FINAL TECHNICAL REPORT

CONTRACT N°: **GRD2/2001/50083/VC-COMPAT**

PROJECT N°: **GRD2/2001/50083**

ACRONYM: **VC-COMPAT**

TITLE: **Improvement of Vehicle Crash Compatibility through the Development of Crash Test Procedures**

PROJECT CO-ORDINATOR: **TRL Limited, CROWTHORNE, UK**

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Summary: Overview of technical progress and management aspects

This report gives a synopsis of the work of the entire VC-COMPAT project. It summarises the technical achievements of the project with relation to its initial objectives, details the main results and conclusions and gives recommendations for future work. It also provides an overview of the management aspects of the project.

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1 TABLE OF CONTENTS

2 EXECUTIVE PUBLISHABLE SUMMARY

Traffic-related accidents are still a major threat to life in the European Union. In 2004 there were 32,951 traffic accident deaths and 251,203 seriously injured casualties in the 15 member states of the EU, out of a population of 377,942,000. Of these road fatalities, 54% were car drivers or passengers, so there remains much potential benefit for improving car occupant safety. Following the introduction of EuroNCAP and the European Frontal and Side Impact Directives, it is widely recognised that improved vehicle crash compatibility offers the next greatest potential benefit for improving car occupant safety. Moreover the European Commission has set a target for traffic fatalities to be reduced by 50% by 2010 (compared to 2000) and improving passenger car compatibility could be one major step towards that aim.

The ultimate aim of the project is to develop crash test procedures, which once implemented in regulatory and / or consumer testing will lead to reduction in the casualties in car to car and car to heavy truck impacts. The specific objectives are:
For car to car impact

- To develop a set of test procedures with associated performance criteria to assess a car's compatibility in frontal impacts.
- To perform an associated cost benefit analysis.

For car to truck impact

- To develop test procedure(s) with associated performance criteria to assess energy absorbing front underrun protection systems for trucks.
- To provide guidelines for improvement of existing legislation on truck rear underrun protection.
- To perform associated cost benefit analyses.

<u>Car to car impact results</u>
For car to car impact the benefit for improved frontal impact compatibility in Europe (EU15) was estimated to be between 721 and 1,332 lives saved and between 5,128 and 15,383 seriously injured casualties mitigated per year. This analysis was based on Great Britain and German accident data only. The cost of improved compatibility was estimated based on the costs required to modify a current car to meet assumed compatibility requirements. Using this information, the cost benefit ratio, defined as value of benefit divided by cost of implementation, was predicted to be between about 4.5 and 0.5. It should be noted that this cost benefit was calculated for the steady state, when the entire vehicle fleet is compatible. The benefit will be less during the initial years as compatible cars are introduced into the fleet.

The results of the project testing and simulation activities provided consistent support for the initial hypotheses: compatibility requires good structural interaction, matched force levels, and good compartment strength. The work mainly focused on the development and initial validation of two tests procedures to assess a car's compatibility, namely the Full Width Deformable (FWDB) and Progressive Deformable Barrier (PDB). The reason for this was that the current EEVC WG15 route map for the improvement of compatibility requires a test to assess a car's structural interaction potential to fulfil its first step. Both of these tests have the potential to assess this. Car to car testing, supported by numerical modelling work, was used to identify the main characteristics that affect a car's compatibility potential. Initial validation of the FWDB and PDB test procedures demonstrated that both procedures were capable of distinguishing these characteristics. It was not possible to choose a definite set of procedures because the FWDB and PDB approaches are so different that an adequate comparison between them could not be made. To be able to make this comparison and the consequent choice, it is likely that both procedures will have to be developed to a state where the performance criteria and initial proposals for performance limits are determined. At the moment, criteria have been proposed for the FWDB test but are still under development by the French government and industry for the PDB test. The current status of each of the approaches is reported, including route maps for their possible implementation. In addition, recommendations for the work required to propose an integrated set of test procedures to enable a first step to improve frontal impact and compatibility, are given.

Currently, a set of test procedures to assess a car's frontal impact and compatibility performance could be based on the FWDB approach, the PDB approach or a combination of both. It is expected that the further work required to complete the development of a set of test procedures to assess a car's frontal impact and compatibility will be co-ordinated via the European Enhanced Vehicle safety Committee (EEVC) and funded by individual governments and / or the European Commission. Also, car manufacturers are expected to be involved, in particular with the evaluation of the procedures.

Car to truck impact results

For car to truck impact the benefit of energy absorbing front underrun protection devices over the current legislative (‘rigid’) devices in Europe (EU15) was estimated to be around 160 lives saved and around 1200 seriously injured casualties mitigated per year. The analysis used an accident data set in which the vast majority of the trucks was not fitted with rigid FUPs as currently mandated by directive 2000/40/EC (ECE Regulation 93). Hence, assumptions had to be made to account for the effect of fitting rigid FUPs. Related to car to truck rear end collisions, an appropriate RUP device would save around 150 lives and mitigate around 1800 seriously injured casualties per year. The cost of energy absorbing FUP structures and improved RUP structures was estimated as cost to modify a current structure which fulfils the current legislation. The additional cost for an energy absorbing FUP is 100 - 200 Euro, and for an improved RUP between 100 – 250 Euro or even more if an adjustable device is required.

A programme of seven car to truck full scale tests was performed with rigid and energy absorbing FUPs. In all the tests underride was prevented, even at closing speeds of 75 km/h. The first four tests showed poor structural interaction with the car’s front structure. This was thought to be the reason why the energy absorbing capability on the truck was not properly activated because in a similar test with a different car, recommended by the car leg of the project for its better structural interaction potential, the FUP’s energy absorption was activated. However, the energy absorber in this test was prevented from collapsing freely and absorbing energy as designed. So, to generate baseline data to show the benefit of an energy absorbing FUP compared to a rigid FUP, a special FUP was designed with a different energy absorption structure than a standard e.a. FUP. Tests with this FUP in a rigid and energy absorbing mode showed a significant improvement in the car’s crash performance for the energy absorbing mode, but not the level of improvement that would be necessary to give the benefit required to justify the introduction of a regulatory test. However, although the benefit of energy absorption by the FUP was not unambiguously proved with the tests performed, the EC project officer requested continuation of the project to develop test/evaluation procedures for e.a. FUPs as planned, rather than redirection to perform additional baseline tests.

In response to this, a number of test procedures to assess e.a. FUPs with different levels of complexity/simplification were defined and investigated regarding their advantages and disadvantages compared to a full scale passenger car test. The procedures investigated were numerical simulation, quasi-static, and dynamic procedures using rigid and deformable impactors. The deformable impactor used was the Progressive Deformable Barrier (PDB), also used in the car to car leg. A definite decision for a final test procedure with performance criteria could not be made, simply because the supporting data from baseline tests were missing. However, all tests have the potential to be used as a final procedure in assessing energy absorbing front underrun protection structures on trucks. To obtain more data, more full scale tests with different types of vehicles and trucks with energy absorbing FUPs with greater energy absorbing capability are needed. Moreover, the amount of energy which can be absorbed underneath the truck without causing too much underride is limited. And also, the energy absorbing capability and capacity of passenger car front structures has improved to such an extend that impact speeds up to 64 – 75 km/h may well be survivable for passenger car occupants in collision with rigid FUPs. This means that additional structural deformation in the front of trucks may be necessary to achieve the benefits originally expected from energy absorbing FUPs to increase the energy absorbing capacity without permitting too much underrun.

For rear underrun, accident data and crash tests show that current rear underrun protection devices as required by present legislation are inadequate for collisions of modern passenger cars into the rear end of a truck/trailer with closing speeds greater than 50 km/h. In this project the properties of an improved RUP structure were determined and tested to prevent impacting passenger cars from underrunning the truck/trailer at speeds up to at least 56 km/h. From this work, recommendations for amendments to be implemented in directive 70/221/EEC (including amendment 2006/20/EG) and ECE Regulation 58 are made. However, it should be noted that the project has only considered amendments to the requirement for vehicles of maximum GVW. Lighter trucks are currently permitted to have reduced test load requirements and the validity of these lower test loads has not been assessed, so further work is needed to do this.

3 OBJECTIVES

This section describes the original objectives of the project which were, in summary, to develop crash test procedures, which once implemented in regulatory and / or consumer testing would lead to a reduction in the casualties in car to car and car to heavy truck impacts.

Car to Car Impact

The focus of this project was on frontal impact compatibility. Please note that the definition of cars used is an M1 vehicle with a total permissible mass of less than 3.5 tonnes and hence includes most SUVs.

In Europe, the frontal impact crash performance of cars is effectively controlled by the frontal impact Directive, 96/79/EC, and the frontal impact Consumer organisation assessment, EuroNCAP. Both these procedures use the same Offset Deformable Barrier (ODB) protocol, with the exception that the test speed is higher for the EuroNCAP assessment, 64 km/h compared to 56 km/h. As regards compatibility, the first shortfall of this test is that, although it ensures that a car can absorb its kinetic energy in its frontal structure without excessive occupant compartment intrusion, it does not control the frontal force levels of the car. Because of this and because heavier cars do not have a significantly larger deformation length than lighter cars, heavier cars have, in general, higher frontal force levels than lighter cars. Hence, in an accident between a heavy and light car, the heavy car with the higher force levels over-crushes the light car causing greater occupant compartment intrusion and increased injury in the light car. To resolve this problem, vehicle frontal force matching is required. In addition, a more serious shortfall of the ODB test procedure is that it does not adequately control a car’s structural stiffness distribution and connectivity sufficiently to ensure good structural interaction occurs in car to car impacts. Because of this, in many car to car accidents, under or override occurs with the result that the energy absorption capability of both cars is reduced leading to greater occupant compartment intrusion and increased injury.

Before this project began, research work has been performed to understand compatibility, by both governments and industry. It was generally agreed that for frontal impact compatibility an essential prerequisite for compatible cars was good structural interaction. In addition, a certain level of frontal force matching would be necessary to ensure that the impact energy is absorbed without exceeding the strength of the occupant compartment. The work of the EC 4th framework compatibility project outlined three possible test procedures to address these requirements in order to assess and control the compatibility of cars in frontal impact collisions. The French, mainly Renault, had also proposed an alternative test procedure to address compatibility issues, which was an Offset Deformable Barrier (ODB) test, which uses a Progressive Deformable Barrier (PDB).

The main objective of this project for car to car impact was to develop a suite of draft test procedures using the outline procedures described above as the starting point. It was intended that this project would complete the initial development and validation of these test procedures, which would include outlines for associated performance criteria. It would aim to demonstrate, in principle, that the procedures could correctly assess a car’s compatibility. It would also determine the best approach to assess compatibility to ensure that the suite of test procedures contained a minimum number of additional tests. An example of how this could be achieved is to adapt current tests to provide compatibility measures. Following this project, it was known that further work would still be necessary to demonstrate that the test procedures can correctly assess the compatibility of the wide range of car designs present in the vehicle fleet, to complete the development of the performance criteria outlines and ensure that the changes to car designs to improve compatibility are not detrimental to side impact, truck, roadside obstacles and pedestrian impact.

The specific scientific and technical objectives for car to car impact were:

- To develop a suite of draft test procedures and associated performance criteria outlines to assess and control car frontal structures for frontal impact compatibility.
- To ensure that the number of additional test procedures is a minimum to keep the test burden on industry to a minimum.
- To develop a framework for a crash compatibility rating system.

- To provide general recommendations for the design of a compatible car.
- To provide an indication of the benefits and costs of improved compatibility.

Car to Heavy Truck Impact

Car to Heavy Truck Impact
The phenomenon of car to HGV underride occurs all around the truck and the trailer/semi-trailer. The worst scenario of these three (front, rear and side) is the car to HGV front underride, mostly because of higher typical impact speeds in head-on collisions. In many cases rear underrun devices have proved to be not sufficiently robust to withstand the dynamic loading from a car or not positioned well enough to interact with the main structural members of the car. Cars are usually less involved in car to truck side collisions. Side protection on trucks, which is also obligatory, is mainly fitted to deflect (motor) cyclists and pedestrians. Even these systems might be considered for improvements.

Installing a rigid front underrun protection device to the truck (obligatory from August 10, 2003 according to Directive 2000/40/EC) should improve the compatibility of trucks with cars considerably. However, it was indicated[1] that another 'more than significant' reduction could be expected from fitting energy absorbing front underrun protection to trucks.

Legislation regarding rear underrun protection (70/221/EC) has existed since 1970. However, recent local statistics indicate that in many cases the requirements are not sufficiently adequate. An initial study by EEVC WG14 showed that the benefit of improved rear underrun protection might be of the same order as the benefit of energy absorbing front underrun protection, depending on the costs of implementation, and could therefore be considered of equal importance.

Side protection, which is obligatory since 1989 (89/297/EC) may need renewed attention to evaluate the effect since introduction. Changes to the design may necessary to improve the effectiveness.

This project aimed to address these types of truck incompatibility and to improve them by defining test procedures and performance criteria to advance the present legislation in this field.

The specific scientific and technical objectives for car to truck impact were:

- To develop test procedures and performance standards for (energy absorbing) (front) underrun protection systems for trucks.
- To define criteria for energy absorbing front underrun protection systems for trucks.
- To provide guidelines for improvement of existing legislation on rear underrun protection.
- To provide an indication of the benefits and costs of (energy absorbing) front and rear underrun protection systems for trucks.

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[1] EEVC Working Group 14, Development of Test Procedure for Energy-absorbing Front Underrun Protection Systems (FUPS) for Trucks: - Estimation of Influence of Rigid FUPDs on Injuries to Car Occupants, - Benefits of energy absorbing FUPS for Trucks compared with Rigid Devices. Document 60, Delft, December 1996.

4 SCIENTIFIC AND TECHNICAL DESCRIPTON OF RESULTS

4.1 Work Package and Task Overview

The table below gives an overview of the work packages and tasks within the project.

Table 4-1 Work packages and tasks, including the actors

WP /Task	Objective	Actors (Task leader)
WP 1	Structural analysis of car and truck/trailer fleet with respect to geometry and underride protection.	UTAC
1.1	Definition car database & makes/models	UTAC
1.2	Measurement & generation Car structural database	UTAC
1.3	Data analysis of current car to car compatibility	UTAC
1.4	Contents & structure of truck/trailer database & makes/models	TRL, CIML, DC, Volvo, SCAN, DAF
1.5	Measurement parameters & Database generation	TRL, CIML, DC, Volvo, SCAN, DAF
1.6	Current underrun devices analysis	TRL, CIML, DC, Volvo, SCAN, DAF
WP 2	Accident Analyses and Cost Benefit Studies	BASt
2.1	Analyses of national databases	TRL, BAST, UTAC, CHUT
2.2	Definition of methodologies	TRL, TNO, BAST
2.3	Estimate national benefits of improved compatibility	TRL, TNO, BAST
2.4	Estimate Cost of improved compatibility	TRL, BAST, FIAT
2.5	Estimate cost benefit for EU by extrapolation of national data	TRL, BAST
2.6	National statistics update	TRL, TNO, BAST, UPM, GDV, Volvo
2.7	Collection of in-depth accident cases	TRL, TNO, BAST GDV, Volvo
2.8	Prediction of benefit on underride protection.	TRL, TNO, GDV, Volvo
2.9	Estimation of costs of underride protection	TRL, TNO, GDV
WP 3	Crash testing & Analysis to development procedures & initial validation	TRL
3.1-3.3	Improvement of test procedures & validation	TRL, BAST, UTAC, CHUT, FIAT, TNO
3.4	Analysis & Development of truck frontal underrun test procedure	TRL, TNO, BAST, UTAC
WP 4	Car to Car and Car to Barrier crash modelling	TNO
4.1	Modelling support for development & validation of crash test procedures	TRL, UTAC
4.2	Role of vehicle vehicle-vehicle and vehicle-barrier properties	TNO
4.3	Influence on real world performance & future vehicle designs	TNO, CHUT
WP 5	Synthesis of Test Procedures for Car to Car Impact	TRL
5.1	Determine test procedure strategy	TRL, TNO, BAST, UTAC, CHUT, FIAT
5.2	Draft test procedure outlines	TRL, TNO, BAST, UTAC, CHUT, FIAT
WP 6	Injury mechanisms & underrun protection with C2T impact.	TNO
6.1	Test definitions & preparation of the test objects.	TNO, BAST, GDV, Volvo, SCAN
6.2	Performance of the tests	TNO, BAST, Volvo, SCAN
6.3	Summary, Discussion and conclusions	TRL, TNO, BAST, Volvo, SCAN
WP7	Modelling (C2T crash tests) & reference baselines for evaluation	TNO
7.1	Simulations to support full scale testing	TNO, Volvo
7.2	Simulations of parameters not evaluated in full scale testing.	TRL, TNO, Volvo

7.3	Establishment of reference	TRL, TNO, Volvo
WP8	Determination of methodology in underrun protection	UPM
8.1	Definition of bullet vehicle	TRL, TNO, BAST, UPM, DC, Volvo, SCANIA, DAF
8.2	Definition of target	TRL, TNO, BAST, UPM, DC, Volvo, SCAN, DAF
8.3	Experimental evaluation	TRL, TNO, BAST, UPM, Volvo
8.4	Numerical evaluation	TNO, UPM, CIML, Volvo
WP9	Synthesis and validation of test procedure(s) and performance criteria for car to truck impact	BAST
9.1	Collection and grading of the relevant information	TRL, TNO, BAST, UPM, GDV
9.2	Set-up of test procedure(s) and performance criteria	TRL, TNO, BAST, UPM, DC, GDV, Volvo
9.3	Validate test procedure(s) and performance criteria	TRL, TNO, BAST, UPM
9.4	Draft outline of test procedure(s) and performance criteria	TRL, TNO, BAST, UPM, DC, GDV, Volvo
WP10	Industrial Liaison and Dissemination	TNO/CHUT
10.1	Industrial liaison/ Stakeholder survey	TRL, TNO, BAST, UTAC, CHUT, FIAT
10.2	Preparation of joint consortium papers	TRL, TNO, BAST, UTAC, CHUT, UPM, FIAT, CIML, DC, GDV, Volvo, SCAN, DAF
10.3	Project Workshop: Mid term and Final	TRL, TNO, BAST, UTAC, CHUT, UPM, FIAT, CIML, DC, GDV, Volvo, SCAN, DAF
10.4	Launch and maintenance of a project website	TRL
WP11	Project Management	TRL, TNO
11.1	Project co-ordination	TRL, TNO

4.2 Description of Results by Work Package

4.2.1 WP 1 Structural analysis of car and truck/trailer fleet

The main objective of this WP was to construct geometric databases of the main structures of cars and trucks involved in car to car and car to truck crashes and perform initial analyses of these databases to investigate geometric compatibility issues. These databases were also used in other WP activities, for example, to develop truck/trailer generic models, to help interpret test results and to help determine assessment areas for the FWDB and PDB test procedures.

Car database

There are two structural properties that determine a vehicle's "compatibility" with its opponent: physical strength (or stiffness) of the vehicle components and the position of these components. The first property is associated with the frontal force level compatibility and the second describes a geometric compatibility. The objective of the structural survey was to measure and create a database of the position and dimensions of vehicle structures involved in frontal and side impact. The database was then used to study current geometric compatibility.

The specific tasks undertaken were to:

- Define the main vehicle structures involved in frontal and side car-to-car impacts.
- Define a representative group of vehicles for measurement.
- Measure the vehicles and generate the database.
- Analysis of the database to determine suitable interaction areas for car-to-car impacts.

The measurement procedure was developed by the car to car leg project partners in consultation with EEVC WG15[2] and IHRA[3] compatibility working group members to ensure as good compatibility as possible between the VC-COMPAT structural database and other databases world-wide. The database contains the following information:

- General information of the vehicle (model, engine and subframe type, mass, length, etc.).
- The front unit measurement (position of bumper, engine, subframe, lower rail, crush can, footwell, etc.).
- Side unit measurement (A, B and C pillar, position of floor sills, fender, etc.).

55 cars were measured with the goal to have cars from different segments and car manufacturers in order to get a good representation of the European fleet. The selected vehicles were representative of 61% of the cars sold in Europe in 2003.

The database provides the positions of the main frontal structures which should interact in car-to-car impacts to ensure good structural interaction. A typical analysis is shown in Figure 1 where the vertical position of the vehicle structures can be described in terms of the maximum, minimum, average, and weighted average values. Similar analyses for the lateral position and sectional dimensions can be conducted.

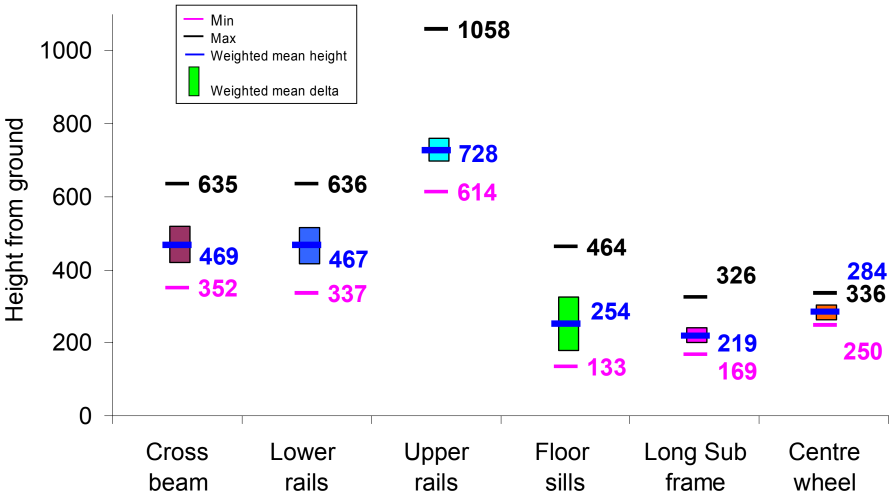

Figure 4-1: Vertical positions of significant structural components.

Information contained in the structural database has been helpful to understand the results obtained in car-to-car and car-to-barrier testing. The data has also been useful to help develop an assessment area for compatibility test procedures. For example, an assessment area would have encompass a vertical range between about 180 mm and 800 mm to include the subframe, main rail, upper rail and wheel sill load paths.

Truck database

The objective was to create a database of the main truck/trailer structures that are involved in front, rear and side collisions, as well as an inventory of current underrun protection devices.

Methodology

The methodology consisted of the following:

- Conduct analysis of truck and trailers.
- Create a database of Heavy Goods Vehicles (HGV's).
- Develop a protocol for measuring truck/trailer geometries for input into a database.
- Obtain measurements from trailer manufacturers.
- Collate the other partner's data for the database.

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[2] EEVC WG15: European Enhanced vehicle Safety Committee Compatibility and Frontal impact working group.

[3] IHRA: International Harmonisation of Research Activities

- Create the geometric database and input data.
- Conduct literature searches (web search and technical library search) for current underrun devices.
- Collate the partners' data on underrun devices.
- Create a report on current underrun devices.

Results

The main results of the sub-tasks 1.4 to 1.6 were:-

- Conducted a structural analysis of truck and trailers.
  The aim of the structural analysis was to provide relevant geometric information that could be used in other work packages for a cost-benefit analysis and also to help in defining tests and modelling trucks/trailers for numerical simulations. The geometrical information related to data for front, rear and side regions of heavy goods vehicles.
- Created a database of Heavy Goods Vehicles.
  A database of HGV geometries based on the collated geometric information was created. It consisted mainly of dimensions related to the main truck/trailer structures that are involved in front, rear and side collisions. A protocol document which included a description of each parameter and diagrams of the dimensions was created by CIC. This approach assisted truck/trailer manufacturers in collecting the appropriate required data. The database included information such as manufacturer's name and model, vehicle types such as rigid or semi-trailer and also some information on EU sales figures for each range.
- Provided a report on current underrun devices.
  A detailed report on the current underrun devices was produced. It contained an analysis of underrun devices, as demanded by regulations described in the literature or currently used in today's truck/trailers. It included both rigid and energy absorbing types. Energy absorption capabilities of these devices were also documented. The advantages and disadvantages, as well as their experimental behaviour and the way they have been or can be modelled in numerical simulations, were collated.
- A joint paper by CIC and other partners in WP1 (structural analysis of truck/trailers with respect to geometry and underride protection) was presented at the 20th International Congress on Truck Safety, October 2003 in Hungary.

Conclusion

Truck and trailer structures were measured to create a geometric database of the main truck/trailer structures that are involved in front rear and side collisions. An inventory of current underrun devices was produced that highlighted the advantages and disadvantages, as well as their experimental behaviour and the way they have been or can be modelled in numerical simulations. In view of the above, the objectives of the project in sub-tasks 1.4 to 1.6 were met.

4.2.2 WP 2 Accident Analyses and Cost Benefit Studies

The overall objective of this WP was to determine the benefits and costs of improved compatibility for car to car frontal impact and car to truck impact. The main results and conclusions of the work are reported below.

Car to Car Impact

In 2004 there were, according to the Community database on Accidents on the Roads In Europe (CARE), 32,951 traffic accident deaths and 251,203 seriously injured casualties in the 15 member states of the EU-15. EFR (European Union Road Federation) state that 54% of these road fatalities were car passengers or drivers.

The aim of this part of the work was to estimate the costs and benefits for improved frontal impact car to car compatibility for Europe (EU15). For the benefit analysis the approach illustrated in Figure 4-2 was followed.

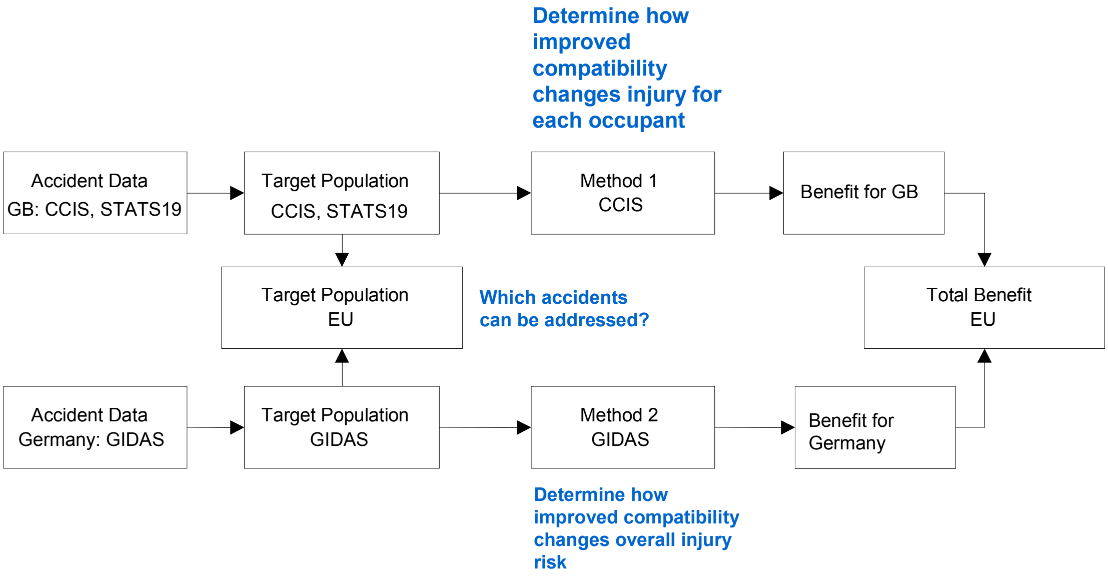

Figure 4-2: Benefit analysis approach.

Firstly, the target population was estimated for Germany and Great Britain (GB) and scaled to calculate the target population for the EU15 countries. The target population is defined as the number of casualties who might experience some injury risk reduction as a result of the implementation of improved compatibility. Building on this work, TRL and BASt developed methodologies and estimated the benefit for compatibility for Great Britain and Germany, respectively. As a definite set of test procedures to assess a car's compatibility has not yet been defined, the methodologies were based on the assumptions of how a compatible car would perform. The GB analysis used detailed accident data from the Co-operative Crash Injury Study (CCIS) and national data from the STATS19 database. The German analysis used detailed accident data from the GIDAS database and German national accident statistics. The methodology used for the GB analysis was based on a retrospective review of real-world vehicle crashes that occurred in GB and an in-depth evaluation of what injuries could have been prevented if the vehicle crash performance was enhanced. The methodology only considered the crashes for injury mitigation where it was believed that it would be realistic to predict some benefit, so high speed crashes and under-run impacts were excluded. The methodology used for the German analysis was based on theoretical concepts that evaluated the current risk of car occupant injury following frontal impacts with respect to collision speed; re-assessed the risk functions for an improved compatibility vehicle fleet with better energy management characteristics and subsequently predicted the likely future casualty reductions.

The economic analysis was undertaken by Fiat and considered the fixed, variable and associate design costs. Two cases were chosen, a worst case, modification of a 4 star EuroNCAP car, and a best case, modification of a 5 star EuroNCAP car. The costs for each star rated car were then evaluated with respect to the number of car units that would be modified per year, with the greater the number of units the lower the cost per car.

From this, the cost benefit for the EU15 countries was estimated by scaling the benefits estimated for GB and Germany and the costs estimated by Fiat. A range of predicted casualty savings for EU15 was calculated by scaling the proportional benefit estimated for GB and Germany. The financial benefit was calculated by multiplying the casualty savings by published values for the cost of fatal and seriously injured road accident casualties. The number of new registrations per year in the EU-15 vehicle fleet was used to estimate the cost per year to introduce frontal impact compatibility. A ratio was then derived based on the potential costs saved through fewer casualties due to the introduction of improved compatibility divided by the expected manufacturer costs. It should be noted that the cost benefit was calculated for the steady state, when the entire vehicle fleet is compatible. The benefit will be less during the initial years as compatible cars are introduced into the fleet.

Results and Conclusions

Target Population

For the EU15 countries the target population for improved car to car frontal impact compatibility was estimated to be:

- About 3,466 (14%) to 7,675 (31%) fatally injured car occupants
- About 50,260 (29%) to 90,122 (52%) seriously injured car occupants

GB Benefit Analysis

The GB benefit analysis predicted that between approximately 5% (67) and 8% (124) of the GB's killed front seat car occupants would be saved and between 5% (732) and 13% (1876) of seriously injured casualties would be prevented if improved frontal impact compatibility were implemented. The lower estimate was made based on a model that assumed that improved compatibility prevented all injuries caused by *contact with a front interior intruding structures* below an impact severity of ETS 56 km/h, whilst the upper estimate was based on a model that prevented all injuries caused by *contact with a front interior structures* below this severity.

Another significant finding of the GB work was the high frequency of moderate (AIS2) and life threatening (AIS 3+) injuries sustained by car occupants due to seat belt induced loading. The majority of thoracic injury was not prevented by the injury reduction models. There is an argument that a more compatible vehicle would benefit from an improved crash pulse and therefore it would be expected to see lower seat belt loads and a reduced risk of thoracic injury. The models, by their design, did not prevent injury attributed to seat belt loading, and therefore underestimate the potential benefit that could be seen for this body region. This is important to note, as head and thoracic injury are known to be associated with fatal outcomes.

German Benefit Analysis

The German benefit analysis predicted that approximately 8% of Germany's killed front seat car occupants would be saved and about 4% of seriously injured casualties would be prevented if improved frontal impact compatibility were implemented. This estimate was based on the assumption that a car with improved compatibility can absorb about 30% additional kinetic energy in frontal impacts and calculating the injury risk reduction for occupants within the target population. This assumption was based on the comparison of the performance of cars in car to car and standard offset barrier crash tests.

Cost Analysis

The cost of improved compatibility was estimated by Fiat, based on the costs required to modify a current car to meet assumed compatibility requirements. This included both the increased manufacturing costs to the industry and the increased running costs to the consumers. The cost was calculated using the best and worse case scenarios to give a possible range. The best case scenario was the cost estimated to modify a 5 star rated EuroNCAP car with a production of 1 million cars. The worst case was the cost to modify a 4 star rated EuroNCAP car with a production of 100,000. The total annual cost given by multiplying the cost for each car by the number of new cars registered in the EU15 every year is given in below.

Table 4-2: Cost of implementing compatibility.

	Cost per car (€)	**No. of cars registered p.a.**	**Total cost p.a. (€)**
Best case scenario	102	14,211,367	1,449,559,394
Worst case scenario	282	14,211,367	4,007,605,383

EU15 Cost Benefit

To estimate the benefit for the EU15 the benefit estimates for GB and Germany were scaled to give the following results, Table 4-3.

Table 4-3: Predicted reduction in EU-15 casulties.

		Predicted Reduction in EU-15 Casualties		
	Frontal car casualties	**CCIS intrusion model**	**CCIS contact model**	**German model**
Fatal	16,014	721	1,332	1,281
Serious	122,084	5,982	15,383	5,128

The financial benefit for the EU15 was calculated by multiplying the benefit in terms of casualties by the value of life saved and serious injury prevented [Table 4-4]. For the GB estimate the casualty value used was that given in Road Casualties Great Britain 2005 (RCGB 2005), which estimates the average value per prevention of casualty. For the German estimate the casualty value used was that calculated by the German Federal Highway Research Institute, Höhnscheid.[4].

Table 4-4: Value of EU15 Benefit

	Benefit per person		Predicted Total benefit		
	Fatal	**Serious**	**CCIS: Intrusion**	**CCIS: Contact**	**German model**
RCGB 2005 (€)	2,136,262	240,043	2,976,180,313	6,538,077,822	-
German (€)	1,161,885	87,269	-	-	1,936,005,641

From this and the cost information presented above the cost / benefit ratio of improved frontal impact compatibility for the EU15 was estimated [Table 4-5].

Table 4-5: Cost Benefit Ratio of improved compatibility for EU15.

	Ratio of financial benefits to implementation costs		
	CCIS intrusion model	**CCIS contact model**	**German model**
Best case scenario	2.05	4.51	1.34
Worst case scenario	0.74	1.63	0.48

Car to Truck Impact

The objective of this work package was to update the statistics regarding car-to-truck frontal and rear end collisions, to predict the benefit of a truck/trailer fleet with appropriate FUP and RUP systems and to estimate the costs for energy absorbing FUP and improved RUP systems.

Methodology

- Update national statistics on truck accidents

The involved partners performed statistical research within their own national statistics. Data from the following six countries could be obtained: France, Germany, The Netherlands, United Kingdom, Spain and Sweden. These data covered a period of 7 years (from 1995 to 2001). All data were collected, analysed and compiled in a final report. The update of national statistics covered following aspects:

1) Analysis of all road accidents with injuries to persons, i.e. all accidents involving all road users and the respective casualty numbers. Significant trends were pointed out.

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[4] Höhnscheid, K.-J., Straube, M. (2006), " Socio-economic costs due to road traffic accidents in Germany 2004".

2) Exposure data of trucks, covering the stock data and traffic performance of trucks. Only trucks with a Gross Vehicle Weight (G.V.W) > 3.5 tonnes were considered.
3) Analysis of road accidents involving trucks regarding the numbers of casualties (slightly, seriously and fatally injured) as well as their change from 1995 to 2001. For specific analysis regarding casualties, the so- called Killed and Seriously Injured Rate (KSI Rate) was defined and used for determining and comparing the risk of being seriously injured or killed in a truck accident.
4) Analysis of truck accidents by accident type (available for year 2001 only) enabled to determine the opponent party, and the distribution of the slightly, seriously and fatally injured occupants in the truck and the opposite vehicle/road user.
5) Analysis of car-to-truck accidents by five common type of collisions (front/front, front/rear, front/side, side/front and rear/front) with regards to the accident frequency and the KSI Rate.

- Obtain accurate information on front and rear underrun

Information on car-to-truck collisions was collected and compiled. The work focussed only on car-to-truck frontal and rear end collisions. In-depth-studies formed the basis of the work and gave detailed insight by means of information on collision speed, overlap, collision (impact) angle, underrun degree and damage of the car (deformation of the occupant compartment).

- Predict benefits of front and rear underrun protection systems

The benefit estimation considered the possible reduction in the number of fatalities and seriously injured per annum due to car-to-truck front/front and front/rear collisions. The figures were determined for France, Germany, The Netherlands, United Kingdom, Spain and Sweden and were then extrapolated in a first approximation to the EU-15 countries.

- Determine the costs of improved underrun protection for trucks/trailers for front and rear underrun

The costs of current underrun protection systems were gathered and supplemented for advanced front and improved rear underrun protection systems. For front underrun protection devices several truck manufacturers provided cost figures of current designs and estimations for the add-on cost for advanced energy-absorbing front underride protection.For rear underride protection this information was obtained from two major European manufacturers of bodywork for trucks and trailers. Information about current costs and the effect of improved designs on cost was provided in overview tables for front and rear underrun protection systems.

- Estimate the actual equipment rate of trucks with front underrun protection systems after EU Directive 2000/40/EC became mandatory by the end of 2003 and determine the cost of personal injury in different EU countries (additional voluntary task by GDV)

Data from all major European heavy truck manufacturers was collected on the number of vehicles sold in Germany and in Europe and the percentage of FUP equipment on these for 2004. Together with sales shares of the manufacturers for most EU countries taken from market study sources, it was possible to estimate the share of vehicles that are equipped and are not equipped with front underrun protection in the segment over 6.0 tons of permissible mass due to a clause which exempts so-called “off-road vehicles” according to 70/156/EEC from the requirement. The socio-economic costs of injury were collected from national authorities of several European countries. It proved difficult to obtain the official figures.

Results

With regards to the exposure data of trucks, a slight increase in stock over the period of seven years could be observed for six considered countries as well as an increase in traffic. However, there is a tendency towards a decrease in accident occurrence. Despite highly variable numbers within the countries, the number of fatalities in truck accidents decreased as well.

A positive development of the truck accident occurrence could be observed for Germany and for France. In Sweden, United Kingdom and especially in Spain, the number of truck accidents increased. It was common for all countries that truck accidents are more frequent on rural roads, accounting for the highest number of fatalities among the occupants of the opponent party. Over 50% of the truck accidents reported for the year 2001 were car-to-truck collisions. Within this group of accidents, in France and Germany front/front collisions were more frequent. UK reported more front/rear collisions, i.e collisions where the truck hit the rear end of the car. The risk of being killed or seriously injured for the car occupants was higher in front/front collisions (Germany, Netherlands, UK) and in collisions where the truck hit the side of the car (front/side collisions).

German in-depth data on fatal and serious accidents revealed that most rear-end collisions occurred with low relative speeds. In 60 % of the 58 cases the speed difference between the car and the truck was up to 30 km/h. Furthermore, 45 % of the cases were related to an underrun at least up to the A-pillar of the car. Similar conclusions could be drawn from UK in-depth data on fatal accidents.

Regarding Front Underrun Protection, the cost for a system with engineered energy-absorbing function was estimated to range between 100 € and 200 € per vehicle in addition to a “rigid” Front Under-run Protection System (FUPS). Some manufacturers supplied additional information expenses for the development, certification and production preparation for new underrun protection systems. Between one and three million Euros more are considered necessary when introducing a new FUPS to the market which has an energy-absorbing capability.

The construction of Rear Underrun Protection devices can become complex, especially when tipping or folding support members are necessary. A wide band of costs applies to these systems accordingly. The associated costs and other important parameters describing a rear underrun protection device would be very different for bodywork and trailer manufacturers depending on the specific purpose of the vehicle or trailer. The costs for current RUP devices range from approximately 500 € to more than 4000 € for complex designs. Three truck manufacturers quoted 100 to 200 € as pure parts costs (excluding development etc.) for very basic components. Rear underrun protection to meet aggravated legal requirements would cost up to 250 € more per vehicle. However, many envisaged construction improvements could be realized for less than 100 € on top of the cost for current designs.

It was estimated that in the medium duty truck segment from 6.0 tonnes to ca. 16 tonnes approximately one third of the newly registered vehicles are not fitted with Front Underrun Protection (FUP). However, this survey includes also trucks from 6.0 to 7.5 tonnes which are not subject to legal FUP requirements. In the mass category of 16 tonnes and over, less than 15% of the trucks do not feature a FUP system or device. Therefore, the benefits for the reduction of fatal and severe injuries in frontal car-to-truck accidents calculated previously were revised.

On the basis of individual case studies benefits were predicted in terms of the annual reduction in the number of fatally and seriously injured car occupants in car-to-truck frontal and rear end collisions when appropriate underrun devices were installed. The analyses (including the above mentioned correction for truck types that are exempted from the requirement) revealed the following figures for EU15.

When having e.a.FUP compared with and existing rigid FUP:
reduction of fatalities ~160
reduction of severe injuries ~1200

When having improved rigid RUP compared with existing rigid RUP:
reduction of fatalities ~150
reduction of severe injuries ~1800

Monetary values for slight, severe and fatal injuries could be obtained for five large EU countries. These are based on very different valuation methods but are largely in line with the results of the EU project HEATCO. The total annual financial benefit for the EU15 can be calculated using these socio-economic costs for fatal and severe injuries, which results in the following figures.

When having e.a.FUP: reduction of fatalities 160 M€ - 300 M€
reduction of severe injuries 100 M€ - 250 M€

When having appropriate RUP: reduction of fatalities 165 M€ - 300 M€
reduction of severe injuries 150 M€ - 400 M€

Conclusions

A lack of harmonized accident data within Europe can be stated. The update of national statistics clearly pointed out that there are big differences in the definition, quality of reporting and compilation of statistical data in different countries which makes direct comparability difficult.

Analysis of the available in-depth accident information led to the following conclusions: For the same cummulative frequency of the accident cases, the closing speeds for front/front collisions are higher than for front/rear collisions. The tendency for offset collisions (partial overlap) is stronger for frontal impacts (opposite driving direction) than for rear impacts (same driving direction).

Car-to-truck frontal collisions occur most frequently at an impact angle around 0°, at relative speeds over 80 km/h resulting is severe and fatal injuries for the car occupants Furthermore, most frequently car-to-truck frontal collisions involve less than 50 % of the front of the truck. From the in-depth analyses a test procedure can be suggested where an overlap of less than 50 % (from the view of the truck) is considered.

Car-to-truck/trailer rear-end collisions frequently result in underrun reaching to the car`s A- and B-pillar for closing speeds already up to 30 km/h, especially in cases with small overlap. Improved rear underrun protection systems show a significant reduction potential. It is suggested to perform further real accident analyses with respect to the loadings in collisions with overlaps of over 75 % (from the view of the truck) and to evaluate how these loadings can be adapted in current test procedures.

An energy absorption capability is expected to add costs in the amount of 30 to 50 % of current costs for front underrun protection devices, ranging between 100 € and 200 € per vehicle in addition to a “rigid” device. Most constructive enhancements of rear underrun protection devices will cost between 20 and 100 € additionally. However, when more complex folding devices are required to meet aggravated geometrical requirements the add-on costs may exceed 200 € per vehicle easily.

The finding that a considerable proportion of trucks will not be fitted with front underrun protection even after 2003 indicates that there will still be a significant danger of poor compatibility between cars and new trucks in the future. As the truck fleet in the EU will be renewed and vehicles built until 2003 be replaced only gradually by vehicles fitted with front underrun protection the effect of penetration of an existing truck fleet was investigated for the German market. From registration statistics it was determined that approximately half of the 2003[5] truck fleet will still be on the road in 2012.

Benefits were predicted in terms of the annual reduction in the number of fatally and seriously injured car occupants in car-to-truck frontal and rear end collisions when appropriate underrun devices were installed. Including the above mentioned correction for truck types not having appropriate devices the following figures for EU15 can be estimated.

When having e.a.FUP compared with an existing rigid FUP:
reduction of fatalities ~160; benefit 160 M€ - 300 M€
reduction of severe injuries ~1200; benefit 100 M€ - 250 M€

When having improved rigid RUP compared with existing rigid RUP:
reduction of fatalities ~150; benefit 165 mio € - 300 M€
reduction of severe injuries ~1800; benefit 150 M€ - 400 M€

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[5] 2003 being the last year where trucks did not have to comply with Directive 2000/40/EC

4.2.3 WP 3 Crash testing & Analysis to development procedures & initial validation

The objective of this work package was to perform crash tests and associated analysis to continue the development and perform initial validation of the Full Width Deformable Barrier (FWDB) and Progressive Deformable Barrier (PDB) approaches.

Currently, the FWDB and PDB approaches consist of the following tests to assess both a car's partner and self protection performance:

FWDB Approach

- A FWDB test to assess a car's structural interaction potential (partner protection) and to provide a high deceleration pulse to assess the restraint system (self protection).
- An Offset Deformable Barrier (ODB) test to assess a car's frontal force levels (partner protection) and to check the compartment integrity (self protection).

PDB Approach

- A Full Width Rigid Barrier (FWRB) test to provide a high deceleration pulse to assess the restraint system (self protection).
- A PDB test to assess a car's structural interaction potential and frontal force levels (partner protection) and to check the compartment integrity (self protection).

Work has focused mainly on the FWDB and PDB test procedures with some work performed on the ODB test procedure for frontal force matching. The main reason for this decision was that the first step of the current EEVC WG15 route map[6] requires a test procedure that can assess a vehicle's structural interaction potential. Both the FWDB and PDB test procedures have the capability to do this.

Approach

The crash test and data collection work consisted of three separate activities. The first two activities were car-to-car and car-to-barrier testing. These were the main focus of this work package. The third activity was to collect and analyse load cell wall force data from 64 km/h ODB tests.

The main aim of the car-to-car and car-to-barrier test activities was to provide data to validate the FWDB and PDB test procedures. Firstly, vehicle characteristics that improved compatibility performance were identified from the car to car tests. These characteristics are referred to as beneficial characteristics. Secondly, an assessment was made of whether or not these beneficial characteristics were adequately identified in the FWDB and PDB tests. A further aim of the car-to-car test activity was to answer the following fundamental questions:

- Can good structural interaction be achieved with a current generation single-level load path car?
- Is a subframe load path a disbenefit in impacts with higher vehicles (SUVs)?
- What size should the assessment area be for the FWDB and PDB tests?

In addition car to barrier tests were performed to check that the procedures could be used to assess cars irrespective of mass, engine orientation, etc.

Test Programme

It should be noted that:

- Adam-Opel AG donated cars to the project for use in the testing programme as they wished to support the compatibility research being performed in this project. This effectively increased the budget for vehicle purchase and helped disseminate the project results.
- After the completion of the planned test programme BASt had some budget remaining in WP3. BASt used this budget to provide part of the funding for two additional crash tests; Supermini vs Supermini and Supermini vs PDB. The results and initial analysis of these tests are reported in an addendum to D27. It is intended that further analysis and interpretation of these results will be performed by EEVC WG15 members after the completion of this project.

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[6] Faerber E (2005). 'EEVC Approach to the Improvement of Crash Compatibility between Passenger Cars', 19th ESV conference, Washington DC, USA, 2005. http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0155-O.pdf

The car-to-car tests performed as part of the VC-COMPAT project can be subdivided into a number of test series (Table 4-6).

Table 4-6: Car-to-car test programme

	Vehicles	Organisation	Aim of test series
1.	Small Family (1 load path) Small Family (1 load path)	BASt	Series 1: Investigate difference in structural interaction performance of vehicle that spreads its load well vertically (two load path level design) with one that doesn't (single load path level design).
2.	Small Family (1 load path) Small Family (2 load path)	TNO	
3.	Small Family (2 load path) Small Family (2 load path)	UTAC	Series 2: Investigate difference in structural interaction performance of vehicle that spreads its load well vertically (two load path level design) with one that doesn't (single load path level design) *for state of the art current design cars*.
4.	Small Family (1 load path) Small Family (1 load path)	FIAT	
5.	Small Family (1 load path) Small Family (2 load path)	TRL	
6.	Supermini Supermini	FIAT	Series 3: Investigate difference in performance of light vehicle when impacted by cars with different structural interaction potential (single and two level load path vehicles used in test series 2).
7.	Supermini Small Family (2 load path)	UTAC	
8.	Supermini Small Family (1 load path)	BASt	
9.	SUV (no SEAS) Small Family (2 load path)	BASt	Series 4: Investigate difference in performance of car in impact with SUV if it has an additional load path not necessarily in alignment with the SUV vehicle structure (single and two level load path cars used in test series 2). Investigate if the performance of the car is improved if the SUV has a secondary energy absorbing structure (SEAS).
10.	SUV (SEAS) Small Family (2 load path)	TRL	
11.	SUV (no SEAS) Small Family (1 load path)	VW*	
12.	SUV (SEAS) Small Family (1 load path)	BASt ADAC*	

*Tests performed outside of the VC-Compat project to which the group have access to the results
Detailed test reports can be found in the appendices of D27 (D17 report appendices for tests 1 and 2)

The different test series investigated changes in vehicle design and vehicle mass upon compatibility performance. The test configuration chosen for the car to car impacts in this project was a 50 % overlap of the narrowest vehicle with a closing speed of 112 km/h.

Examples of a car with a single load path level and two load path level design are shown (Figure 4-3).

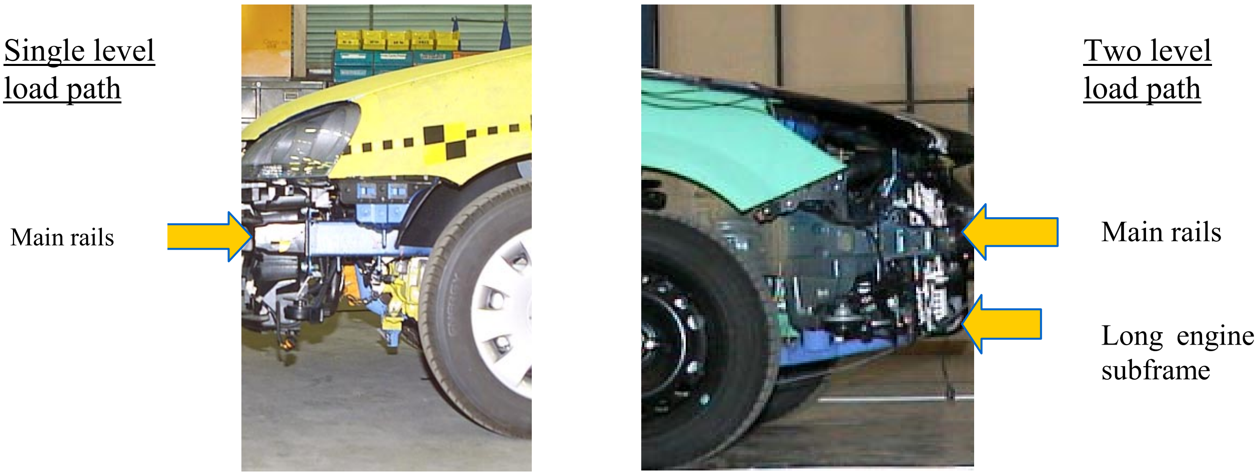

Figure 4-3: Examples of cars with single and two load path levels.

The car-to-barrier tests performed are shown in (Table 4-7). FWDB, PDB and ODB test data was available for all vehicles tested in the car-to-car test programme.

Table 4-7: Car-to-barrier test programme

	Full Width	PDB (tests with v7 barrier only)	64 ODB (LCW Data)	80 ODB	EuroNCAP Assessment
Supermini	**v LCW 50mm[1]**	**v v7 (WG15)[3]**	**X**	**v (EUCAR)**	**3***
Supermini 1 **(Car to Car Series 3)**	**v LCW 80mm[2]**	**v v7[2]**	**v (364kN)**	**X**	**3***
Supermini	**X**	**v v7[4]**	**X**	**X**	**4***
Supermini	**X**	**v v7 (LHD)[4]** **v v7 (RHD)[4]**	**X**	**X**	**5***
Small Family 1 **(Car to Car Series 1)**	**v LCW 112.5mm[1]** **v LCW 50mm (TRL)[1]**	**v v7[2]**	**v (341kN)**	**X**	**4***
Small Family 2 **(Car to Car Series 1)**	**v LCW 165mm (WG15)[3]**	**X**	**v (391kN)**	**v (EUCAR)**	**4***
Small Family 1 **(Car to Car Series 2,3,4)**	**v LCW 80mm[2]**	**v v7[2]**	**v (457kN)**	**X**	**5***
Small Family 2 **(Car to Car Series 2,3,4)**	**v LCW 80mm[2]** **v LCW 80mm (TRL)[2]**	**v v7[2]**	**v (401kN)**	**X**	**5***
Large Family	**v LCW 50mm (WG15)[3]**	**v v7 (LHD)[4]** **v v7 (RHD)[4]**	**v (440kN)**	**X**	**5***
Large Family	**X**	**v v7 (LHD)[4]** **v v7 (RHD)[4]**	**X**	**X**	**5***
Large Family	**v LCW 50mm (ACEA)[5]**	**X**	**X**	**X**	**4***
Executive	**X**	**v v7 (WG15)[3]**	**v (461kN)**	**X**	**4***
Executive	**v LCW 50mm[1]**	**v v7[1]**	**v (463kN)**	**X**	**5***
Small SUV	**v LCW 50mm[1]**	**v v7[1]**	**v (475kN)**	**X**	**4***
Large SUV 1 **(Car to Car Series 4)**	**v LCW 50mm[1]**	**v v7[1]**	**v (691kN)**	**X**	**5***
Large SUV 2 **(Car to Car Series 4)**	**v LCW 80mm[2]**	**v v7[2]**	**v (789kN)**	**X**	**5***
Large Family **(weakened and strengthened crossbeams)**	**v LCW 50mm (ACEA)[3]**	**v v7 (ACEA)[3]**	**X**	**X**	**N/A**

Those highlighted yellow indicate that the test was performed as part of the VC-Compat project
The total number of test performed by the VC-Compat project was 8 PDB, 9 FWDB and 1 ODB (20 units)

Detailed test reports for the PDB and FWDB tests can be found in the following locations:
[1] VC-Compat D17 Report (Appendices)
[2] VC-Compat D27 Report (Appendices)
[3] Paper Number 05-0052, Nineteenth International Technical Conference on the Enhanced Safety of Cars, Washington DC 2005
[4] Paper Number 05-0010, Nineteenth International Technical Conference on the Enhanced Safety of Cars, Washington DC 2005

Car-to-Car Test Summary – Identification of beneficial characteristics

Test Series 1 & 2

The aim of these two test series was:

- To investigate the difference in structural interaction potential of a two-level load path vehicle design compared to a single-level load path vehicle design.

Please note that only the results of test series 2 are summarised here as these tests were performed with current state of the art design cars, test series 1 wasn't, so the results of test series 2 were thought to be more relevant.

To judge the difference structural interaction performance of the cars in the car-to-car tests, a comparison to a benchmark test has to be made to normalise the effect of other compatibility parameters such as frontal force levels and compartment strength. The benchmark test used was a 64 km/h ODB test, because the EES in of each car in this test and a car-to-car test with a 50% overlap and a closing speed of 112km/h are approximately equal. In addition, a car's deformation behaviour should be best in the 64 km/h ODB test because cars are, in general, designed for optimum performance in this test. The closer the performance of the car in the car-to-car test to the benchmark test, the better the structural interaction performance.

When the performance of the cars in the car-to-car tests was compared to those in the benchmark test, it was seen that the performance of the two-level load path vehicle was closer to the benchmark than the single-level load path vehicle. This was illustrated by a comparison of compartment deformation measures, in particular the difference in the A pillar movement and door aperture closure movement, which was far less for the two-level load path vehicle. In addition there was less under/override and the stability of the main structures was much better for the two level load path design.

This result indicated that the structural interaction performance of the two level load path design car was better than the single level load path design. It was concluded that the FWDB and PDB test procedures should encourage car designs with good vertical load spreading capabilities.

Test Series 3
The aims of this test series were:
1. To investigate if the performance of a lighter vehicle (supermini) is improved against a two-level load paths vehicle small family vehicle compared to a single-level load path small family vehicle.
2. To investigate the effect of mass ratio.

In each of the car-to-car tests there was initial over/underride due to unstable activation of the lower rail load path of the lighter vehicle. This over/underride was limited by interaction between the upper to lower rail vertical connection of the lighter vehicle and the lower rail / crossbeam structure of the target vehicle. However, the stiffer main rail / crossbeam structure overloaded the weaker upper load path resulting in collapse of the occupant compartment.

The results of this test series demonstrated the importance of high compartment strength for light cars and good vertical connections between the upper and lower rails. It was concluded that the FWDB and PDB test procedures should encourage car designs with good vertical connections between the upper and lower rails.

Test Series 4
The aims of this test series were:
1. To determine if the performance of a car is worse if it has an additional load path not necessarily in alignment with the opposing vehicle structure, i.e. to answer the fundamental question, ‘Is a subframe load path a disbenefit in impacts with higher vehicles (SUVs)?’
2. To determine if the performance of the car is improved if the SUV has a secondary energy absorbing structure.
3. To investigate the effect of mass ratio.

For (1), when the performance of the single and two level load paths cars in the car-to-SUV with SEAS impacts were compared to those in the benchmark tests no disbenefit was observed for the two level load path small family, in fact a benefit was observed. The loads applied by the SUV with SEAS were well distributed into the occupant compartment of the two level load path small family car, which made the most of its compartment strength. This limited the intrusion into the occupant compartment.

For (2), there was dynamic lateral misalignment in the tests with the SUV without SEAS. This was due to the narrower front structure (as a percentage of the overall width) of this SUV. For the test with the two-level load path small family car the lower rail of the SUV w/o SEAS loaded the footwell area resulting in penetration of the footwell. The strong crossbeam of the SUV limited the maximum extent of this footwell penetration by directing the lower rail loading into the A-Pillar of the opposing vehicle. For the test with the single-level load path car the lower rail of the SUV w/o SEAS moved outboard of the A-Pillar. The result was similar footwell and instrument panel intrusion for the single level load path vehicle when compared to the baseline 64 km/h ODB test. So in this particular test the dynamic lateral misalignment (poor structural interaction) helped to enhance the crash outcome, i.e. it was beneficial. However, this result was shown to

be unpredictable and serendipitous the test with the two level load path car the dynamic lateral misalignment (poor structural interaction) led to compartment intrusion problems. Hence, it was concluded that for a predictable beneficial outcome in the full range of real-world impacts good structural interaction should be encouraged. Furthermore additional accident analysis is required to define the relevance of lateral misalignment in real world accidents.
In summary, the results of this test series demonstrated that there was no disbenefit for the two-level load path small family car in the impact with a vehicle with a higher structure, in fact a benefit was observed. The results of this test series also demonstrated the importance of a strong crossbeams to help interaction with the stiffer parts of the opposing vehicle structure. It was concluded that the FWDB and PDB test procedures should encourage car designs with crossbeams that are able to effectively distribute lower rail loads.

The main beneficial characteristics identified from these tests are summarised below:

- Improved vertical load spreading capability (Can be achieved with additional load paths)
    - In car to car tests structural interaction performance of two load path level vehicles was shown to be better than single load path level vehicles
- Strong vertical connections between load paths
    - In car to car tests structural interaction performance was improved by connections between the lower rails and subframe and upper and lower rails
- Strong lateral connections able to distribute rail loads
    - In car to car tests strong bumper crossbeams were shown to distribute lower rail loads and improve compatibility performance
- Adequate compartment strength and frontal force levels, especially for light cars
    - In car to car tests the compartment strength of a small car was shown to be insufficient to prevent substantial intrusion, even in an impact with itself.

In addition to the beneficial characteristics detailed above, the width of the front structure was also observed to have an effect on the compatibility of the impact. Significant differences in intrusion of target car were observed due to lateral misalignment of lower rail structures.

Car to Barrier testing - Development and Validation of Test Procedures

Work was performed to develop the FWDB approach. In this approach, to monitor (and control) end of crash force levels, it is proposed to use load cell wall (LCW) force measurements from ODB tests. However, engine impact on LCW (engine dump) in the ODB test with an EEVC barrier can give an incorrect measure of vehicle force level. A methodology was developed to minimise this problem which used an excedence approach, i.e. the force level exceeded over a set time period. Based on the available test data, a time period of 10ms was suggested. A comparison of the LCW force histories and the peak LCW force measurements for repeat tests carried out at the same test facility found that the LCW force measurement in the 64 km/h ODB test was reproducible.

The validation of both the FWDB and PDB tests was conducted in three parts. The initial validation was based on the ability of the tool / measurement to detect the beneficial characteristics, this being the load cell wall force distribution in the case of the FWDB test and the barrier deformation profile in the case of the PDB test. The second part was the ability of the criterion in the case of the FWDB test to detect the beneficial characteristics and the parameters in the case of the PDB test to detect the beneficial characteristics and rate the vehicle aggressivity. The third part was an assessment of the repeatability of the test procedures.

From the work done to validate the FWDB test the following conclusions were made:

- The assessment tool – the force distribution measurement – was shown to recognise the vehicle characteristics beneficial to compatibility identified from the car-to-car tests, specifically additional load paths and lower rail / crossbeam imbalance. However, the assessment tool only indirectly detects connections with a length close to or less than the load cell spacing, i.e. it detects the effect they have on the overall load distribution but does not directly detect load from them. This includes most vertical connections.

- The assessment criterion – the VSI and HSI – was shown to recognise the vehicle characteristics beneficial to compatibility identified from the car-to-car tests, specifically additional load paths and lower rail / crossbeam imbalance. However, the assessment criterion only indirectly detects connections with a length close to or less than the load cell spacing.
- The assessment tool and assessment criterion have also been shown to recognise differences in vehicle front structure width. However, further study is required to define the relevance of this observation in real world accidents
- Comparison of the results from two tests in which the vertical impact alignment difference of the car with the LCW was about 1mm showed the load cell wall force distribution measurement and the assessment criterion (VSI and HSI area 1) to be repeatable (This was based on the fact that the majority of peak cell loads were within 5kN, whilst the row and columns loads were within 10kN. Further tests are needed to identify the maximum vertical impact alignment tolerance permissible for test repeatability).

From the work done to validate the PDB test the following conclusions were made:

- Tests performed on this program help to validate the tool and measurements proposed by PDB test procedure. The obstacle, test speed and overlap chosen are able to reproduce front end loading and collapse mode observed in car to car tests.
- First and main goal of the PDB is also validated, energy absorption capability of the barrier face changed vehicle test severity. PDB introduction will allow harmonising vehicle front end force, an essential step before hoping solving incompatibility problems.
- As regard self protection, the combination of new obstacle, higher speed and overlap make this test severe for the light car without penalise heavy one.
- Regarding partner protection, tests performed show that sufficient information to assess it is contained in the barrier deformation. The PDB deformation is able to detect different front end design in terms of geometry and stiffness. Due to its accurate recording, this barrier will give good evaluation of structural interaction performance level. However, before proposing criteria based on this deformation, we will have to quantify with objective data what it is really needed, what is a good structure engagement, what is an aggressive car in other words: what is a compatible car etc...

Summary

The main characteristics that influence a car's compatibility potential, in particular its structural interaction, have been identified. The FWDB and PDB approaches have been developed further and initial validation has shown that they are both capable of distinguishing the beneficial characteristics that influence a car's compatibility. However, at the moment it is not possible to recommend a definite set of procedures because the FWDB and PDB approaches are so different that currently an adequate comparison cannot be made between them. To be able to make this comparison and the consequent choice, it is likely that both procedures will have to be developed further to a state where the performance criteria and initial proposals for performance limits are determined. At the moment, criteria have been proposed for the FWDB test but are still under development for the PDB test.

4.2.4 WP 4 Car to Car and Car to Barrier crash modelling

This work package provided modelling support to the improvement and initial validation of the crash test procedures and cost benefit analysis for car-to-car impact. The work consisted of: 1) the improvement and initial validation of the crash test procedures and assessment criteria by Finite Element Modelling; 2) vehicle fleet modelling studies to estimate the benefits of improved compatibility; 3) investigating the relationship between crash test results and real world crash behaviour as well as preliminary investigations of future vehicle structures in side impact

Modelling support for development and validation of crash test procedures

The work reported here relates to the numerical modelling work package (WP4). The objective of this work was to perform FE modelling studies to support the development of the Full Width Deformable Barrier (FWDB) and Progressive Deformable Barrier tests. This work was carried out by TRL and UTAC.

To support the development of the FWDB test a FE model of the deformable element and Load Cell Wall (LCW) was constructed and validated. This model was used to help investigate the sensitivity of the homogeneity assessment criterion to changes in the alignment of the car with the LCW at impact. To attempt to reduce this sensitivity, a methodology to use barrier deformation information to effectively increase the resolution of the high resolution LCW measuring device was developed and its feasibility assessed. To support the development of the PDB test a FE model of the PDB was constructed and validated.

From the work to support the development of the FWDB test the following conclusions were made:

- A FE model of the FWDB test deformable element and LCW has been constructed using the RADIOSS software. The model has been validated using data from a Mobile Rigid Barrier test. Further work to improve the model has been outlined.
- A parametric study to investigate the effect of impact alignment on the repeatability of the FWDB test showed that the assessment criterion values could vary by up to about 30 % for a car with poor compatibility, if impact alignment differences of the order of 60 mm were allowed between tests. A variation of 30 % is not acceptable for repeatability for a test procedure intended for regulatory application. Hence, changes to the test procedure to improve its repeatability are needed. Two approaches are recommended to investigate further, to increase LCW resolution and / or constrain impact alignment differences.
- A methodology based on a supplementary barrier deformation measure to effectively increase LCW resolution in the FWDB test procedure was developed. It was shown that this methodology could help reduce the sensitivity of the assessment criterion to impact alignment differences. However, since this work has been performed, in a number of FWDB tests it has been observed that parts of the deformable element have been removed by the car during the impact. This would make an accurate measure of the deformable element deformation impossible. On this basis, it is recommended that future work to improve the repeatability of the FWDB test procedure with relation to impact alignment should focus on an approach to reduce impact alignment differences between tests.

.From the work to support the development of the PDB test the following conclusions were made:

- A FE model of the PDB deformable element has been constructed using the PAMCRASH™ software. The model has been validated and shows a satisfactory global behaviour in three validation test cases with rigid impactors; namely, an “Offset” test, a cross member test and a “Crash Box” test.

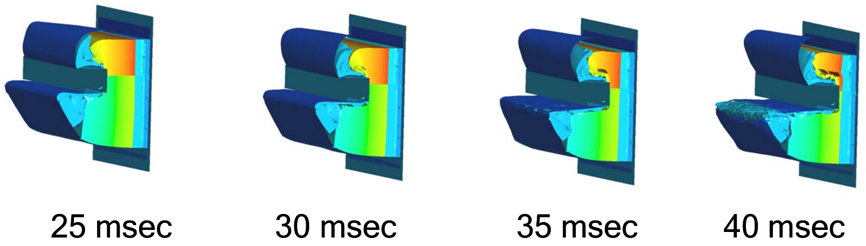

Figure 4-4 Barrier deformation over time of the PDB impacted with the rigid beam impactor

Both the FWDB and PDB FE models are available to other parties for use on future research projects.

Role of vehicle vehicle-vehicle and vehicle-barrier properties

The aim was to investigate the role of the vehicle in vehicle-vehicle and vehicle barrier crash scenarios.

Numerical fleet studies were performed using multi-body vehicle models. Currently nine vehicle models are available, each of a different vehicle class, two vehicle models with a modified front-structure. The aim is to develop strategies for evaluation of front-end structures minimizing the total harm in car-to-car crashes on a fleet-wide basis in different accident scenarios.

For these studies multi-body models were constructed from existing finite element models. Front-end structure and passenger cell were modelled in detail to provide realistic deformation modes. Furthermore dummies, airbags, belts and main interior parts like dashboard and steering wheel were included. To qualify the performance of the multi-body vehicle models for crashworthiness in an entire fleet, a study on offset frontal impacts was performed. Several parameter sweeps over relevant accident and design parameters were performed using the multi-body models. The accident parameters included vehicle type, vehicle speed and frontal overlap

Non-linear spring and damper elements representing the stiffness behaviour connect the rigid bodies. Comparison with test results shows that the models provide realistic crash and occupant behaviour. The models integrate vehicle and occupant models that were separated in previous fleet studies. The geometry is easily adjusted by adding structures (new bodies) and characteristics (joint properties). Although less accurate than finite element models the multi-body models require substantially less CPU time, making them suitable for the large amount of simulations required in fleet studies. In the fleet study, frontal offset impacts between the nine vehicles were considered. For the smaller vehicles design variants for improved compatibility were considered. Crashes between the vehicles are simulated varying the initial velocity and the overlap. Results were processed using a statistical analysis tool. Fleet study comparing results between the improved vehicles and the original models showed a significant reduction in injury values for the overall fleet. Injury levels in the smaller cars decreased significantly whereas injury values in the larger cars remained unchanged. Statistical analysis of the overall results revealed clear trends between static car properties (AHoF, PDB readings), dynamic car related readings (e.g. .v) and typical crash scenarios such as glance off and overrun. The simulation results were showed to be in-line with the (650) cases selected from the NASS-CDS database based on the HARM criterion, which gives confidence in the modelling method.

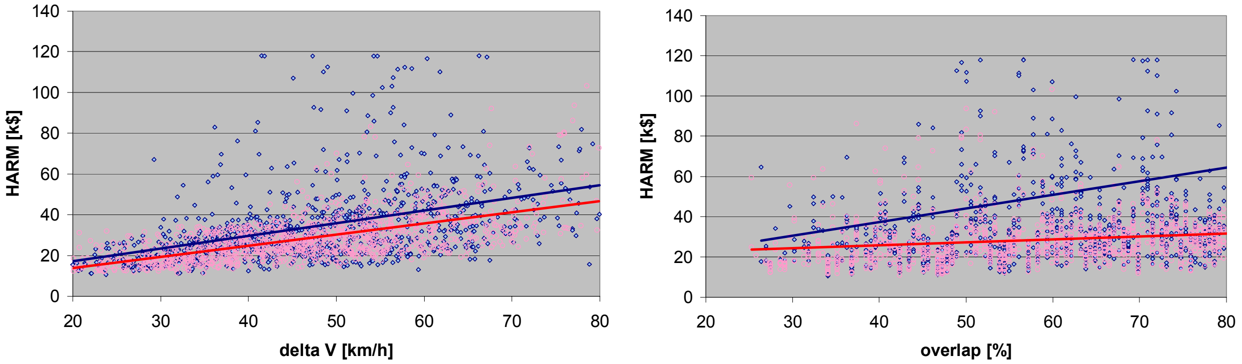

Figure 4-5 Simulation results in terms of HARM of the original (blue) and the modified fleet (red) over Δv (left) and the overlap (right)

A benefit of improved compatibility is shown by comparing a large range of crash scenarios in the original fleet and the same crash scenarios with the improved vehicle fleet (smallest passenger cars). The results showed a significant reduction in injury values for the overall fleet between the improved vehicles and the original models. Injury levels in the smaller cars decreased significantly, up to 35%, whereas injury values in the larger cars remained unchanged. Prevention of intruding elements as well as prevention of compartment collapse as a result of improved compatibility is seen as the major reason for the reduction in injury values.

Influence on real world performance and future vehicle designs

The primary goal was to investigate the influence of vehicle front structures on compatibility. Specifically, changes of the vehicle force levels (stiffness) and geometry were to be investigated. Computer models were used to perform analyses that were not possible within the VC-Compat test program. Specific goals were:

- Develop mathematical tools that can be used to investigate frontal stiffness levels for vehicles in car-to-car frontal impacts.
- Investigate frontal stiffness levels with consideration to stiffness compatibility and self-protection between vehicles of different masses.
- Investigate the effects of these stiffness levels in crash test procedures.
- To conduct an initial study of the influence of vehicle frontal designs to the injury risk of occupants in struck vehicles during side impact conditions.

The first study identified the consequences of different design strategies for vehicle frontal force levels. Work focused on how much the stiffness for smaller vehicles (under 1400 kg) must be increased to provide protection in impacts with heavier (1.6 times heavier) vehicles. The converse, how much longer and less stiff large vehicles must be to be compatible with lighter vehicles was also investigated in addition to a combination of measures for both vehicle classes.

Future vehicles should have stiffness properties that are designed with consideration to both self-protection and compatibility. The results show that there are difficulties in raising the frontal stiffness levels of smaller vehicles only. Frontal stiffness levels of larger vehicles should also be considered in a stiffness harmonization. Current crash tests do not promote a stiffness harmonization but rather enlarge the rift in stiffness levels. A mass-dependent crash test could help to enforce vehicles to harmonize their stiffness levels and thus introduce stiffness compatibility. This could be achieved by utilizing a mass-dependent test speed - a higher test speed for lighter vehicles and lower test speed for heavier vehicles. In this reasoning a reference target vehicle would be selected which would provide a reference kinetic. All vehicles would then be tested according to the reference kinetic energy. Important issues in this discussion are the mass of the target vehicle and the reference test speed. Figure 18 shows mass-dependent test speeds based on six target vehicles and a reference test speed based on the speed currently used in EuroNCAP. The dashed line represents the reference test speed and the grey area represents the mass ratio of 1.6. It should be noted that the results shown in Figure 4-6 are based on the assumption that the vehicles absorb all the kinetic energy. This is not true in crash tests with deformable barriers. The exact numbers in Figure 4-6 cannot therefore be used directly; only the concept can be used. However, it may be difficult to gain the general acceptance of car buyers for a crash test procedure that has a higher test speed for smaller vehicles than for heavier ones. It may seem to the general public as though smaller vehicles would be able to over-crush larger vehicles.

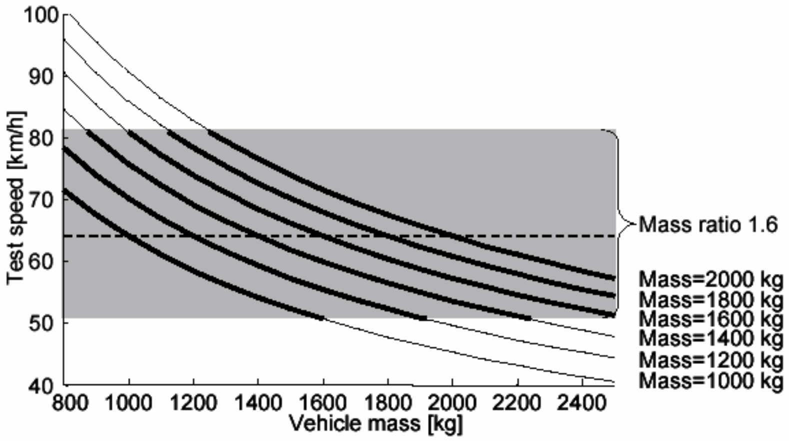

Figure 4-6 Relation between vehicle mass and test speed plotted over the range of mass ratios

Incorporating an MDB (moving deformable barrier) in crash test procedures could also help enforce harmonized stiffness levels. Such crash tests would expose vehicles to a change of velocity that is dependent on the vehicle mass. Smaller vehicles would experience a higher change of velocity than larger ones. Smaller vehicles would thereby be enforced to raise frontal stiffness. Larger vehicles would then also be encouraged to lower frontal stiffness. The consequence would be that frontal stiffness levels would be harmonized when vehicles are designed for a MDB crash test procedure. Although this reasoning concerning mass-dependent crash test procedures would lead to harmonized stiffness levels and better stiffness compatibility, it must be noted that it may also lead to a decrease in self-protection in heavier vehicles. The self-protection of larger vehicles was not included in the scope of this task, however, and was thus not included in the studies. Nevertheless, Kuchar (2001) found that decreasing the frontal stiffness of larger vehicles would have greater benefits in terms of compatibility than the drawback of poorer self-protection in these vehicles.

The levels of impact forces that should be used to ensure that smaller vehicles are not over-crushed in impacts with larger vehicles was also investigated. Based on the frontal force levels that could provide survivable impacts for both vehicles, a minimum frontal force level of 350-400 kN should be considered. However it should be noted that a single reference value is not truly sufficient to ensure compatibility and some sort of stiffness corridor would be more relevant for matching force levels. Practical issues for implementing measurement and control of vehicle frontal force levels still requires discussion with the automotive industry.

The results clearly show that smaller vehicles must become stiffer and that moderate changes to heavy vehicles can provide better compatibility when there are mass differences between the vehicles. The small car can be made to provide survivable conditions for occupants when the vehicle impacts a heavier (1.6 times heavier) vehicle. The results also suggest that 350 – 400 kN is a force level requirement to ensure this performance.

The final study was an investigation of the side impact performance of the bullet vehicle, based on the injury risk for the target vehicle. A parameter study using the side impact barrier was developed to investigate the influence of local stiffness distributions in the bullet vehicle front. The Average Height of Door Force (ADoHF) was found to be a useful predictor for the compatibility of vehicle fronts when impacting the door of a target vehicle.

In the side impact study the force distribution study showed a significant influence on the dummy loading. The horizontal force distribution variation resulted in large changes in dummy loading. The horizontal distribution variation study reflects the importance of utilising the energy absorption capacity of the structural side members. The horizontal force distribution with respect to the dummy position greatly determines the amount of door loading, this resulting in the loading of the dummy. A better energy absorption by the A- and B-pillar results in a lower loading of the door. The vertical force distribution variation study showed a similar relation between AHoDF and dummy loading as between the ride height variation and dummy loading. The relation between the AHoDF and the energy absorption, resulting in a decrease of total dummy loading with a decrease of AHoDF, is straightforward. The AHoDF is a suitable measurable for the vertical force distribution, because the AHoDF reflects the actual contact force on the door.

4.2.5 WP 5 Synthesis of test procedures and performance criteria for car to car impact

The main objectives of this WP were:

- To determine the strategy for the development of the procedures
- To write the draft test procedures
- To develop a framework for a car crash compatibility rating system
- To provide recommendations for the design of a compatible car.

The main results and conclusions of the work performed to achieve each of these objectives are described below.

Strategy

The strategy determined for the development of a set of test procedures to assess a car's frontal impact protection, including its compatibility potential, is summarised below:

- Integrated set of test procedures to assess a car's frontal impact protection
    - Address partner and self protection without decreasing current self protection levels
    - Minimum number of procedures

  - Internationally harmonised procedures
- Both full width and offset tests required
  - Full width test to provide high deceleration pulse to assess the occupant's deceleration and restraint system
  - Offset test to load one side of car for compartment integrity
- Procedures designed so that compatibility can implemented in a stepwise manner

Test Procedures

The project has focused on the development and evaluation of two approaches for assessing compatibility, the Full Width Deformable Barrier (FWDB) approach and the Progressive Deformable Barrier (PDB) approach. Although good progress has been made, the work is not sufficiently advanced to recommend one definite set of test procedures to assess compatibility because the FWDB and PDB approaches are so different that an adequate comparison cannot be made between them until they are developed further. To be able to make this comparison and the consequent choice, it is likely that both procedures will have to be developed to a state where the performance criteria and initial proposals for performance limits are determined. At the moment, criteria have been proposed for the FWDB test but are still under development for the PDB test.

To assess a car's compatibility potential its structural interaction potential, frontal force levels and compartment integrity have to be measured. A set of test procedures to assess a car's compatibility and frontal impact performance could be based on the FWDB approach, the PDB approach or a combination of both.

<u>Set 1 – FWDB approach</u>

- Full Width Deformable Barrier (FWDB) test
  - Structural interaction
  - High deceleration pulse to check restraint system performance
- ODB test with EEVC barrier
  - Frontal force levels
  - Compartment integrity

<u>Set 2 – PDB approach</u>

- Full Width Rigid Barrier (FWRB) test
  - High deceleration pulse to check restraint system performance
- • Progressive Deformable Barrier (PDB) test
  - Structural interaction
  - Frontal force matching
  - Compartment integrity

<u>Set 3</u>

- Combination of FWDB and PDB

The two candidate approaches fulfil the strategy aims in quite different ways which makes it very difficult to compare them. However, in spite of this, some of the fundamental differences between the approaches are discussed below:

- The FWDB approach uses mainly LCW force measurements whereas the PDB uses mainly barrier deformation measurements. LCW force measurements are recorded throughout the impact whereas barrier deformation measurements only reflect the vehicle deformation at the end of crash. Thus the FWDB approach thus has the potential to make time based assessments whereas the PDB does not. However, a time based assessment is not used today and may not be necessary.
- The PDB test produces more longitudinal deformation of the vehicle than the FWDB test because it is an offset test whereas the FWDB test is a full overlap test. Hence in principle, the PDB test can detect structures further back from the front of the vehicle than the FWDB test. It is not yet known if structures beyond the detection limit of the FWDB test (~ 400 mm) are necessary and thus this requires further investigation.

- The PDB approach aims to harmonise the test severity for the offset test by changing the current R94 barrier, whereas the FWDB approach does not. To help achieve this objective the PDB barrier has a higher energy absorption potential than the current R94 barrier. In principle, it may be possible, that vehicles could be designed to take advantage of this higher energy absorption potential which could lead to a reduction in the test severity. This issue was discussed extensively by industry participants in the final VC-COMPAT workshop, and no conclusion was reached. This issue is also under discussion in EEVC WG15 as an area for further investigation.
- Vehicles do not tend to bottom out the PDB barrier face, whereas many vehicles do bottom out the barrier in the FWDB test. Because of this, the vehicle loading in the PDB test more closely matches that seen in vehicle-to-vehicle accidents compared to the FWDB test. While in principle it is desirable to load the vehicle in a similar way as in an accident, it may not be a necessary requirement for regulation/consumer testing. It is important that a compatibility test procedure enforces compatible vehicle designs in future vehicles that will work in the full range of real world impacts.

All of the points listed above are issues that must be resolved in the further development of the FWDB and PDB test procedures so that their performance can be evaluated and a suitable testing approach selected. Recommendations for the work required to do this and reach the position to make a proposal for a 1st step to improve compatibility are given in the ‘Conclusions and Recommendations’ section.

For both approaches route maps to introduce the procedures in a stepwise manner have been developed. The route map for implementing the FWDB approach consists of the following steps:

- Step 0 – Use LCW to measure force levels in ODB test to monitor compatibility problem.
- Step 1 – Introduce FWDB test to improve self protection and structural interaction
- Step 2 – Improve frontal force matching by controlling force levels in ODB test or introduction of PDB test.

The route map for implementing the PDB approach consists of the following steps:

- Step 1 – Introduce PDB test to harmonise test severity and FWRB test to improve self protection.
- Step 2 – Improve partner protection by controlling barrier deformation criteria in PDB test.
- Long term step – Introduce mobile PDB test

Framework for Rating System

Currently, the assessment criteria for the test procedures are not sufficiently developed to be able to propose a framework for a rating system, so some guidelines to what will be needed from a rating system are given below:

- Performance criteria need to be continuous.
- Ideally, performance criteria and associated performance limits should be directly related to those used in regulation.
- To be able to encourage improvement, performance criteria should be able to distinguish between different types of aggressive vehicles and not just classify them all as aggressive. A mass independent measure would help this.

Also it should be noted that consumer testing offers a great opportunity to collect data for research and monitoring purposes.

Recommendations for Design of Compatible Car

The results of the testing and simulation activities in the VC-Compat project have provided consistent results that support the initial hypotheses for improving compatibility: compatibility requires structural interaction, matched force levels, and good compartment strength. The general design guidelines for improving vehicle compatibility in frontal impacts are:

- Improved vertical load spreading capability (Can be achieved with additional load paths)
- Strong vertical connections between load paths
- Strong lateral connections able to distribute rail loads
- Adequate compartment strength and frontal force levels, especially for light cars

Summary

A strategy to develop a set of test procedures to assess a car's frontal impact performance, including its compatibility, has been formulated. Following this strategy, the FWDB and PDB approaches have been developed further and their initial validation has shown that they are both capable of distinguishing the main characteristics that influence a car's compatibility. However, at the moment it is not possible to choose a definite set of procedures because the FWDB and PDB approaches are so different that an adequate comparison cannot be made between them until they are developed further. To be able to make this comparison and the consequent choice, it is likely that both procedures will have to be developed to a state where the performance criteria and initial proposals for performance limits are determined. Guidelines for a rating system have been outlined. General recommendations for the design of a compatible car based on the work performed in this project have been given. The additional work needed to reach the position to make a proposal for a 1st step to improve compatibility is outlined in the 'Conclusions and Recommendations' section of this report.

4.2.6 WP 6 Injury mechanisms and underrun protection with Car to Truck impact.

Objective

The objective of this work package is to determine a relationship between injuries to the occupants of the colliding pasenger cars and the performance of underride protective structures on the front end of a truck and the rear end of truck or trailer through full scale testing.

For the front of the truck this means:
Show that the FUP prevents underride, that the FUP improves the compatibility (structural interaction) with the passenger car and show the (positive) effect of energy absorption by the FUP, related to injury of car occupants, with respect to the present obligatory devices.

For the rear of the truck or trailer this means:
Show the effect of more adequate rear underrun protective devices (RUP) with respect to the present obligatory devices.

Methodology

Front underrun protection was investigated by evaluation of existing test results, by carrying out additional tests and by carrying out numerical simulations to investigate the influence of parameters, which could not be varied in the tests (WP7). Rear underrun protection was investigated by literature survey and by carrying out numerical simulations to investigate the influence of additional parameters being of influence on the performance of the RUP (WP7). Both parts result in information and advice to be used in Work Package 8.

Results

A series of 7 tests have been carried out according to a pre-defined and fixed test protocol.
In Table 4-8 the specifications of all 7 tests have been summarized. The details of the individual tests including the results can be found in separate reports and in the summary of the tests in D11.

Table 4-8 Test specifications

Test #	Car	Mass (kg)	Speed (km/h)	Truck	Mass (kg)	FUP
1	Supermini	1093	64	Volvo FH12	11900	Standard e.a.
2	Supermini	1091	75	Volvo FH12	11900	Standard e.a.
3	Supermini	1093	56	Scania R124	11800	Standard statutory 'rigid'
4	Supermini	1087	64	Scania R124	12300	Standard statutory 'rigid'
5	Small family	1440	64	Volvo FH12	11900	Standard e.a.
6	Small family	1434	75	Volvo FH12	11925	Special designed e.a.
7	Small family	1419	75	Volvo FH12	12110	Special designed rigid

In test #1 through test #4 the standard FUP devices on both trucks were used. The Volvo is fixed with a standard energy absorbing device and the Scania is fixed with a standard rigid device. Both trucks are shown in Figures 1 and 2.

Figure 4-7 Details of standard e.a.FUP.

Figure 4-8 Details of standard rigid FUP.

The tests with the supermini car (test #1 through test #4) did show that the FUP prevented the car from underrunning the truck. The tests also showed poor structural interaction between the car's front structure and the FUPs of both trucks, resulting in instability of the front structure of the car during the collision. The tests did not significantly show the benefit of an energy absorbing front underrun protection system, probably due to the fact that the system was not sufficiently activated.

In order to improve the structural interaction between passenger car and truck a different passenger car (i.e. a small family car) was chosen in the next tests. Test #5 showed that the structural interaction indeed was improved: there was a stable load transfer to the FUP system and there was still no underride. However, the energy absorption capability of the FUP was not sufficiently activated, resulting in very low energy absorption by the FUP.

In test #6 a special design energy absorbing FUP was installed, using the standard Volvo FUP beam. Details are shown in Figure 3. Energy absorption was realised by means of aluminium foam blocks (silver) installed in between the FUP beam (blue) and the support brackets (orange). The distance over which the FUP was able to move backward was increased by replacing the pivot points (top of red brackets/arms) of the FUP beam.

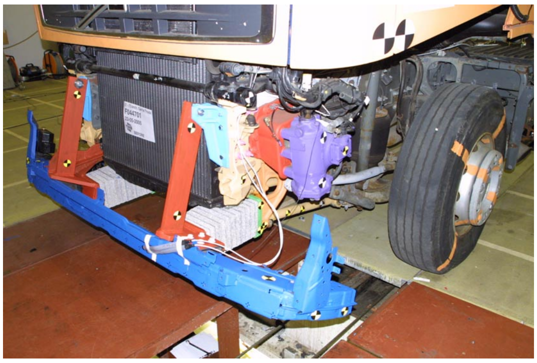

Figure 4-9 Details of special design e.a.FUP

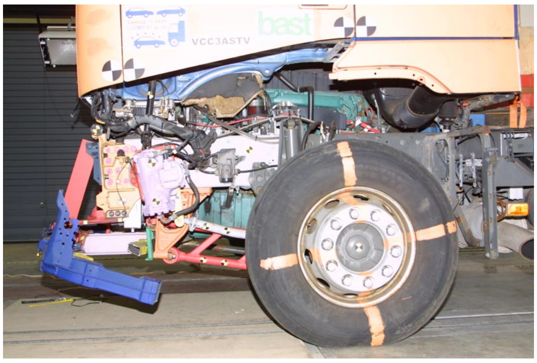

Figure 4-10 Details of special design rigid FUP

In test #7 a special design rigid FUP was installed, using the same structure as in test #6. Details are shown in Figure 4. However, in test #7 the energy absorbing capability was nullified by replacing the aluminium foam blocks in test #6 by very stiff supporting beams (pink).

Figure 4-11 shows the deformed front structure of the cars in top view. Detailed analysis learned that at bumper level the deformation near the engine of the car in test #6 (75 km/h, with e.a.FUP) was considerably less than in test #5 and test #7. On upper rail level the maximum deformation occured in test #6 due to the rigid contact with the FUP bracket. No significant compartment intrusion occurred in any of the 7 tests.

a. Test #5: 64 km/h, standard e.a.FUP b. Test #6: 75 km/h, special e.a. FUP c. Test #7: 75 km/h, special rigid

Figure 4-11 Deformed front structures of passenger cars in test #5, test #6 and test #7.

Table 4-9 summarizes the energy management in the tests. Car mass, car speed and truck mass are the measured input values. Values of the truck speed have been estimated from the integrated truck acceleration signals. The total energy and the energy in the truck were calculated with $1/2mv^2$. The FUP deformation energy was assumed to be zero in all cases except in test #6, where the energy was estimated from the deformation of the aluminium foam. The energy absorbed by the car was the total energy minus the energy by the truck and the FUP. The work was calculated using a deformation estimated from the double integration of the average car deceleration (i.e. the total deformation=car+FUP).

Table 4-9 Results of energy management analysis

		Car		Truck							
Test		Mass	Speed	Mass	Speed	E total	E truck	E FUP	E car	E car	Work
#	Collision type	kg	kph	kg	m/s	kJ	kJ	kJ	kJ	%	kNm
1	supermini/standard e.a.FUP	1093	64.3	11900	1.7	174	17	0	157	90	158
2	supermini/standard e.a.FUP	1091	75.5	11900	2.0	240	24	0	216	90	216
3	supermini/standard rigid FUP	1093	56.1	11800	1.5	133	13	0	119	90	118
4	supermini/standard rigid FUP	1087	64.2	12300	1.5	173	14	0	159	92	154
5	small family/standard e.a.FUP	1440	63.8	11900	2.0	226	24	0	202	89	225
6	small family/design e.a.FUP	1434	74.7	11925	2.4	309	34	50	224	73	272
7	small family/design rigid FUP	1419	75.0	12110	2.5	308	38	0	270	88	268

The following can be concluded.

- The assumption that the FUP did not absorb much energy was true for test #1 through test #4, because the value of Ecar and Work were approximately the same.
- The absorbed energy by the FUP in test #5 was approx. 23 kJ (=Work-E_{car}), which was 10% of the total energy.
- The absorbed energy by the FUP in test #6 was approx. 48 kJ (=Work-E_{car}), which was also estimated from the foam deformation.
- The FUP in test #7 appeared to be very rigid (Work$\cong$ E_{car}).
- In test #6 the FUP absorbed approx. 16% of the total energy.
- In test #7 the car absorbed approx. 15% more energy than in test #6.

The main dummy readings and injury values have been summarized in Table 4-10.

Table 4-10 Injury levels for different body regions

		Test #1	**Test #2**	**Test #3**	**Test #4**	**Test #5**	**Test #6**	**Test #7**
Truck	Type	Volvo FH12	Volvo FH12	Scania R124	Scania R124	Volvo FH12	Volvo FH12	Volvo FH12
	FUP	Standard e.a.	Standard e.a.	Standard rigid	Standard rigid	Standard e.a.	Special design e.a.	Special design rigid
Car	Type	supermini	supermini	supermini	supermini	small family	small family	small family
	Speed (km/h)	64	75	56	64	64	75	75
Belt	Shldr frc (kN)	4.6	4.7	4.6	5.0	4.5	4.6	5.3
	Lap force (kN)	10.6	10.0	10.6	10.6	8.5	10.0	11.0
Head	HIC	1082	2054	742	930	360	587	665
Neck	My (Nm)	47	49	22	21	27	20	11
Chest	Acc 3ms (g)	450	770	780	900	430	460	530
	Compression	38	38	32	26	36	31	41
	VC (m/s)	0.24	0.32	0.18	0.13	0.23	0.15	0.31
Pelvis	Acc 3 ms (g)	660	780	550	500	570	640	740

The following can be concluded.

- In all cars the belts are supplied with load limiters which have approx. the same limits.
- The small family car produces the lowest HIC values and neck bending moments.
- The chest injury values in test #1 through #4 do not show much regularity. This might be explained by ‘arbitrary’ airbag deployment. The values in test #5 through test #7 do fulfil the expectations. The test with the energy absorbing FUP (test #6) in general results in lower values than test #5 and test #7.
- The pelvis 3ms accelerations follow more or less the impact severity.

A commonly used value for indicating the severity for the occupants of an impacting vehicle is the ASI value. The ASI values for all 7 tests are shown in table 3. It shows that the small family car is the 'safer' car in these accidents and that a properly addressed e.a.FUP (compare test #6 and test #7) reduces the severity.

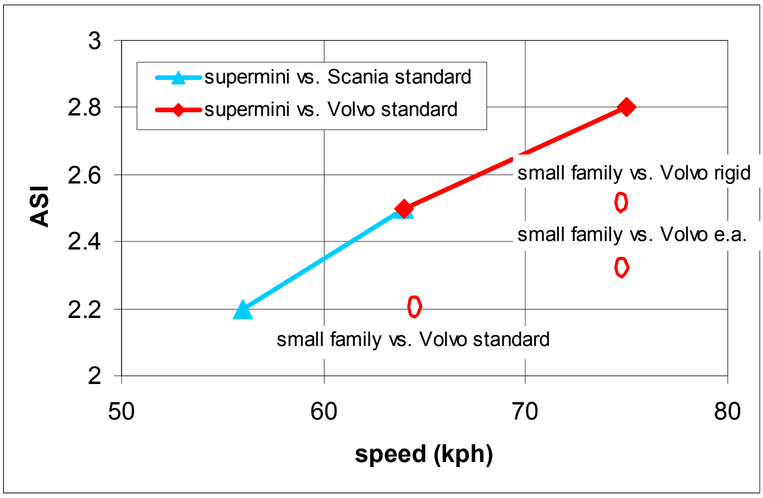

Figure 4-12 ASI values of the Supermini to Truck equipped with standard FUP

Conclusions

No underrun occurred in any of the 7 tests.

Structural interaction was not adequate in all tests. The supermini car showed an unstable (single) loadpath; the small family car showed a stable (multiple) loadpath.

Energy absorption by the FUP reduced the peak deceleration values of the colliding passenger car.

Comparing the results of test #6 and test #7 it can be concluded that energy absorption by the truck is beneficial since it results in reduced injuries.

The amount of energy absorption by the truck is limited. This is related to the deformation distance provided by the truck before passenger compartment intrusion occurs. Another important parameter which determines the amount of energy absorption is the force which is stably and (during some time) continuously generated by the car during the collision. An estimated value for the deformation distance is 300 – 400 mm. The force which can be generated by the car is estimated at 200 – 300 kN (in offset situation).

The amount of energy absorbed by the truck will probably always be smaller than the energy absorbed by the car. At higher relative speeds this difference will even be more distinct. However, energy absorption by the truck will result in injury reduction to some extend and reduce vehicle deformation.

The test results show that a 75 km/h, 72% overlap head-on collision can be handled by a passenger car similar to the small family car used here without dramatic injuries to the car driver.

Although demonstrated qualitatively, a direct relationship between energy absorption, accident severity and injury reduction can not (yet) be formulated or mathematically expressed.

Recommendations

The conclusions are based upon a successful series of tests with one type of passenger car running into a truck which was fitted with a special design energy absorbing FUP. To support the above conclusions it is recommended that the effect of energy absorption should be investigated in combination with other types/sizes of colliding passenger cars.

Although the benefit of energy absorption by the FUP was not unambiguously proved with the present investigation, continuation of the project into developing test/evaluation procedures for e.a. FUPs was requested by the EC project officer.

It is recommended that further work should be considered in order to investigate methods by which greater levels of energy absorption capability could be built into the front of a truck in order to provide larger clearer benefits in terms of dummy injury measurements.

4.2.7 WP 7 Mathematical Modelling of Car to Truck crash tests

Objective

The objective of this work package was to support the actual testing in WP6 and to evaluate parameters not involved in testing.

Regarding front underrun protection, to evaluate parameters such as vehicle type and mass, vehicle speed and on the truck side the rigid components in the front structure.

Regarding the rear underrun protection, to evaluate parameters such as impact speed, RUP ground clearance, cross-member height and RUP position underneath the trailer, related to occupant injury.

To establish a reference baseline to evaluate future (simplified) test procedures where no passenger cars and dummies are used for the direct relationship between injury and the performance of underrun protection on trucks regarding prevention for underride, offering structural interaction and absorption of energy during a crash.

Methodology

Numerical simulations were used to evaluate the influence of parameters which could not be included in the limited number of crash tests. For these simulations a ‘vehicle fleet’ was developed with different types of passenger cars with different masses, see figure Figure 4-13.

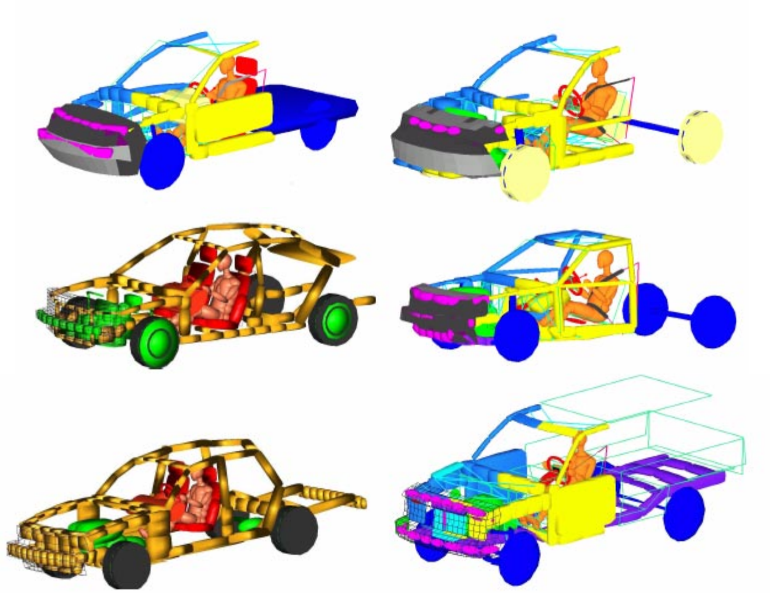

Figure 4-13 Numerical (multibody) vehicle models in various sizes, masses and classes

Parameters varied were:

- vehicle size
- vehicle mass
- vehicle speed
- impact angle
- offset

All models were supplied with a Hybrid III driver dummy model, safety belts and airbag so that the impact severity could be evaluated.

A generic truck model has been created which can be used for front underrun simulations as well as for rear underrun simulations. The truck front includes the usual 'rigid' components which may influence the performance of the FUP regarding energy absorption, such as chassis beams, cabin brackets, cooler support components, towing brackets and steering module, see figure 2. The truck rear end includes a model of a RUP, adaptable for parameter variations such as ground clearance, cross-member height, cross-member location. Simulations have been carried out with model setups shown in figure 3. It should be noted that the multi-body models developed were not considered to simulate passenger cell intrusion accurately, and thus can only be used to derive relationships to injuries caused principally be acceleration.

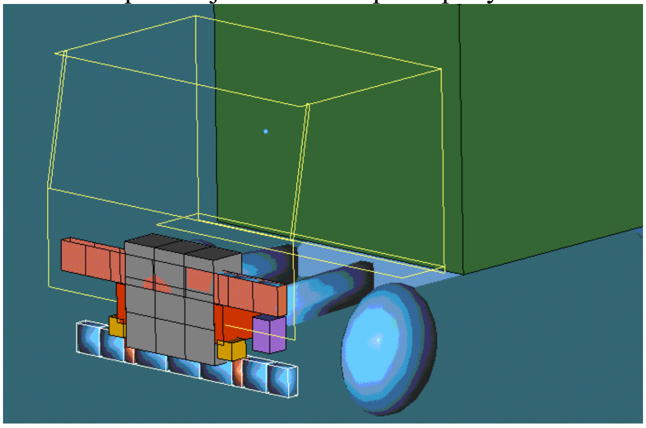

Figure 4-14 Figure 2: Model of truck front structure including FUP and rigid components

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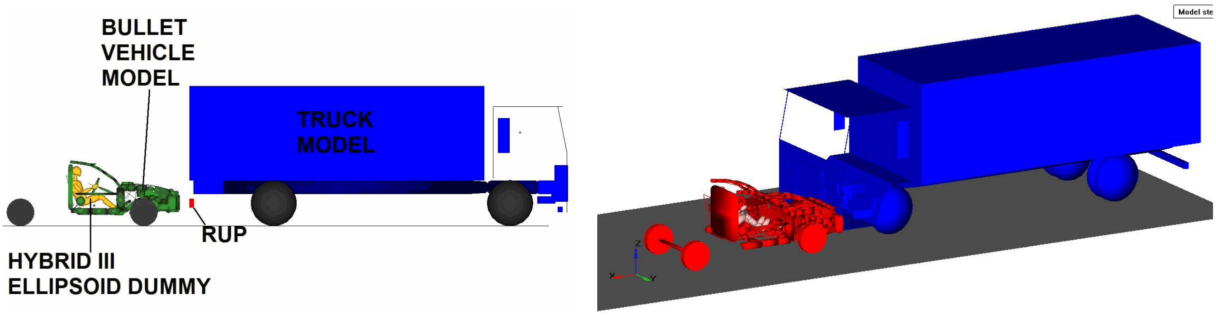

Figure 4-15 Models te evaluate car-to-truck frontal and rear end collisions

Results

Evaluation of FUP device

A large number of simulations have been carried out using two types of FUP devices, one rigid (legal) FUP (to compare with present status of vehicles on the road) and one energy absorbing FUP, where the effectiveness of the e.a. FUP was varied by including and deleting obstructing rigid components near the FUP. The results of these simulations are compared with respect to initial velocity and overlap. The comparison is also performed in terms of the expected HARM, which is an injury and cost related parameter.

The simulations predict a lower average HARM for the energy absorbing FUP for all velocity ranges and overlap ranges compared to the rigid FUP.
The simulations also showed a direct and explicit relationship between ASI and HARM, which implies a relationship between vehicle criteria and occupant injury. This is supported by the results of the tests in WP6. However, because the simulations do not accurately represent situations where extensive passenger cell intrusion occurs, the relationship can only be considered valid in collisions without excessive intrusion.
The simulations confirm what was shown in WP6 by testing, that energy absorption by the truck results in a lower and longer deceleration pulse of the passenger car.

Evaluation of RUP device

The results of the computer simulations clearly predicted that a RUP that was minimally compliant to the stiffness requirements of Directive 79/490/EEC failed in preventing underrun when in collision with a modern car travelling at 56 km/h (Figure 4-16). This clearly suggests that the structural stiffness required by the Directive needs to be increased in order to prevent underrun.

When the simulated RUP was minimally compliant to the ground clearance requirements of Directive 79/490/EEC (550mm) but was sufficiently stiff, the results clearly showed that the device failed in maximising the cars self protection capability. Although preventing full underrun, effectively the front of the car was bending upwards and some limited underride was occurring.

When the RUP was sufficiently stiff and the ground clearances were very low (300mm) the RUP also failed to offer good structural interaction, this time because the stiff longitudinals were passing over the cross-member of the RUP. Full underrun was still prevented but the front of the car was bent downwards and there was a limited amount of override.

RUPs with a larger cross-member (200mm tall instead of 100mm) and sufficiently stiff were found to reduce the sensitivity of the results to variations in ground clearance and increase the deceleration of the vehicle, demonstrating improved structural interaction. Despite the increased deceleration, the predicted deceleration injuries remained within acceptable limits.

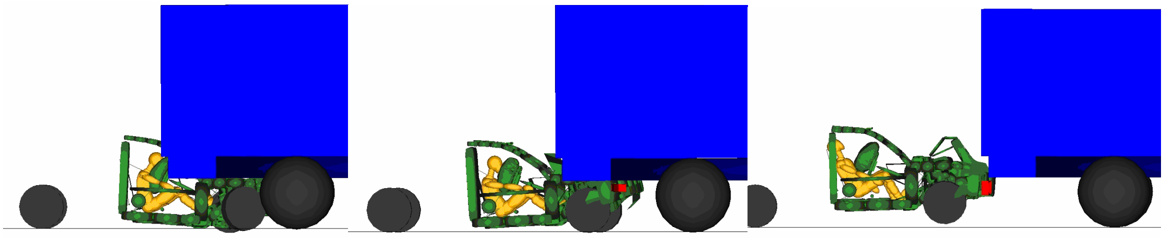

Figure 4-16 (left): current legislation without any interaction with the chassis; b (middle): current legislation with structural interaction between car and trailer chassis; c (right): improved RUP strength and larger cross-member supplies improved structural interaction

Conclusions

Numerical studies show that reduced complexity models can be used to assess modifications in front and rear underrun protection systems for heavy duty vehicles.

The numerical simulations show that energy absorption by the FUP will reduce injury, measured in HARM, compared to the present 'rigid' FUPs. The benefit of e.a.FUPS was seen over the entire range of crash configurations.

The average benefit based on injury reduction was 15% for all crash configurations.

Numerical simulations show a sharp relationship between HARM and ASI. In a dynamic test procedure the use of ASI can be considered as one parameter to assess front underrun protection systems without the use of a dummy. However, this could only be used in combination with a measure that ensured that excessive underrun did not occur in order that the test procedure does not allow a situation that would result in low acceleration but high levels of passenger cell intrusion.

Simulations show that energy absorption by the FUP (by allowing the FUP to displace) improves when rigid parts like the steering unit and towing hooks are not interacting during a collision.

- From simulations an improved RUP device was defined with increased cross-beam height, decreased ground clearance and increased strength. The literature reviewed in WP6 and the simulation suggested that the following tests loads would be appropriate to be applied in an adapted regulation:
    - P1 110kN
    - P2 180kN
    - P3 150kN
- The ground clearance should be less than 400 mm for adequate interaction with the colliding vehicle.
- The RUP beam height should be at least 200 mm for adequate structural interaction with the passenger car fleet.
- The work also suggested that, although not ideal, simply replicating the requirements for front underrun protection within the rear underrun Directive would provide a substantial improvement over the current requirements.

Recommendations

Interacting rigid parts should be taken into account in both dynamic and static tests.

Based on the relationship between ASI (vehicle parameter) and HARM (injury parameter) a future test procedure could be developed without the use of a dummy. However, more understanding of the relationship between these parameters is desirable.

The size and shape of rigid components interacting with the colliding passenger car may have an influence on the energy absorbing capability of the FUP. This requires more investigation.

The requirements developed for an improved RUP device should be investigated by testing as part of WP8 and WP9.

4.2.8 WP 8 Determination of methodology to evaluate front and rear underrun protection without using a car

Objective

The main objective of work package 8 is the determination of a methodology for the evaluation of front and rear underrun protection without using a complete passenger car and a complete truck/trailer.

Related to this:

- To replace the passenger car as bullet device by an alternative and representative loading device, quasi-static or dynamic, rigid or deformable.
- To investigate if the complete truck/trailer can be replaced by just the front or rear structure or even the underrun protection system only.
- To investigate the applicability and feasibility of these ‘simplifications’ using a number of tests and simulations.
- To assess the results and compare them with the results of the full scale tests.
- To investigate what the requirements of an improved RUP device should be and how it should perform regarding improved structural interaction and improved strength (actually this activity was moved forward from WG9).

Methodology

Front underrun protection

A passenger car can be replaced by a deformable or a rigid bullet device, both quasi-static or mobile (dynamic). A quasi-static or moving PDB are options to replace the passenger car in car-to-truck frontal tests. In contrast, a rigid pusher or rigid moving barrier may also be considered for this purpose. The full truck can act as target device or may be replaced by just the (energy absorbing) isolated FUP system, installed on a rigid support.

The schedule in Figure 4-17 shows the tests which have been carried out in order to evaluate the applicability of a simplified test method for assessing the front underrun protection.

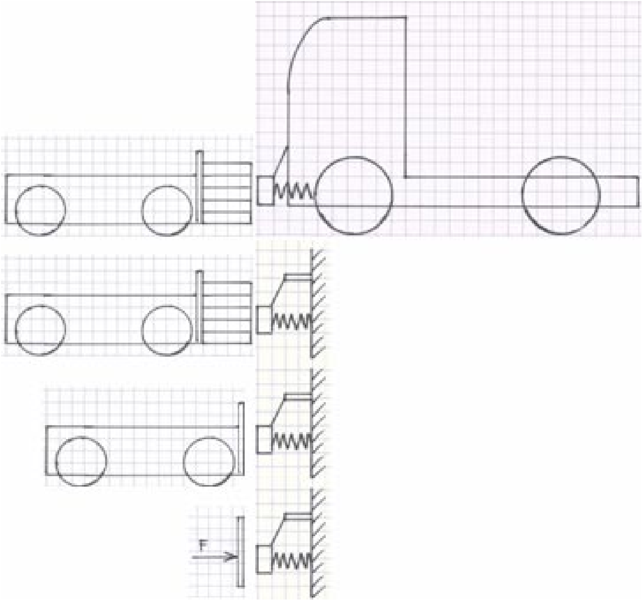

Figure 4-17 Overview of 'simplified' tests for evaluation of test procedures.

The schedule of Figure 4-17 results in tests detailed as follows:

Dynamic tests:

1. MPDB against full truck with eaFUP
2. MPDB against full truck with rigid FUP
3. MPDB against isolated eaFUP
4. MPDB against isolated rigid FUP
5. Rigid impactor against isolated eaFUP

Static tests:

6. Rigid pusher against isolated eaFUP
7. Rigid pusher against isolated rigid FUP

The approach of this test schedule was to progress from a full crash test to a simplified test procedure, keeping the link between each step.

Rear underrun protection

A prototype RUP device having improved strength and structural interaction capability was designed, constructed and quasi-statically tested and assessed (actually done as part of WP9).

Results

The results are summarized in Table 4-11. For comparison purposes two full scale tests carried out in work package 6 have been added as test #a and #b. The data in the table have been processed based on an extensive analysis showing that the energy calculated from the PDB deformation was not correct. Figures in blue are accurate data, measured and/or processed. Figures in red are derived figures based upon the above mentioned analysis. Figures in green are data determined from measurements. The black figures are calculated using all data.

Table 4-11 Results after 'corrective measures' for the tests carried out in WP 8.3

	Dynamic tests							Quasi-static tests	
	F044701	VCC3ASTV	VCC4MBTV	VCC5MBTV	VCC6MBTV	VCC7MBTV	15SD01	WP8QST01	WP8QST02
	#a Astra vs. truck with eaFUP	#b Astra vs. truck with rigid FUP	#1 MPDB vs. truck with eaFUP	#2 MPDB vs. truck with rigid FUP	#3 MPDB vs. eaFUP	#4 MPDB vs. rigid FUP	#5 rigid trolley vs. eaFUP	#6 rigid pusher vs. eaFUP	#7 rigid pusher vs. rigid FUP
Mass bullet	1434	1419	1030	1030	1030	1030	1030	n.a.	n.a.
Mass target	11925	12110	11880	11880	n.a.	n.a.	n.a.	n.a.	n.a.
Impact speed	74.7	75	56.2	56.6	55.9	55.9	42.6	n.a.	n.a.
Rest speed bullet	0.5	1	-0.7	1.2	-1.8	-1.8	-2.25	n.a.	n.a.
Rest speed target	2.4	2.5	1.6	1.2	n.a.	n.a.	n.a.	n.a.	n.a.
Peak acceleration bullet	39	46	39	42	33	44	54	n.a.	n.a.
ASI	2.3	2.5	2.35	2.48	2.4	2.7		n.a.	n.a.
Initial energy	309	308	125.5	127.3	124.2	124.2	70.6	16	4.6
Car/PDB	215.8	260.3	70.4	103.1	79.5	113.5	n.a.	n.a.	n.a.
Foam deformation	50	n.a.	29	n.a.	34	n.a.	48	15	n.a.
FUP beam deformation	9	9	9	9	9	9	20	1	4.6
Rebound bullet	0.2	0.7	0.3	0.7	1.7	1.7	2.6	n.a.	n.a.
Rebound target	34	38	16.8	14.5	n.a.	n.a.	n.a.	n.a.	n.a.

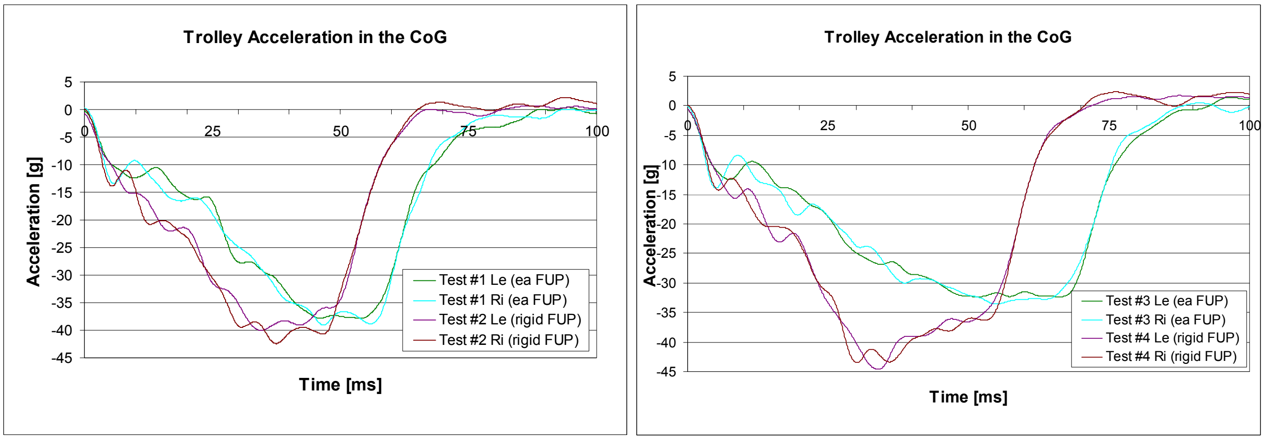

Figure 4-18 Trolley deceleration test #1 through #4; lower peak and longer duration when using e.a.FUP

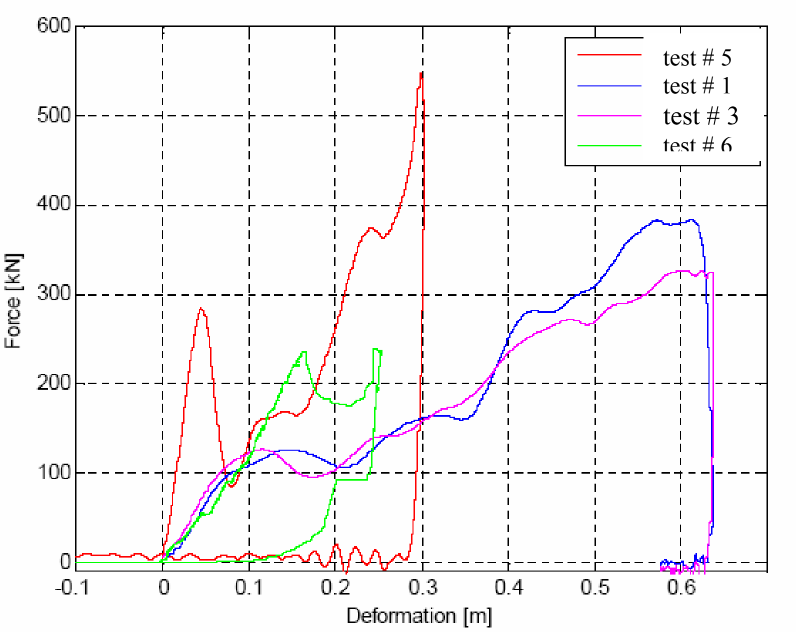

Figure 4-19 Force/deformation curves resulting from tests with eaFUP

From Table 4-11, Figure 4-18 and Figure 4-19 the following can be concluded.

- by comparing tests with a rigid FUP and an e.a.FUP, the use of an e.a.FUP results in lower peak accelerations and longer duration of the crash pulse in all cases.
- by comparing tests with a rigid FUP and an e.a.FUP, the use of an e.a.FUP results in lower ASI values in all cases.
- a rigid FUP results in more energy absorption by the opponent
- the infuence of rigid components near the e.a.FUP can be determined (Figure 4-18, compare left and right characteristics and Figure 4-19, compare test #1 and test #3)
- use of a rigid sled and a rigid pusher results in less detailed information about parameters to be evaluated and assessed (see ‘n.a.’ in Table 4-11)

For rear underrun, quasi-static tests were conducted in accordance with the method described in Directive 79/490/EC and its subsequent amendments (Figure 4-20). However, the test loads were substituted with the following test loads: P1 = 110 kN, P2 = 180 kN, P3 = 150 kN.

Figure 4-20 Test set-up point P3

Finite element analysis suggested that the RUP would withstand the test loads within the permitted deflection of 400mm and predicted a deflection under the prescribed load of 6.4mm at point P1. When the RUP was quasi-statically tested (in an assembly including replicas of the chassis beams of the trailer) the maximum deflection recorded at point P1 was 44.6mm.

Conclusions

Regarding front underrun protection

- A Mobile Progressive Deformable Barrier (MPDB) as bullet device absorbs ~25% more energy when running into a rigid device than when running into an energy absorbing device.
- The maximum deceleration level of the MPDB is ~10% higher when running into a rigid device than when running into an energy absorbing device.
- The duration of the crash pulse of the MPDB is ~15% shorter when running into a rigid device than when running into an energy absorbing device.
- The ASI value is ~10% higher when running with the MPDB into a rigid device than when running into an energy absorbing device.
- Prints of contacting objects are visible and can be recognized in the deformed PDB face.
- No reliable method is available yet to calculate the amount of energy absorbed by the PDB using the Barrier deformation.
- Rigid contacts between a rigid bullet device and target may lead to overloading and damage to the bullet device and measurement system.
- No rigid objects should be allowed on target device when using a rigid bullet device in assessment region.
- A quasi-static pusher should be able to (stably) generate the same force level as developed in dynamic testing.
- Rigid contact between quasi-static pusher plate and rigid objects in the target device may lead to an unstable test system.
- Using the complete truck is an expensive but realistic solution; it is the only way to ensure that all objects are involved in the assessment.
- When using a complete truck as target device, the assessment may be influenced since part of the energy may be taken by some truck structure other than the front underrun protection device.
- A speed dependent FUP device can only be assessed in a dynamic test
- An isolated FUP structure, without surrounding structural objects taken into consideration, may result in too optimistic results regarding energy absorbing capability and capacity.

Regarding rear underrun protection

- The quasi-static test of the prototype rear underrun device would meet the proposed increased test loads and was suitable for use in a full scale validation test.

Regarding numerical simulation

- Multibody models are capable of predicting structural interaction in a global way and the crash severity. The resulting injury to the occupant of the passenger car can only be indicative due to lack of detail of the interior models of the car fleet.
- Finite element simulations show a high level of accuracy, once the boundary conditions are known. Due to the fact that FUP and RUP structures are relatively simple structures, future replacement of structural testing may seriously be considered. A restriction is that also the bullet device should be of relatively simple design.

Recommendations

On energy absorbing front underrun protection

Since one specific procedure could not be selected yet from the performed tests and analyses, it is suggested to carry out additional tests to the current series of tests to supply additional data and to better understand the results obtained so far. However, it may be considered more important to carry out research to clearly demonstrate the benefit of more effective FUPs in impacts with modern cars before carrying out investigations of how best to test such improved FUP devices.

A deforming bullet device similar to the front structure of a car in a dynamic test should be considered for evaluation in future research. The PDB installed on a moving barrier could be considered for this purpose. The investigation should focus on the answering the following items before a final test procedure could be suggested:

- Determine how to accurately assess the amount of underrun and what the performance requirement should be.
- Determine how to evaluate and quantify structural interaction between the test device (PDB) and eaFUP.
- Determine how to evaluate and quantify the effect of rigid objects on the energy absorbing capabilities of the eaFUP.
- Determine how to evaluate and quantify the energy absorbed by the test device (PDB) and the eaFUP.
- Determine the performance measures and limit values to be used and how they correlate to injury.

4.2.9 WP 9 Synthesis of Test Procedures for Car to Truck Impact

The objectives of WP 9 were to describe and check the test procedure and the performance criteria for underrun protection systems for trucks in order to improve vehicle compatibility and as an advice to be included in guidelines and regulations by regulatory authorities.

These objectives were divided into the following categories:

- To collect, order and assess the information from the previous work packages
- To set up the contours of the test procedure(s), the performance criteria and requirements
- To validate and update the test procedure(s)
- To create a final version of the procedure and the performance criteria for car to truck underrun and and provide advice for implementation in future regulation.

The main results and conclusions of the work performed to achieve each of these objectives are described in the following paragraphs.

Information from individual Work packages

In Work packages 4, 6 and 7 several topics were investigated to give recommendations to WP 9 with regard to potential test procedures for both Front Underrun Protection (FUP) and the Rear Underrun Protection (RUP) systems. A procedure for evaluating and assessing front underrun protection devices regarding their ability to reduce injuries to car occupants in a car to truck frontal collision should be able to address the following characteristics:

- Does the underrun protection system effectively prevent for underrun by passenger cars for appropriate impact speeds, impact angles, overlaps?
- Does the underrun protection system provide the structural interaction potential necessary to ensure that the passenger car can activate its energy absorption capability?
- Does the underrun protection system absorb energy to a significant amount, within limited self-deformation and at force levels that can be generated by the passenger car during the impact?.

For the RUP system the main considerations were:

- Does the underrun protection system effectively prevent underrun by passenger cars at appropriate impact speeds, impact angles, overlaps?
- Does the underrun protection system provide the structural interaction potential necessary to ensure that the passenger car can activate its energy absorption capability?

These questions were taken into account during the testing and simulation investigations.

Contours of Test Procedures, Performance Criteria and Requirements

For FUP systems the following test procedures have been examined in the previous work packages:

- full scale testing
- quasi-static component testing
- dynamic component testing using a rigid bullet device
- dynamic component testing using a moving bullet device with a deformable element

- numerical simulation

For the RUP systems numerical simulations and quasi-static component testing were performed.

For front underrun protection systems the advantages and disadvantages of the five draft test procedures investigated are shown in **Table 4-12**.

Table 4-12 Summary of advantages and disadvantages of test procedures

		Advantages	Disadvantages
Test procedure	**Numerical Simulation**	• All test procedures can be simulated • Detailed information can be obtained	• Detailed car models not available • Complicated with detailed car models • Development of car models extremely expensive • Models must be validated
	Quasi-static Test	• Simple • Cheap • Universal impact device • Levels of energy absorption measurable	• Outcome dependent on size of rigid pusher plate • No information on structural interaction • No dynamic influences measurable
	Rigid sled test	• Relatively simple • Relatively cheap • Universal impact device • Dynamic influence is covered	• Outcome dependent on size of rigid impactor face • No information on structural interaction • Rigid contact lead to damage • Can only measure pass/fail criteria and not quantify energy absorption precisely
	Moving deformable barrier test	• Universal impact device • Dynamic influence is covered • Same type of procedure is considered for determining car compatibility • Structural interaction can be evaluated • Acceleration data barrier related with average passenger car	• Relatively complicated • Relatively expensive • Complicated relationship between barrier deformation and energy absorption by barrier, which appears difficult to measure accurately
	Full scale test	• Real life situation and results directly visible; performance is demonstrated • Information on underrun and compatibility • Data on severity and injury	• Complicated • Expensive • Outcome dependent on car and test specification/parameters • Grading of FUPs only possible if same bullet device is used each test

These five approaches have been proposed for assessing energy absorbing front underrun protection systems. Further work is necessary to decide which is the best combination, since it seems at this stage not possible to adequately cover all the parameters that should be assessed with one specific procedure.

There is a lack of baseline data from full scale testing, namely that although test data are available that show an improvement in the crash performance of a car which impacted a truck with an energy absorbing FUP

compared to a rigid FUP, there are no data available which show the higher level of improvement that a regulatory test would be expected to encourage. These data are needed to be able to determine the performance criteria and limits for a test procedure to assess an energy absorbing FUP. Therefore it is recommended that improvements to existing rigid FUPs should be investigated further. These improvements could possibly be achieved by increasing the deformation length (and hence energy absorption potential) available and/or improving the structural interaction such that the much improved energy absorption capability of modern cars is used more effectively in collisions with a truck.. Work package 6 showed the limitations of full scale testing in producing all of the information necessary to investigate what happens in detail in such collisions. Therefore the emphasis should be put on numerical simulation, if access to detailed models of various modern passenger cars and truck models is available. This needs further co-operation with the car and truck manufacturers.
For the rear underun protection assessment a quasi-static test on the RUP was carried out according to the standard ECE Regulation 58 test procedure, applying the higher loads suggested by the research.

The loads applied during this test were derived from a literature survey carried out in WP6 of the various actual regulatory requirements worldwide to see what force levels at which points are applied. To gain more information, simulations have been performed with the actual and a modified RUP setup. Also analyses of passenger car load cell wall data was carried out to see what maximum force levels are generated during different impact configurations and speeds. The average height at which the force levels were applied played an important role during these analyses. A rear underrun guard was designed that met the proposed upgraded regulatory test loads with more stringent ground clearance requirements. The guard consists of two upright parts that are connected to the chassis rails and a 200 mm tall cross-beam, mounted with a ground clearance of 400mm.

Following the current ECE R-58 procedure these different loads were applied to the indicated points on the RUP. This means that a force of 110 kN was applied on point P1, a force of 180 kN was applied on point P2 and a force of 150 kN was applied on point P3.

A full scale test was performed (see paragraph Validation in this section) to confirm that the suggested specifications regarding higher loads, lower ground clearance and increased beam height are adequate for the real world situation.

Validation

For the front underrun protection system a number of approaches have been proposed for assessing the energy absorption capabilities. These approaches were full-scale testing, component testing (dynamic and quasi-static) and numerical simulation. Further work is necessary to decide which is the best combination, since it seems at this stage not possible to adequately cover all the parameters that should be assessed with one specific procedure.

The main reason for not being able to make definitive test procedure proposals for assessment of energy absorbing FUPs is a lack of baseline test data which should be provided by the full-scale tests of Work package 6. In WP6 although test data are available that show an improvement in the crash performance of a car which impacted a truck with an energy absorbing FUP compared to a rigid FUP, there are no data available which show the higher level of improvement that a regulatory test would be expected to encourage. These data are needed to be able to determine the performance criteria and limits for a test procedure to assess an energy absorbing FUP. Therefore it is recommended that work is initially focussed on devising means by which the performance of FUPs can be improved and demonstrated. Work package 6 showed the limitations of full scale testing in producing all information necessary to investigate what happens in detail in such collisions. Therefore the emphasis should be put on numerical simulation, if access to detailed models of various modern passenger cars and truck models is available.

Work package 8 showed that more information regarding component testing was also needed in order to determine a complete detailed procedure based on component testing, dynamically or statically.

The validation tests on FUP devices were not performed as planned due to missing baseline test information from Work package 6. Moreover, this work initially planned to be performed in Work package 9 was shifted to other Work packages (6 and 8) to gain additional baseline information in this field. And finally, more tests were performed, which answered several open questions. However, baseline information is still missing and therefore no recommendations for a complete test procedure and performance criteria can be made at this stage.

This outlook was communicated with the Commission's project officer when starting with Work package 8. In their answer sent December 6, 2005 the Commission preferred the 'submission of deliverables as outlined and defined in the technical annex'. In case of front underrun protection, the advice from the project is not just a single and definitive procedure. The consortium therefore suggests a number of candidate procedures (given in **Table 4-12**) which have to be studied in more detail before a consensus of support from all members will be achieved.

Under Work package 9 (but actually performed under Work package 8) a modified rear underrun protection (RUP) system has been tested. This was done by means of a quasi-static component test on a RUP device for evaluating this modified RUP against the proposed amendments to the Directive 70/221/EEC regarding the strength of the RUP, the height of the cross-member and ground clearance. These amendments are being proposed as a result of the VC-Compat project. This initial test procedure is presented in detail in deliverable D23.

As a validation process this modified RUP was mounted on a semi-trailer and tested in a full scale test with a popular mid-size car with state-of-the-art front structure design. The bullet vehicle was also used and recommended by the car-to-car leg due to its compatible design and good overall performance. Another aspect was also to share the results and therefore to have a range of tests as wide as possible while still providing as much comparability as possible.

The objectives of this test were:

- To demonstrate the effectiveness of a RUP designed to meet proposed increased strength requirement for the quasi-static regulatory test
- To demonstrate the effectiveness of the proposed geometry changes relating to ground clearance and the height of the RUP cross-member
- To validate the quasi-static test procedure to which the designed RUP device was tested
- To demonstrate that a RUP, designed to meet the proposed changes to the regulation, prevented the car from under-running the rear of the trailer in a realistic scenario involving a car and a trailer.

The results have shown the interaction between the car tested and the RUP was good and the RUP prevented the car from under-running the rear of the trailer.

For the validation test of the rear underrun protection device the following conclusions can be drawn:

- The RUP that was tested was capable of preventing the car from under-running the rear of the trailer. However, the semi-trailer chassis beams to which the RUP was mounted deformed excessively resulting in a total forward deflection of the RUP beam of 499mm. If the bullet vehicle had a shorter bonnet, contact could have occurred between the trailer load bed and the car A-pillars. The chassis beams had also been replicated as part of the quasi-static test and did not fail in that test. The reasons for the different behaviour in each test are not known and could be associated either with the test methods or with the material properties of the actual and simulated chassis beams.
- The impact was managed to minimise the risk of injury to the car occupants. The occupant compartment integrity was maintained and the firing time of the airbag was not adversely affected.
- The design of the lower rails (with crush cans) resulted in good interaction with the RUP and hence energy absorption. It is not clear whether this interaction would occur if the car had no crush cans.
- Further investigation should be carried out to determine the reasons for chassis deformation and the differences between test methods.

Overall it can be stated that the validation of the RUP device was successful although the differences between the quasi-static test and the dynamic validation test have to be further investigated whether the differences are resulting of the weak trailer chassis or the difference in loading between static and dynamic forces.

Please note that tests carried out by ADAC in Germany (end of year 2006) have shown that the recent amendment to the EC RUP Directive to increase test loads at point P1 to 50kN was insufficient to prevent underrun of a modern passenger car at 56 km/h. They also proved that a sufficiently strong RUP device is capable of preventing a passenger car from under-riding a trailer.

Final Test Procedures

For the definition of a procedure to assess energy-absorbing **front underrun protection systems** more research is needed. At the moment, a number of candidates have been defined, but none of them alone adequately assess all the FUP parameters needed to ensure its good performance. Ongoing discussion about the most favourable candidates in the consortium indicates the need for additional tests with supporting data. At this stage a final test procedure for assessing energy absorbing front underrun protection systems cannot be recommended.

For the **rear underrun protection systems**, as a result of the investigations together with the validation test the performance criteria set in the static test can be given as an advice for a regulation. The detailed requirements and performance criteria are defined as follows (see also Figure 4-21):

- Ground Clearance of the RUP max. 400 mm
- RUP beam height min. 200 mm
- Point loads during quasi-static testing at **P1 = 110 kN**, at **P2 = 180 kN** and at **P3 = 150 kN**
- Static loads applied not being dependent of GVW (Gross Vehicle Weight)

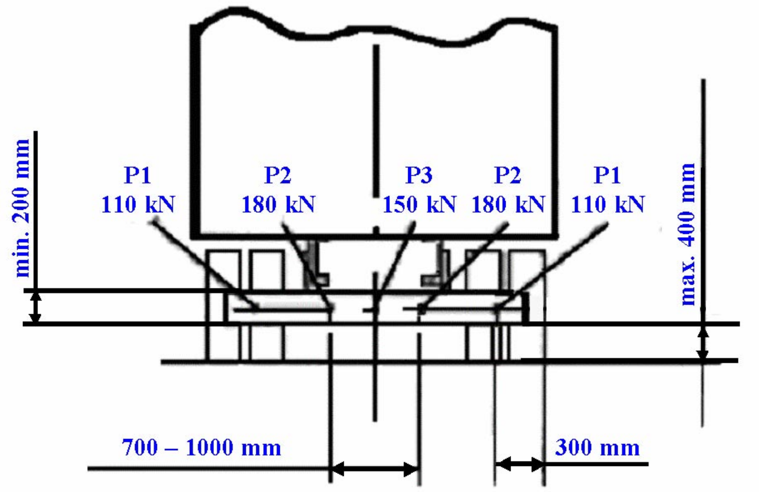

Figure 4-21 ECE R-58 Overview of new recommended requirements for RUP systems for adoption in regulation

These amendments are recommended to be implemented in regulation ECE R-58 to prevent cars from under-riding trailer and trucks. It should be noted that VC-COMPAT has only considered amendments to the requirement for vehicles of maximum GVW. Lighter trucks are currently permitted to have reduced test load requirements and the validity of these lower test loads has not been assessed. In addition to this, practical issues associated with implementing a lower ground clearance at the rear have not been formally assessed. Anecdotal feedback received at the mid-term and final workshop has suggested that while easily achieved for many trucks some, for example those that travel on ferries, may require more complex and expensive devices in order to meet both the revised regulation and their operational needs.

Advice and Summary

For the front underrun protection system further research is necessary to gain more baseline information for setting up a possible final test procedure to assess the benefit of energy absorption in the truck front for other road user.

For the rear underrun protection system it is recommended to change the actual ECE Regulation 58 to the requirements given above. However, it is also recommended that before this change is implemented:

- The requirements for smaller trucks are investigated
- The exemptions to the current regulation are reviewed
- The difficulties with implementing lower ground clearance that may be experienced in some operations are investigated
- The reasons for the failure of the chassis beams and, thus the validity of the static test method, are investigated.

The amendment on the regulation 70/221/EEG which comes into effect March 11, 2007 is a step forward to improve safety, but it is far from being sufficient to prevent cars from under-riding trucks and trailers at collision speeds that could be considered survivable for occupants of modern cars. It is therefore recommended to revise this amendment to the increased requirements found during the investigations in this research project.

4.2.10 WP 10 Industrial Liaison and Dissemination

The purpose of the Dissemination Work Package was to exchange information with road safety stakeholders, in particular those with close ties to crash compatibility. Four different dissemination approaches were used: project newsletters, conference publications, technical workshops and the project website. These are discussed in more detail below with focus on the Workshops as they consumed most of the resources in WP10.

Two short newsletters were generated and distributed by the consortium. These newsletters contained short descriptions of the project activities, results to date, and images from the project.

Seven conference publications (four car leg and 3 truck leg) were written and presented by the VC-Compat partners. Deliverable 16 states that this should be four in total, the list of publications is given in section 6.3.

To facilitate a dialog between the VC-Compat project and the main dissemination audience – the automotive industry (manufacturers and suppliers), research organisations, and regulatory bodies – workshops were held at the critical stages of the project. An industrial liaison workshop was held in conjunction with the project Kick-off meeting. This workshop was organized so the project plan could be presented to the relevant stakeholders (approximately 50 delegates) and identify areas for mutual information exchanges, collaboration, and input to the future VC-Compat activities. Comments obtained from the delegates was discussed by the consortium members and used in the planning of subsequent activities.

A midterm workshop was held (February 2005, Gothenburg) to report the project findings at that date and solicit further input from the target audience. A considerable number of delegates (64) participated in the two-day event. The workshop had a significant international impact and attracted delegates and speakers from Asia, Australia, Europe and North America. Important discussions between the consortium and the stakeholders resulted in input for the continuation of the project.

The final workshop was held in the last weeks of the project (October 2006, Eindhoven). A significant international audience (80) participated in the event. An important feature of this last workshop was the discussion sessions where future needs were identified as well as ideas for research activities needed to follow up the VC-Compat project. In this final workshop it was clear that there are common global issues, however considerable effort is still needed to promote international harmonisation.

The last dissemination activity is the project website, which is used for posting project information. A secured (password restricted) and a public section were designed for disseminating information between consortium members as well as the general public. Conference and journal publications prepared by the consortium and individual partners are listed on the public site. Archiving of project reports and meeting minutes was also facilitated. The project website has been running over the project life time successfully, with over the 3500 hits and 54 different users on the restricted section. The website will be accessible after the project runtime for at least three years, vc-compat.rtdproject.net.

In summary, the VC-Compat project successfully integrated wide dissemination activities in the form of newsletters and conference papers, with close technical discussions in planned workshops. These activities were the main communication techniques for the project. Project activities were also presented in the PSN and APSN networks, ACEA, as well as the regular reporting of results at EEVC Working Group 15 meetings.

4.2.11 WP 10 Industrial Liaison and Dissemination

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4.3 Comparison of planned activities and actual work

The original Description of Work is summarised in Table 4-1 and all tasks as described in Table 4-1 are completed. During the project there was a contract amendment, the main effect of which was to transfer some resource between work packages and to extend the project duration by 9 months. The contract amendment is described in detail in the 'Management and Co-ordination Aspects' section. A summary of the changes between the actual work done and that originally planned for each work package is described below.

Differences compared to original DoW.

Work package 3

- Reduction of number of crash test units performed by UTAC from 12 to 10.

The original resource allocation in WP3 was based on a number of crash tests with a budget of approximately 15 keuro allowed for the purchase of each vehicle. In order to produce the test data required by the project, the crash test matrices were defined by VC-COMPAT partners and EEVC WG15 taking into account the overall aims of the project. UTAC were requested to perform FWDB and PDB crash tests with a large car and a PDB crash test with an SUV together with a number of other tests. The UTAC original consumable budget was not sufficient to purchase these vehicles as their cost was far above the 15 keuro originally budgeted. To allow sufficient consumable budget to purchase these vehicles UTAC transfered budget from labour to consumables, by reducing the number of crash test units that they performed from 12 to 10.

- Additional tests performed by BASt

After the completion of the planned test programme BASt had some budget remaining in WP3. BASt used this budget to provide part of the funding for two additional crash tests; Supermini vs Supermini and Supermini vs PDB. Results and initial analysis of these tests are reported in an addendum to D27. It is intended that further analysis and interpretation of the results from these tests will be performed by EEVC WG15 members after the completion of this project.

Work package 6

- Two additional tests performed

Originally 5 tests were planned in this work package. In consultation with the partners in the consortium it was decided to use one supermini car in different test setups for comparison purposes. The choice for one vehicle type was correct, only the performance in these tests was poor. Therefore it was decided after advice from the car consortium to switch to another type of car which would show a more stable front structure and would be able to generate a higher load to the e.a.FUP. Only, this time the choice for the car was right but the FUP was not sufficiently activated. However, proof of benefit of an e.a.FUP was needed to continue with the next work packages. Therefore it was decided to develop an e.a.FUP which would definitely absorb energy. But if one extra test would be carried out there would not be any possibility to compare the results, so therefore 2 tests were scheduled. The two extra tests were shifted from work packages 8 and 9. BASt conducted 3 tests instead of 2 and TNO conducted 4 tests instead of 3.

- Activities shifted from work package 8 to work package 6

TNO developed a target device which was originally planned in work package 8. This included the design of the bullet device and the determination of the properties of the aluminium foam used as energy absorber by quasi-static and dynamic component testing. The resulting dimensions and force/deflection curves of the aluminium foam used as energy absorbing elements in Work package 8 were determined here.

Work package 8

- Two tests less

Originally 9 component tests were planned. BASt carried out 4 tests, TRL 1 test and UPM 2 tests. The tests by TNO were shifted to work package 6, which not only included a full scale test on the new bullet device, but also the design of the bullet device and the determination of the properties of the aluminium foam used as energy absorber by quasi-static and dynamic component testing. Furthermore, most of the tests in this work package turned out to be more complicated (and thus more expensive) than originally planned. This caused for the partners involved in WP8 and WP9 a capacity and budget problem.

- Extra analyses

Due to the complexity of the (component) tests and the questions which arose when processing the results, much effort had to be put in extra analyses to explain the results. TNO had the lead in that, shifting budget from work package 9 to work package 8.

Work package 9

- Test shifted from WP9 to WP6

In this Work package originally 5 tests were planned to prove and support the proposed test procedure for energy absorbing front underrun protection devices and 2 tests were planned to support the test procedure for an improved rear underrun protection device. One test was shifted from this Work package 9 to WP6.

- Transfer of test work to analysis work

The baseline test data from WP6 showed an improvement in the crash performance of a car which impacted a truck with an energy absorbing FUP compared to a rigid FUP, but they did not show the higher level of improvement that would be necessary to give the benefit required to justify the introduction of a regulatory test. This problem was communicated with the EC who advised that the project should continue with development of test procedures rather than generate additional baseline test data. As this type of baseline data is absolutely necessary to be able to recommend a specific test procedure to assess an energy absorbing FUP and determine its performance criteria and limits this work package has evaluated the pros and cons of selected test procedures instead of validating one specific test procedure. To determine the pros and cons for the selected procedures for future reference and decisions additional analysis was performed instead of tests. This process was time and manhour consuming, with the result that the original test budget for validation of the eaFUP procedure was spent for these purposes.

Note: The quasi-static and dynamic tests on an improved rear underrun protection device were carried out by TRL, albeit at an earlier stage than planned.

4.4 State of the art review, evolution of trends of current available technologies

According to the partners of the consortium, the State of Art with respect to the subject of the project has not changed since the start of the project.

According to the partners, there are no alternative technologies or developments on the market.

5 LIST OF DELIVERABLES & MILESTONES

Table 5-1. List of deliverable items and major milestones

No.	Completion	Nature of Deliverable and brief description
D1	100%	Minutes from industrial and related stakeholders meeting.
D2	100%	Website with information to the public and the project consortium.
D3	100%	Truck geometrical/structural database.
D4	100%	Report defining state of the art of present truck underrun devices.
D5	100%	Report detailing estimation of the benefits on a national and European scale of improved truck underride protection and the costs of improved truck underride protection.
D6	100%	Report detailing estimation of the scope of improved car to car compatibility.
D7	100%	Car numerical models for use in truck impact modelling.
D8	100%	Test specification describing test, necessary equipment and data to be measured for car to truck frontal collision.
D9	100%	Car geometrical/structural database with report detailing results of analysis of current car-to-car geometric compatibility.
D10	100%	Simulation models of frontal and rear end car to truck collisions.
D11	100%	Report containing results of the 7 crash tests and analyses performed in WP6.
D12	100%	Report containing a brief summary of all the tests performed in WP6 and conclusions and recommendations regarding the relationship between injury mechanisms and the type of underrun protection.
D13	100%	Report detailing comparison of future accident status with present accident status in terms of expected injury reduction.
D14	100%	Report detailing reference baselines to evaluate truck underrun guard test procedure(s).
D15	100%	Minutes from workshops.
D16	100%	Four conference papers, 2 for both car-to-car impact (Task 10.2) (month 20 and 43) and car-to-truck impact (Task 10.2) (month 20 and 43).
D17	100%	Report detailing crash test results and analyses for all the tests completed before month 18 for WP3
D18	100%	Report detailing benefit estimation for improved car to car impact compatibility using a fleet modelling approach.
D19	100%	Report detailing definition of the bullet and target device and supporting test results.
D20	100%	Report detailing recommendations for evaluation method, i.e. static or dynamic test or use of numerical simulation.
D21	100%	Report detailing information of the costs of improved truck underride protection
D22	100%	Report detailing results of an optimisation study for vehicle front-end stiffness and recommendations for structural improvements of car front ends.
D23	100%	Report detailing initial test procedure outline(s) and performance criteria for car to truck underrun.
D24	100%	Estimation of the costs and benefits on a national and European scale for improved car to car compatibility.
D25	100%	Report detailing test procedure(s) validation results.
D26	100%	Report detailing results of FEM modelling studies to support development and initial validation of crash test procedures.
D27	100%	Report detailing crash test results and analyses of those results for all the tests completed after month 18 in WP3.
D28	100%	Report detailing final test procedure(s) and performance criteria for car to truck underrun.
D29	100%	Report detailing draft test procedures with performance criteria outlines, a framework for a car crash compatibility rating system and general recommendations for the design of a compatible car.

6 EXPLOITATION AND DISSEMINATION OF RESULTS

6.1 Exploitation plans

The final version of the eTIP is available at http://etip.cordis.lu/ containing the project summary and partner details. In total 13 results are described in the eTIP, owned by 6 partners.
All public results will be also available on the public part of the website: Vc-compat.rtdproject.net

6.2 Contacts with potential users and indication of customer requirements

Virtually, all partners have regular contacts with potential users, customers and other stakeholders. Through the information from these contacts, it is clear that there is a significant interest in the results of the project. EEVC WG15 contacts, regular information sharing through EEVC WG15 meetings. In WG15 the following members were active during the project duration:

National representatives		**Industry advisor**		**Observer**	
Eberhard FAERBER	BASt (Germany)	Robert ZOBEL	VW (Germany)	Stephen SUMMERS	NHTSA (USA)
Joaquim HUGUET	IDIADA (Spain)	Anders KLING	Volvo (Sweden)		
Cor van der Zweep	TNO (Netherlands)	Martin HARVEY	Jaguar (UK)		
Mervyn EDWARDS	TRL (UK)	Danilo BARBERIS	FIAT (Italy)		
Tiphaine MARTIN	UTAC (France)	Richard ZEITOUNI	PSA (France)		
Pascal DELANNNOY	French substitute				
Robert THOMSON	Chalmers (Sweden)	Ton VERSMISSEN	TNO (Netherlands)		
Giancarlo DELLA VALLE	Elasis (Italy)				

Next to the EEVC WG15 there was a regular contact with the ACEA (European Automobile Manufacturers Association) by workshops and meetings.

6.3 Publications and conference presentations resulting from the project

Car Leg

Cor Van Der Zweep, Gijs Kellendonk, Paul Lemmen (all TNO), **Evaluation of Fleet Systems Model for Vehicle Compatibility,** 2004 Icrash conference

F Jenefeldt, R Thomson (both Chalmers), **A Methodology to Assess Frontal Stiffness to Improve Crash Compatibility,** 2004 Icrash conference

R. Thomson (Chalmers) and M. Edwards (TRL) on Behalf of the VC-Compat Consortium, **Passenger Vehicle Crash Test Procedure Developments in the VC-Compat Project,** 19th ESV Conference, 2005

M. Edwards (TRL), R. Thomson (Chalmers), C. van der Zweep (TNO), **Car – Car Crash Compatibility: development of crash Test Procedures in the VC-COMPAT Project**, International Crashworthiness conference 2006

Truck Leg

Leneman, F. (TNO), Anderson, J. (CIML), Gwehenberger, J.; Bende, J. (both GDV), **Truck/Trailer compatibility with cars and trucks – related topics from VC-COMPAT,** Proceedings of the 20th International Congress on Truck Safety, Tata, Hungary, October 16–17, 2003

Smith, T.; Couper, G.; Knight, I. (all TRL), **Analysing and improving the Performance of Rear Underrun Protection Devices,** Proceedings of the DEKRA/VDI Symposium 'Sicherheit von Nutzfahrzeugen', Neumünster, Germany, October 20-21, 2004

Leneman, F.; Kellendonk, G.; de Coo, P. (all TNO) on behalf of the VC-COMPAT truck leg consortium, **Assessment of energy absorbing underrun protection devices,** Proceedings of the DEKRA/VDI Symposium 'Sicherheit von Nutzfahrzeugen', Neumünster, Germany, October 20-21, 2004, (Paper written)

Workshops

To facilitate a dialog between the VC-Compat project and the main dissemination audience – the automotive industry (manufacturers and suppliers), research organisations, and regulatory bodies – workshops were held at the critical stages of the project.

- An industrial liaison workshop was held in conjunction with the project Kick-off meeting. This workshop was organized so the project plan could be presented to the relevant stakeholders (approximately 50 delegates) and identify areas for mutual information exchanges, collaboration, and input to the future VC-Compat

- A midterm workshop was held (February 2005, Gothenburg) to report the project findings at that date and solicit further input from the target audience. A considerable number of delegates (64) participated in the two-day event. The workshop had a significant international impact and attracted delegates and speakers from Asia, Australia, Europe and North America.

- The final workshop was held in the last weeks of the project (October 2006, Eindhoven). A significant international audience (80) participated in the event.

A joint workshop was held on February 12, 2004. ACEA and the VC-Compat members organised the workshop on compatibility with the topic: Car-to-car / Van / SUV / Truck Compatibility; 'What height should a structural interaction area be set?' Various presentations were made at this workshop, see website.

6.4 Other aspects concerning dissemination of results

- Link with APROSYS EC project

It should be noted that the EC 6th framework project APROSYS asked the VC-COMPAT project to supply APROSYS the car structural database generated in this project. APROSYS intend to extend the database to include more measurements of the car side structure so that the database can be used for side impact compatibility studies. With the aim of ensuring good dissemination of the information generated in this project the VC-COMPAT partners have agreed to supply the database to APROSYS with the condition that the updated database is made available to VC-COMPAT consortium members.

- Link with IMPROVER EC project

Subproject 1 of the IMPROVER project requested to use the geometrical database of the European Car fleet to be used in an investigation to the differences of passenger cars and SUVs on a European scale. Within this project 5 SUVs and 8 MPVs were measured and added to the database.

7 MANAGEMENT AND CO-ORDINATION ASPECTS

7.1 Project co-ordination activities

7.1.1 Contract Amendment

The following request for a full contract amendment was submitted to the Commission on September 2nd, 2005.

Project extension

The project started on 1st March 2003 and was scheduled to finish on 1st March 2006. A nine month extension has been requested, so that the project will finish 1st December 2006. The reasons for this extension are:

- For the car to car compatibility part of the project, the original plan for the crash test programme in WP3[7] was to define a large matrix of crash tests and perform the tests in parallel at the project partner facilities. Unfortunately, it has been found that the test programme has had to be performed in an iterative manner (that is a test is performed, the results analysed and based on these results the next test(s) planned) to ensure that the test resource is used in the most cost effective way. An example why this is necessary was the choice of the target car. A family car was chosen as a target car, into which it was intended to crash many other cars to provide data to validate the test procedures. After, 2 tests it was found that the chosen family car was unsuitable as a target car because of its lower rail stability and weak passenger compartment, so another car had to be chosen as a target car. If the original approach of performing the complete matrix of tests in parallel had been followed many tests with an unsuitable target car would have been performed and effectively wasted.

  EEVC WG15[8] are acting as a steering committee to oversee the VC-COMPAT project and ensure a good link of the project to industry as requested by the EC. A knock on effect of performing the test programme iteratively is that more meetings are required with WG15 to present recent test results and review the proposed test programme. This required additional time, especially as WG15 do not meet that often.

  In addition, there were a number of issues that needed to be resolved with 2 of the candidate test procedures, namely the Full Width Deformable Barrier (FWDB) and Progressive Deformable Barrier (PDB) procedures. These were addressed outside the project - using individual government funding - and have contributed to a programme delay.

- For the car to truck compatibility part of the project, there have been problems with the baseline tests in WP6[9] which have caused a delay. The baseline tests performed to date with a truck fitted with energy absorbing Frontal Under-run Protection (eaFUP) have failed to show the benefit of an eaFUP compared to a rigid FUP because the energy absorbing capability of the eaFUP was not activated because of poor structural interaction between the car and the eaFUP. Because of this, 2 additional baseline tests needed to be performed, one in which an eaFUP is activated. This has caused a knock on delay to the project as these tests were on the project critical path.

2) Budget transfer

A transfer of 1 test from WP9 to WP6 and budget of 42 kEuro from Volvo 3P to TNO has been requested. The reasons for this are:

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[7] WP3 – Workpackage 3 'Crash testing and analysis to support development of crash test procedures and to perform initial validation'

[8] EEVC WG15 – European Enhanced Vehicle safety Committee Working Group 15 (Compatibility and Frontal Impact).

[9] WP6 – Work Package 6, 'Determination of injury mechanisms and the relationship with underrun protection for car to truck impact'.

- As mentioned above 2 additional baseline tests needed to be performed in WP6, one with an eaFUP that is activated, to provide data to show the difference in car occupant injury with an eaFUP and rigid FUP. To fund the first of these tests it was proposed to transfer 1 test from WP9 to WP6. This reduced the number of tests for validation of the proposed procedure in WP9 from 5 to 4. However, it was believed that 4 tests are sufficient for validation purposes. To fund the second of these tests it was proposed to transfer 42 keuro from Volvo 3P to TNO.

A transfer of budget of 27 kEuro from labour to consumables cost head has been requested for UTAC. The reasons for this are:

- The original resource allocation in WP3 was based on a number of crash tests with a budget of approximately 15 kEuro allowed for the purchase of each vehicle. In order to produce the test data required by the project, the crash test matrices were defined by VC-COMPAT partners and EEVC WG15 taking into account the overall aims of the project. UTAC were requested to perform the FWDB and PDB crash tests with a large car and the PDB crash test with a SUV together with a number of other tests. The UTAC original consumable budget was not sufficient to purchase these vehicles as their cost is far above the 15 kEuro originally budgeted. Hence it was requested that UTAC transfer budget from labour to consumables, by reducing the number of crash test units that they perform from 12 to 10, to allow sufficient consumable budget to purchase these vehicles.

3) Partner change
The Cranfield Impact Centre Ltd (CIC Ltd) has been bought by Cranfield Innovative Manufacturing Ltd (CIM Ltd). The implications of this for the VC-COMPAT contract was that there is no longer a CIC payroll and staff working on the contract are employed by CIM Ltd.

4) The address of TRL Ltd has changed. The new address is:
TRL Limited
Crowthorne House
Nine Mile Ride
Wokingham, Berkshire
RG40 3GA
United Kingdom

On February, 20th, 2006 the EC project officer Mr. Bormans informed the co-ordinator that the Contract amendment would be granted.

7.1.2 Budget transfers

Budget transfer between partners

1. Budget transfer between Volvo and TNO of 10 kEuro.

TNO and Volvo requested a budget transfer between partners within the truck leg of 10 kEuro, due to problems with the baseline test in WP6. The baseline test performed with a truck fitted with energy absorbing Frontal underrun Protection (eaFUP), have failed to show the benefit of an eaFUP compared to a rigid FUP, because the energy absorbing capability of the eaFUP was not activated. This was due to poor structural interaction between the car and the eaFUP. Because of this, two additional tests were performed in WP6. These additional tests showed effect, which have been compared in detail with already performed tests and the component tests, performed in WP8. The analysis and comparison of these tests were performed at TNO instead of Volvo Trucks. As a result, a budget of 10 kEuro has been transferred from Volvo Trucks to TNO.

Table 7-1 Overview of budget transfers between partners

Participant No	Participant Short Name	Adjusted requested Contribution from the Community	Original requested contribution from the Community	Difference between original and modified
1	TRL	753,263	753,263	0
2	TNO	586,274	560,274	26,000
3	BASt	512,543	512,543	0
4	UTAC	451,418	451,418	0
5	CHUT	164,000	164,000	0
6	UPM	75,978	75,978	0
7	FIAT	130,066	130,066	0
8	CIC	84,104	84,104	0
9	DC	25,920	25,920	0
10	GDV	49,440	49,440	0
11	Volvo	119,604	145,605	-26,001
12	Scania	32,411	32,411	0
13	DAF	14,985	14,985	0
	TOTAL	**3,000,003**	**3,000,003**	

7.1.3 Payments

Advanced payment

TRL has received 900,000.00 Euro being the EC contribution for the first year covering 30% of the requested EC contribution.

1st project year payment

TRL has received 547,312.46 Euro being the EC contribution for the 1nd project year. A 30% reduction was made to recover part of the advance payment.

2nd project year Payment

TRL has received 472,376.21 Euro being the EC contribution for the 2nd project year. Another 30% reduction was made to recover part of the advance payment. An intermediate ceiling was set to 70% (payment up to 70% of maximum EC contribution). As a result, GDV and CIC/CIM will not receive their periodic payments.

Final payment

To be paid after finalising the complete project and the payment will be based on the final Cost Statements of the partners.

Table 7-2 Payments, PART E-3 Summary sheet of the amounts transferred to the Contractors from the Coordinator, all amounts in Euro

Name of	Advance:		Period: 1st project yr		Period: 2nd project yr		Total
Contractor	amount	date	amount	date	amount	date	
TRL	225,979.00	19-nov-03	91,139.58	16-jun-05	148523.63	7-feb-06	465,642.21
TNO	168,082.00	19-nov-03	121,234.92	16-jun-05	102,874.48	7-feb-06	392,191.40
BASt	153,763.00	19-nov-03	76,669.80	13-jun-05	65,793.25	2-feb-06	296,226.05
UTAC	135,425.00	20-nov-03	132,000.82	16-jun-05	48,565.38	7-feb-06	315,991.20
Chalmers	49,200.00	19-nov-03	36,936.87	16-jun-05	28,663.13	7-feb-06	114,800.00
UPM	22,793.40	5-mrt-04	1,961.69	16-jun-05	7,811.77	7-feb-06	32,566.86
Fiat	39,020.00	19-nov-03	3,064.95	13-jun-05	30,210.98	7-feb-06	72,295.93
CIM	25,231.00	19-nov-03	33,641.60	13-jun-05	0.00	7-feb-06	58,872.60
DC	7,776.00	19-nov-03	3,796.35	13-jun-05	3,625.55	2-feb-06	15,197.90
GDV.	14,832.00	19-nov-03	19,776.00	16-jun-05	0.00	7-feb-06	34,608.00
Volvo	43,681.00	19-nov-03	16,764.30	16-jun-05	27,675.62	7-feb-06	88,120.92
Scania	9,723.00	19-nov-03	6,855.15	13-jun-05	6,109.05	2-feb-06	22,687.20
DAF	4,495.00	21-nov-03	3,470.43	16-jun-05	2,523.37	7-feb-06	10,488.80
Totals	900,000.40		547,312.46		472,376.21		1,919,689.07
Amounts paid by EC	900,000.00		547,312.46		472,376.21		1,919,688.67

7.1.4 Communication

The degree of communication between partners can be assessed from Table 7-3.

Table 7-3 – Overview of meetings attendance of all partners (0: not attended, X: attended).

PARTNER	KOM	TM01	PM01	PM02	PM03 /MA	PM04	PM05	PM06	FM
TRL	X	X	X	X	X	X	X	X	X
TNO	X	X	X	X	X	X	X	X	X
BASt	X	X	X	X	X	X	X	X	X
UTAC	X	X	X	X	X	X	X	X	X
CHUT	X	X	X	X	X	X	X	X	X
UPM	X	0	X	X	X	X	X	X	X
FIAT	X	X	X	X	X	X	X	X	X
CIM	X	0	X	0	X	X	X	0	0
DC	X	0	X	X	X	X	X	X	X
GDV	X	0	X	X	X	X	X	X	X
VOLVO	X	0	X	X	X	X	X	X	X
SCANIA	X	0	X	X	X	X	X	X	X
DAF	X	0	X	X	X	X	X	X	X

KOM	Kick off meeting (5th March 2003)
TM01	Technical meeting for car leg (July 2003)
PM01	Progress meeting 1 (15th September 2003)
PM02	Progress meeting 2 (2nd and 3rd March 2004)
PM03/MA	Progress meeting 3 and Mid Term Assessment (8th and 9th September 2004) MA = Mid Term Assessment Meeting
PM04	Progress meeting 4 (21st and 22nd February 2005)
PM05	Progress meeting 5 (6th and 7th September 2005)
PM06	Progress meeting 6 (21st and 22nd February 2006)
FM	Final Meeting (16th of October) and final workshop (17th and 18th of October)

7.1.5 The VC-Compat website

The project website has been running over the project lifetime successfully, with over 3500 hits and 54 different users in the restricted section. The website will be accessible after the project runtime for at least 3 years, at vc-compat.rtdproject.net.

7.2 Manpower / budget overview

Table 7-4 Manpower and budget overview over the runtime of the project

Participant No.	Participant Short Name	Number of Man Hours	Personnel Costs	Durable Equipment	Sub-Contracting	Travel and Subsistence	Consumables	Computing	Other Specific Costs	Overhead Costs	Adjustment previous period	Total Costs	Costs Basis	% Req. from EC	Requested Contribution from the Community[10]	Adjusted Contribution from the Community[11]
1	TRL	9,518	352,056	0	0	28,401	309,601	50,589	215,399	428,181	51,646	1,435,873	FC	50%	717,936	**753,263**
2	TNO	13,063	461,556	0	0	36,312	3,171	0	100,039	555,250	-5,965	1,150,363	FC	50%	575,182	**581,274**
3	BASt	7,822	328,936	53,156	0	15,514	347,444	0	107,844	183,696	0	1,036,591	FC	50%	518,296	**512,543**
4	UTAC	5,689	290,025	0	0	18,721	223,738	0	119,703	319,407	61,798	1,033,391	FC	50%	516,696	**451,418**
5	CHUT	3,247	88,824	3,203	10,847	14,833	11,775	0	8,515	25,430	0	163,429	AC	100%	163,429	**164,000**
6	UPM	1,494	43,886	12,586	0	9,969	4,018	14,200	4,505	35,109	0	124,274	FF	50%	62,137	**75,978**
7	FIAT	3,153	103,152	0	0	19,702	69,670	1,972	9,368	59,327	0	263,192	FF	50%	131,596	**130,066**
8	CIC	1,586	61,036	1,355	337	7,711	425	0	16	91,553	0	162,431	FC	50%	81,216	**84,104**
9	DC	440	23,320	0	0	5,459	0	0	0	13,200	0	41,979	FC	50%	20,990	**25,920**
10	GDV	1,562	65,080	0	0	7,045	0	0	70	52,061	0	124,256	FF	50%	62,128	**49,440**
11	Volvo	1,764	95,080	0	5,000	0	26,490	0	0	69,467	0	196,037	FC	50%	98,018	**124,605**
12	Scania	860	31,165	0	0	18,985	0	0	11,000	40,514	0	101,663	FC	50%	50,832	**32,411**
13	DAF	466	29,022	0	0	5,590	0	0	0	0	299	34,911	FC	50%	17,456	**14,985**
	Total	**50,662**	**1,973,139**	**70,300**	**16,184**	**188,242**	**996,333**	**66,761**	**576,460**	**1,873,195**	**107,778**	**5,868,390**			**3,015,909**	**3,000,004**

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[10] Requested Contribution from the Community is based on the total sum of what the partners reported in their Cost Statements

[11] Adjusted Contribution from the Community are the modified (budget reallocation between partners) figures of the original proposed contribution from the Commission

7.3 List of partner organisations, contact persons, etc.

Table 7-5. Updated list of all partner organisations, contact persons, addresses and telephone numbers.

Partner	Title	Name	Car / Truck	Role in the project:	Address	Phone nr.	E-mail
TRL	Dr.	Mervyn Edwards	C	Project Co-ordinator and Chairman Car TRL	Crowthorne House Nine Mile Ride Wokingham Berkshire RG40 3GA, UNITED KINGDOM	0044 1344 770 723	medwards@trl.co.uk
	Mr.	Iain Knight	T	Truck WP leader TRL		0044 1344 773 131	iknight@trl.co.uk
	Mr.	Huw Davies	C			0044 1344 773 131	hdavies@trl.co.uk
	Mr.	Richard Cuerden	C/T			0044 1344 770 801	rcuerden@trl.co.uk
	Mr.	Mike McCarthy	C/T	Cost/MM Leader TRL		0044 1344 770 681	mmccarthy@trl.co.uk
TNO	Mr.	Peter de Coo	T	Chairman Truck TNO	Steenovenweg 1, Helmond, The Netherlands	0031 40 265 2609	peter.decoo@tno.nl
	Mr.	Richard Schram	C		Steenovenweg 1, Helmond, The Netherlands	0031 40 265 2656	richard.schram@tno.nl
BASt	Mr.	Eberhard Faerber	C/T		Bruderstrasse 53, 51427 Bergisch Gladbach, GERMANY	0049 220 44 3656	faerber@bast.de
	Mr.	Richard Damm	C/T	Project leader BASt		0049 220 44 3657	damm@bast.de
UTAC	Mrs.	Tiphaine Martin	C	Project leader UTAC	Autodrome de Linas – Montlhéry, 91311 Montlhery Cedex, FRANCE	0033 1 69 80 3412	tiphaine.martin@utac.com
	Mr	Pascal Delannoy	C			0033 1 69 80 1721	pascal.delannoy@teuchos.fr
CHUT	Mr.	Rob Thomson	C	Project leader CHUT	Hoersaelsvaegen 5, 412 96 Gothenburg, SWEDEN	0046 31 772 36 45	robert.thomson@chalmers.se
UPM	Mr.	Javier Páez	T	Project leader UPM	Campus Sur UPM, Ctra de Valencia, 28031 Madrid, SPAIN	0034 91 336 5328	jpaez@insia.upm.es
FIAT	Mr.	Giancarlo della Valle	C	Project leader Fiat	Via Fausto Coppi 2, 10043 Orbassano (TO), ITALY	0039 081 196 95 480	giancarlo.dellavalle@elasis.it
CIML	Mr.	Ras Hashemi	T	Project leader CIML	Wharley End, Cranfield, Bedford, MK43 OJR, United kindom	0044 1234 756514	s.m.r.hashemi@cranfield.ac.uk
DC	Mr.	Heinrich Stubenböck	T	Projectleader DC	Mercedesstrasse 137, HPC A605, 70546 Stuttgart, GERMANY	0049 711 170	heinrich.h.stubenboeck@daimlerchrysler.com
GDV	Mr.	Axel Malczyk	T	Project leader GDV	Friedrichstr. 191, 10117 Berlin, GERMANY	0049 30 2020 5879	a.malczyk@gdv.org
	Mr.	Jenö Bende	T			0049 30 2020 5843	j.bende@gdv.org

VGT	Mr.	Hervé Desfontaines	T	Projectleader Renault	B.P. 310, F-69802 Saint Priest Cedex, FRANCE	0033 472 96 4142	herve.desfontaines@renaultvi.com
	Mr.	Philippe Deloffre	T			0033 472 96 7859	philippe.deloffre@renault-trucks.com
	Mrs.	Anna Wrige	T	Projectleader Volvo	S-40508 Göteborg, SWEDEN	0046 31 322 4665	anna.wrige@volvo.com
SCANIA	Mr.	Mattias Sjoberg	T		S-15187 Södertälje, SWEDEN	0046 855 381 365	mattias.sjoberg@scania.com
	Mr.	Dick Andersson	T	Project leader Scania	S-15187 Södertälje, SWEDEN	0046 855 385 809	dick.andersson@scania.com
DAF	Mr.	Coco Jongerius	T	Project leader DAF	Postbox 90065, 5600 PT Eindhoven, THE NETHERLANDS	0031 40 214 2769	coco.jongerius@daftrucks.com

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Car to Car Impact

8.1.1 Conclusions

Cost Benefit

The costs and benefits for improved frontal impact car to car compatibility for Europe (EU15) were estimated. The casualty benefit that could be realised with improved frontal impact compatibility performance was estimated for Great Britain and Germany, by TRL and BASt respectively. As a definite set of test procedures to assess a car's compatibility has not yet been defined, the study was undertaken based on the assumptions of how a compatible car would perform, which are described previously in this report. The GB and German benefit estimates were then scaled to give the benefit for the EU15 countries. The cost of improved compatibility was estimated by Fiat, based on the costs required to modify a current car to meet assumed compatibility requirements. Using this information, the cost benefit ratio was calculated for Europe (EU15).

The benefit of improved compatibility for EU15 was estimated to be between 721 and 1,332 lives saved and between 5,128 and 15,383 seriously injured casualties mitigated per year. Please note that in 2004 there were approximately 33,000 fatalities on the road in the EU15 of which approximately 54% were car occupants. There are a number of limitations to the benefit estimates, the main one being that the possible benefit of improved frontal impact compatibility for side impacts has not been considered.

The cost benefit ratio, defined as value of benefit divided by cost of implementation, was predicted to be between about 4.5 and 0.5. It should be noted that this cost benefit has been calculated for the steady state, when the entire vehicle fleet is compatible. The benefit will be less during the initial years as compatible cars are introduced into the fleet.

An additional significant finding of the GB work was the high frequency of moderate (AIS2) and life threatening (AIS 3+) injuries sustained by car occupants due to seat belt induced loading. The majority of thoracic injury was not prevented by the injury reduction models. There is an argument that a more compatible vehicle would benefit from an improved crash pulse and therefore it would be expected to see lower seat belt loads and a reduced risk of thoracic injury. The models, by their design, did not prevent injury attributed to seat belt loading, and therefore underestimate the potential benefit that could be seen for this body region. This is important to note, as head and thoracic injury are known to be associated with fatal outcomes.

Test Procedures

Following the strategy noted below, this project has focused on the development and evaluation of two approaches for assessing compatibility, the Full Width Deformable Barrier (FWDB) approach and the Progressive Deformable Barrier (PDB) approach.

- Integrated set of test procedures to assess a car's frontal impact protection
    - Address partner and self protection without decreasing current self protection levels
    - Minimum number of procedures
    - Internationally harmonised procedures
- Both full width and offset tests required
    - Full width test to provide high deceleration pulse to assess the occupant's deceleration and restraint system
    - Offset test to load one side of car for compartment integrity

- Procedures designed so that compatibility can implemented in a stepwise manner

Most of the work has focused on the development and initial validation of these approaches for the assessment of structural interaction because this is a requirement for the first step of the current EEVC WG15 route map[12]. However, significant other work has also been performed, such as the development of a metric to measure a car's frontal force levels in an ODB test.

From car to car testing the following beneficial characteristics that influence a car's compatibility, in particular its structural interaction potential, were identified:

- Improved vertical load spreading capability (Can be achieved with additional load paths)
- Strong vertical connections between load paths
- Strong lateral connections able to distribute rail loads
- Adequate compartment strength and frontal force levels, especially for light cars

Also the width of the front structure was also observed to have an effect on the compatibility of the impact. However, further work is needed to determine the relevance of this characteristic.

Initial validation of the FWDB and PDB test procedures has shown that they are both capable of distinguishing these characteristics. However, at the moment it is not possible to choose a definite set of procedures because the FWDB and PDB approaches are so different that an adequate comparison cannot be made between them until they are developed further. To be able to make this comparison and the consequent choice, it is likely that both procedures will have to be developed to a state where the performance criteria and initial proposals for performance limits are determined. At the moment, criteria have been proposed for the FWDB test but are still under development for the PDB test. The current status of each of the approaches is reported including route maps for their possible implementation. Currently, a set of test procedures to assess a car's compatibility and frontal impact performance could be based on the FWDB approach, the PDB approach or a combination of both:

Set 1

- Full Width Deformable Barrier (FWDB) test
    - Structural interaction
    - High deceleration pulse
- ODB test with EEVC barrier
    - Frontal force levels
    - Compartment integrity

Set 2

- Full Width Rigid Barrier (FWRB) test
    - High deceleration pulse
- Progressive Deformable Barrier (PDB) test
    - Structural interaction
    - Frontal force matching
    - Compartment integrity

Set 3

- Combination of FWDB and PDB

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[12] Faerber E (2005). 'EEVC Approach to the Improvement of Crash Compatibility between Passenger Cars', 19th ESV conference, Washington DC, USA, 2005. http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0155-O.pdf

A structural analysis survey was performed to provide information to help interpret test results and develop the test procedures, in particular to help define assessment areas.

Modelling work was performed to support the cost benefit analysis and development of the test procedures. For the benefit analysis a fleet modelling approach was developed and used to demonstrate the benefit of changes to the car design to improve its structural interaction potential. For the development of the test procedures Finite Element models of the FWDB and PDB barriers were developed. Also, work was performed to investigate the frontal force levels required for compatibility and a minimum level of about 350 kN recommended.

8.1.2 Recommendations

This section outlines the recommended work needed to reach the position to make a proposal for a set of test procedures suitable to implement a 1st step to improve compatibility in regulation and / or consumer testing.

- Further definition of compatibility requirements.
  - Finalise the test severity (EES) for regulation test.
  - Finalise assessment criteria for regulation test.
    - Finalise objective assessment procedures to analyse results of car to car tests with respect to:
      - Good structural interaction
      - Good compartment strength
      - Compatible car
  - Finalise a compatibility scale for a rating system.
- Further development of test approaches to the point where a decision on the most appropriate set of test procedures can be made.
  - For the FWDB test major work items are:
    - Confirm test repeatability / reproducibility
    - Refinement of performance criteria (VSI/HSI)
  - For the PDB test major work items are:
    - Confirm that PDB test increases the self protection level of light cars while maintaining self protection level of heavy cars.
    - Continue the development of assessment parameters.
    - Propose and validate assessment criteria when fundamental questions have been answered
    - Propose performance limits when fundamental questions have been answered
    - Confirm test repeatability / reproducibility
- Additional accident analysis to answer remaining questions
  - The GB benefit analysis model predicted that even with improved compatibility thorax injury will still be a substantial problem. Further work is needed to confirm this preliminary conclusion, establish why it is the case (if it is) and propose measures to reduce it. This is an important issue because a possible explanation could be that the injury mechanism in car frontal impacts is no longer predominantly related to compartment intrusion, which is the primary issue that the FWDB and PDB procedures have been designed to address. Hence, it is recommended that this work is performed as soon as possible, in parallel with, or before further development of the test procedures.
  - Structural width has been shown to have a large influence on a vehicle's performance in car to car tests. However, its relevant in real-world accidents is not known, so a decision whether or not tests should assess it cannot be made. Hence, additional accident analysis is required to answer this question.

- Performance limits for 1st step
    - For this a car to car crash testing programme with associated barrier tests will be required to show that cars that meet the performance requirement perform better in car to car tests than those that don't. It is likely that modified cars will be required for this. Some of the tests already performed in the VC-COMPAT project could form a starting point for this programme.
- Cost benefit analysis for implementation of 1st step
    - The results from the test programme to set the performance limits will be used to make the assumptions to perform this analysis.

8.2 Car to truck impact

8.2.1 Conclusions

Accident Statistics and Cost Benefit

A lack of harmonized accident data within Europe was found. The update of national statistics clearly pointed out that there are big differences in the definition, quality of reporting and compilation of statistical data in different countries which makes direct comparison difficult.

The available in-depth accident information indicated that:

- Of all car-to-truck frontal collisions causing serious and fatal injuries, 60 – 90% happen with a relative speed of more than 80 km/h.
- Collisions of cars into the rear end of trucks or trailers, causing passenger compartment intrusion due to underrun, cause severe and fatal injuries at closing speeds of only 30 km/h, especially in cases with small overlap.

On the basis of individual case studies, benefits were predicted in terms of the annual reduction in the number of fatally and seriously injured car occupants in car-to-truck frontal and rear end collisions when appropriate underrun devices were installed. The analyses (including correction for truck types that are exempted from the requirement of having front underrun protection) revealed the following figures for EU15.

When having e.a.FUP compared with existing rigid FUP:

- Reduction of fatalities ~160; benefit 160 M€ - 300 M€
- Reduction of severe injuries ~1200; benefit 100 M€ - 250 M€

When having improved rigid RUP compared with existing rigid RUP:

- Reduction of fatalities ~150; benefit 165 M€ - 300 M€
- Reduction of severe injuries ~1800; 150 M€ - 400 M€

The costs of current, i.e., state-of the-art underrun protection systems and estimates of the add-on cost for advanced FUP and RUP systems were gathered.

- Current 'rigid' FUP devices cost 120 € - 300 € and the cost for a system with engineered energy-absorbing function was estimated to range between 100 € and 200 € per vehicle in addition to the cost of a "rigid" FUP device. Between one and three million Euro for the development, certification and production preparation are considered necessary when introducing a new FUP which has an energy-absorbing capability
- Current RUP devices cost 100 € - 200 € per vehicle. Additional costs ranging from 20 € to 100 € are estimated for 'low profile' improved RUP, while additional costs for more complex folding devices may exceed 200 € per vehicle.

Test Procedures

The overall objective of the project was to develop test procedures leading to improved vehicle crash compatibility. For car-to-truck compatibility test procedures to assess energy absorbing front underrun protection and improved rear underrun protection were developed.

Front underrun protection

A procedure for evaluating and assessing front underrun protection devices regarding their ability to reduce injuries to car occupants in a car to truck frontal collision should be able to assess the following characteristics:

- Does the FUP effectively prevent for underrunning of passenger cars under certain conditions, such as impact speed, impact angle, overlap
- Does the FUP provide sufficient structural interaction potential to ensure its energy absorption capability is activated and that the passenger car can effectively activate its energy absorption capability and the occupant restraint system
- Does the system absorb sufficient energy, within limited self-deformation and at force levels that can be generated by the passenger car during the impact.

The full scale tests that were carried out led to the following conclusions:

- No underrun was seen in any of the tests performed. However, it should be noted that it has been observed that FUP devices currently installed on trucks are generally stronger than regulation requires which is likely to have been a contributory factor to this result.
- In tests performed with a closing speed of 75 km/h dummy injury criteria were below regulatory limits showing the good performance of modern cars in impacts of this severity.
- The difference in frontal structure design in modern cars was seen to cause a substantial difference in the way the car interacted with the energy absorbing FUP and consequently its energy absorption performance to the extent that in one test the eaFUP’s energy absorption capability was not activated at all. .
- The results of two tests which compared the performance of a specially designed energy absorbing FUP and a rigid one showed a significant reduction of up to 25% in dummy injury measures for the energy absorbing FUP.
- Since the previous research carried out by EEVC WG14, the front structure of cars has improved considerably such that they can absorb much greater energy (i.e. higher collision speeds) without exceeding injury criteria thresholds. In the same time period the amount of energy that can be absorbed by an e.a.FUP has remained the same such that it is a smaller proportion of the total crash energy at test speeds where injury criteria become critical with rigid FUPs.

For greater confidence in these conclusions more tests with different passenger cars and other, standard energy absorbing FUP systems, are needed. It may be that new FUP designs, permitting increased energy absorption over a greater deformation length, will be required to achieve the magnitude of benefits predicted by previous research in EEVC WG14. Although the benefit of energy absorption by the FUP was not unambiguously proved with the tests performed, continuation of the project into developing test/evaluation procedures for e.a. FUPs was requested by the EC project officer.

A number of test procedures to assess e.a. FUPs with different levels of complexity/simplification were defined and investigated regarding their advantages and disadvantages compared to full scale tests with passenger cars. Investigated were numerical simulation procedures, quasi-static procedures, and dynamic procedures using a rigid and a deformable impactor with a full truck front and an isolated FUP structure. The deformable impactor which was used was the Progressive Deformable

Barrier (PDB), also used in the car to car leg. A summary of the evaluation of the procedures is given in the Table below.

Table 8-1 Summary of advantages and disadvantages of test procedures

		Advantages	Disadvantages
Test procedure	**Numerical Simulation**	• All test procedures can be simulated • Detailed information can be obtained	• Detailed car models not available • Complicated with detailed car models • Development of car models extremely expensive • Models must be validated
	Quasi-static Test	• Simple • Cheap • Universal impact device • Levels of energy absorption measurable	• Outcome dependent on size of rigid pusher plate • No information on structural interaction • No dynamic influences measurable
	Rigid sled test	• Relatively simple • Relatively cheap • Universal impact device • Dynamic influence is covered	• Outcome dependent on size of rigid impactor face • No information on structural interaction • Rigid contact can lead to damage • Can only measure pass/fail criteria and not quantify energy absorption precisely
	Moving deformable barrier(PDB) test	• Universal impact device • Dynamic influence is covered • Same type of barrier (PDB) is considered for determining car compatibility • Structural interaction can be evaluated • Acceleration data barrier related with average passenger car	• Relatively complicated • Relatively expensive • Complicated relationship between barrier deformation and energy absorption by barrier, which cannot be measured accurately at the moment
	Full scale test	• Real life situation and results directly visible; performance is demonstrated • Information on underrun and compatibility • Data on severity and injury	• Complicated • Expensive • Outcome dependent on car and test specification/parameters • Grading of FUPs only possible if same bullet device is used each test

It was not possible to recommend a specific test procedure because of a lack of baseline test data from the full scale testing. Although the available data show an improvement in the crash performance of a car which impacted a truck with an energy absorbing FUP compared to a rigid FUP, there are no data available which show the higher level of improvement that would be necessary to give the benefit required to justify the introduction of a regulatory test. These data are absolutely necessary to be able to recommend a specific test procedure to assess an energy absorbing FUP and determine its performance criteria and limits.

Rear underrun protection

Accident data and crash tests show that collisions of modern passenger cars into the rear end of a truck/trailer with closing speeds greater than 50 km/h can be catastrophic. This is because many current RUP devices are insufficient to prevent underrun in these conditions (although the same type of impact with the same closing speed does not seem to be a problem for current front underrun protection devices).

A full scale test at a closing speed of 56 km/h with a small family car colliding with the rear end of a trailer supplied with a stronger RUP device (w.r.t. the legislative device) showed that underrun was prevented (although the trailer's longitudinal chassis beam failed locally). The numerically determined load increase together with improved compatibility through increased cross member height and decreased ground clearance could be the basis for an improved directive regarding rear underrun protection.

The analysis was carried out for those vehicles which apply to the highest loading regarding their gross vehicle weight. The influence or consequence of applying the same rules to vehicles with lower Gross Vehicle Weight (GVW) has not been investigated yet.

8.2.2 Recommendations

This section outlines the recommended work needed to define a test procedure for assessment of energy absorbing front underrun protection systems and finalise the proposed procedure for improved rear underrun protection systems for trucks. It also includes suggestions for more accident analyses and cost benefit analyses taking the effect of the latest regulatory measures into account.

Accident investigation and cost benefit

Directive 2000/40/EC (related to ECE Regulation 93) mandated the fitting of 'rigid' FUP devices on new trucks from 2003. The accident and benefit analysis performed in this project used an accident data set in which the vast majority of the trucks were not fitted with rigid FUPs as mandated by the regulation above. Hence, assumptions had to be made in the analysis to account for the effect of fitting rigid FUPs. An update of the analysis with more recent accident data in which more trucks are fitted with rigid FUPs would result in better founded and more reliable estimates regarding the benefit of energy absorbing FUPs.

The present accident analysis and benefit figures are based on the effect of a passenger car impacting the front or rear end of a truck/trailer. The effect of a truck impacting into the side or rear end of a passenger car has not been accounted for, which definitely has an additional benefit. Extension of the analysis in this direction may result in a foundation and justification for further new measures.

Off-road vehicles and other special HGVs are exempted from the current regulations, but may cause accidents with significant injury. It would be worthwhile to investigate how these accidents relate to the overall scene and how these vehicles could be included in the specific regulations.

Front underrun protection

There is a lack of baseline test data showing the benefit of energy absorption by truck front structures. To obtain more data, more full scale tests with different types of vehicles and trucks with energy absorbing FUPs with greater energy absorbing capability are needed. Moreover, the amount of energy which can be absorbed underneath the truck without causing too much underride is limited. And also, the energy absorbing capability and capacity of passenger car front structures has improved to such an extend that impact speeds up to 64 – 75 km/h may well be survivable for passenger car occupants in collision with rigid FUPs. This means that additional structural deformation in the front of trucks may be necessary to achieve the benefits originally expected from energy absorbing FUPs to increase the energy absorbing capacity without permitting too much underrun.

In order to overcome the huge costs of an extensive full scale test programme it is recommended to use finite element simulation techniques. This would allow an evaluation of many parameters in detail. To achieve this in future research programmes both truck and car manufacturers should be involved and willing to contribute by supplying or exchanging models.

The problem of structural interaction needs further investigation. However, when detailed car and truck models are available the necessary information should become available through numerical simulation.

Rear underrun protection

For rear underrun protection systems, the following amendments are recommended to be implemented in regulation ECE R-58 to prevent cars from under-riding trailer and trucks. The detailed requirements and performance criteria are defined as follows (see also **Figure 8-1**):

- Ground clearance of the RUP **max. 400 mm**
- RUP beam height **min. 200 mm**
- Horizontal forces applied successively at **P1 = 110 kN**, at **P2 = 180 kN** and at **P3 = 150 kN**
- The current requirement regarding the reduction of these forces depending on the maximum technically permissible mass of the vehicle may considered to maintain.
- Vehicles now exempted from the current legislation may be included in future legislation in some way.

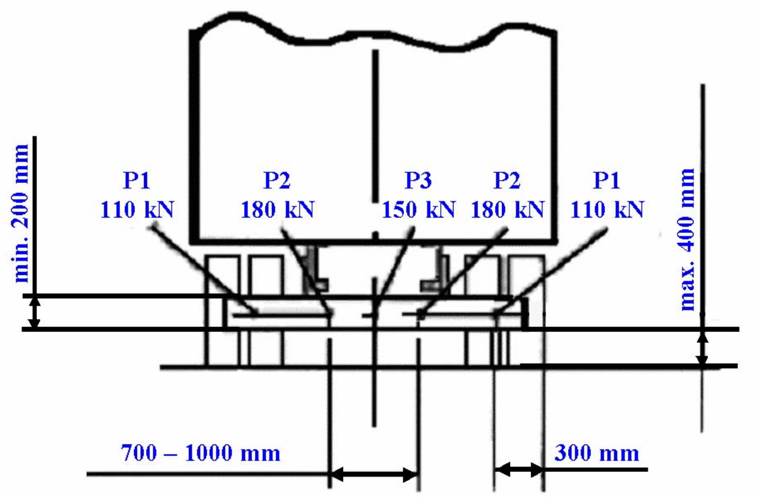

Figure 8-18-2 Overview of recommended requirements for RUP systems for adoption in regulation ECE R-58

It should be noted that VC-COMPAT has only considered amendments to the requirement for vehicles of maximum GVW. Lighter trucks are currently permitted to have reduced test load requirements and the validity of these lower test loads has not been assessed, so further work is needed to do this. In addition to this, practical issues associated with implementing a lower ground clearance at the rear have not been formally assessed. However, anecdotal feedback received at the mid-term and final workshop has suggested that while easily achieved for many trucks some (for example those that travel on trains and ferries) may require more complex and expensive devices in order to meet both the revised regulation and their operational needs.

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- The support of PSA who donated a car for use in the crash testing programme.
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- IVECO and MAN who provided information concerning their front underrun protection systems and performance according to the present standard.
- Trailer manufacturer Grey & Adams who provided their trailer for rear underrun test purposes.

ANNEXES

All the mentioned reports and deliverables can be found on the VC-Compat website, http://vc-compat.rtdproject.net