead to additional weight reducing the payload of the heavy vehicle. Hauliers will not ask for these devices and industry will not take them into account, if there is not additional benefit or it is required by legislation.

The state-of-the-art design of heavy goods vehicles uses a latter frame concept with two main longitudinal beams. These beams are the main load paths, where protective devices can have their interface. Complex and heavy add-on parts have to be designed to close the critical gaps where cars can underrun the heavy vehicle.

For the integration of an (all-around) underrun protection for cars and vulnerable road users a complete and comprehensive redesign of the truck/trailer frame is required. Such a new frame concept has to provide the main structure around the vehicle instead of the middle of the vehicle: a space frame concept. This structure has to be designed to provide the operational stability as well as underrun protection with no extra weight compared to the two beam concepts.

The reliability of computer aided engineering and a joint development of new truck/trailer concepts in Europe will bring a cost-efficient passive safe truck/trailer. Also the developments of active safety devices and driver assistant systems have to be taken into account.

For the partners of APROSYS **SP2** the main benefits are to have better knowledge on side underrun protection and provide this to the European society and the European commission. The results show also a good correlation with results on rear underrun. Specific support from APROSYS **SP2** can be given to a new initiative aiming to redesign the truck frame for urban trucks using an aluminium space frame concept.

For the industrial partner a ready to use concept for side underrun protection resulted from APROSYS **SP2**.

5 Recommendations

This chapter gives recommendations based on the results from APROSYS **SP2** and indicates future use of the results as well as research gaps.

The final activities in APROSYS **SP2** gave an outlook on the integration of truck safety together with e.g. fuel reduction.

As discussed in the previous chapters, the measures and strategies developed for heavy goods vehicles based on pure passive safety systems needs integration into the truck design and provide additional benefits.

The current truck and trailer design does only allow add-on solution for passive measures leading to added weight and length. Active safety concepts are more and more reliable, but cannot prevent all critical situations from resulting in a collision. Therefore a recommendation for **integrated** passive and active safety is given by the so-called “Greener Truck Safety” initiative.

Changes in truck and trailer design require a lot of time. A platform stays up to 10 years in production. So the change to integrated designs is a long term task, which is described in the “Roadmap for Greener Truck Safety” (see Figure 18) (17).

Figure 18 Roadmap for Greener Truck Safety

This road map was discussed during workshops as well as distributed to partners and stakeholders. The road map is aiming on the following topics for the truck/trailer in 2030. The new integrated designs will be:

1. Safe;

2. Economic,
3. Eco-friendly,
4. Ergonomic and
5. Longer

These five postulates have the following meanings:

1. **Safe** – Partner protection for cars and vulnerable road users is integrated in the streamlined design. Under-run protection in all directions increases the compatibility with smaller vehicles.

2. **Economic** – The streamlined design reduces drag loads and resistance, leading to reduced fuel consumption.

3. **Eco-friendly** – Reduced fuel consumption results in greener transport, including reduced CO_2 emissions.

4. **Ergonomic** – An integrated design can potentially allow more space to design an improved working environment for the driver.

5. **Longer** – A small increase in length (0.5 to 1.0 meter) is used for the integrated design and introduction of the listed benefits.

The main conclusion of the road map for greener truck safety is that there has to be raised a discussion on truck length regulations to create the legal basis of greener truck safety. Only an extended truck length for the implementation of an aerodynamic cabin, improved working place for the driver as well as vulnerable road safety into an integrated design will bring the maximum benefit.

Side underrun is more difficult to be beneficial. New designs or topology of the freight area of a truck/trailer will lead to an integrated design. Otherwise it’s a political decision e.g. under the “Vision Zero” to force the introduction of side underrun protection by legislative measures.

All add-on solutions or changes to default designs have the same disadvantages – additional weight and/or additional costs. The most feasible way of integration of an (all-around) underrun protection is a redesign of the truck / trailer frame concept. A change in the topology of two centred longitudinal main beams towards a frame concept, where the structure has an integrated function of stability and underrun protection as well as other benefits will be the most efficient. This means a complete new design, construction and production process. By means of state-of-the-art computer aided engineering tools new concepts can be optimized and evaluated within a short period of time at comparable little costs. This is a long-term process and will need support by RT&D projects to make these changes possible.

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