

EEVC Approach to Develop Test Procedure(s) for the Improvement of Crash Compatibility Between Passenger Cars

Eberhard Faerber
Bundesanstalt für Strassenwesen (BASt)
Federal Highway Research Institute, Germany
on behalf of EEVC WG 15
Paper Number: 07-0331

ABSTRACT

As set out in the *Terms of Reference*, the objective of European Enhanced Vehicle-safety Committee (EEVC) Working Group (WG) 15 *Car Crash Compatibility and Frontal Impact* is to develop a test procedure(s) with associated performance criteria for car frontal impact compatibility. This work should lead to improved car to car frontal compatibility and self protection without decreasing the safety in other impact configuration such as impacts with car sides, trucks, and pedestrians.

Since 2003, EEVC WG 15 served as a steering group for the car-to-car activities in the “Improvement of Vehicle Crash Compatibility through the development of Crash Test Procedures” (VC-COMPAT) project that was finalised at the end of 2006 and partly funded by the European Commission.

This paper presents the research work carried out in the VC-COMPAT project and the results of its assessment by EEVC WG 15. Other additional work presented by the UK and French governments and industry - in particular the European industry - was taken into consideration. It also identifies current issues with candidate testing approaches. The candidate test approaches are:

- an offset barrier test with the progressive deformable barrier (PDB) face in combination with a full width rigid barrier test
- a full width wall test with a deformable aluminium honeycomb face and a high resolution load cell wall supplemented by the forces measured in the offset deformable barrier (ODB) test with the current EEVC barrier.

These candidate test approaches must assess the structural interaction and give information of frontal force levels and compartment strength for passenger vehicles.

Further, this paper presents the planned route map of EEVC WG 15 for the evaluation of the proposed test procedures and assessment criteria.

INTRODUCTION

Since the 2005 ESV-Conference [1] WG 15 continued to focus its research activities on the VC-COMPAT project [2] with unchanged Terms of Reference and Route Map. The VC-COMPAT project was completed in November 2006. It was funded by the European Commission and the contributions of national governments and industry. This paper is a compilation of the latest activities of European Enhanced Vehicle-safety Committee Working Group 15 – Car Crash Compatibility and Frontal Impact (EEVC WG15). Besides the VC-COMPAT project research work the paper comprises information from three main origins: 1) activities of the individual working group members conducted in national or industrial projects; 2) joint research activities involving several working group members; and 3) activities of organisations outside the working group and reported at specific meetings.

Working Group 15 was created in 1996 to develop a better understanding of crash compatibility between passenger cars. This was reported in 2001. The group was then tasked with developing test procedures that would evaluate a vehicle’s frontal crash compatibility. The key characteristics that were deemed to influence compatibility are:

1. Structural interaction (local geometric and stiffness properties that determine how structures will deform)
2. Global force levels (total force / deformation properties that govern how energy dissipation is shared between crash partners)
3. Compartment strength (passenger compartments must be maintain the survival space for the occupants as well as support the deformation processes in the vehicle front).

ACCIDENT AND COST BENEFIT ANALYSIS

General trends in accident data

The historical performance of passenger cars in frontal crashes has been presented to WG15 by VW. The main details were derived from the GIDAS database (Germany). The first important result presented is that the US fatality rate is not improving as quickly as in Europe. This suggests that the reduction in Europe is not part of a global trend, but it is a consequence of the special situation in Europe, as a consequence of European car design and European regulation. Benefits in the European fleet are attributed to increasing levels of self protection.

There are indications that vehicle deformations, in particular compartment intrusions, for both the vehicle and its collision partner are decreasing. The reduced deformations are attributed to increased vehicle stiffness encouraged by recent legislated and consumer test requirements in Europe. Parallel to reduced vehicle deformations are reductions in occupant injury levels (lower proportions of AIS 3+) for both vehicles in the collision. The improvements in occupant safety cannot be solely attributed to post-crash rescue since no improvement in the fatality outcomes were observed for the different MAIS levels over the years of investigation.

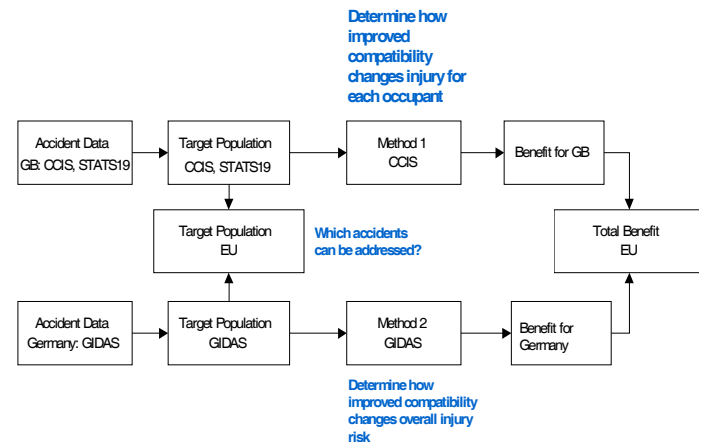
Cost benefit analysis

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 1](#) was followed.

A target population was estimated using data from Germany and Great Britain (GB) and scaled to calculate the target population for the EU15 countries. The target population was defined as the number of casualties who might experience some injury risk reduction as a result of the implementation of improved compatibility. As a definite set of test procedures to assess a car's compatibility was defined, the methodologies were based on the assumptions of how a compatible car would perform.

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.



[Figure 1](#): Benefit analysis approach.

The economic analysis was undertaken by Fiat and considered the fixed, variable, and associated 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.

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.

The costs for improved compatibility show [Table 1](#) below.

	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

Table 1: Cost of implementing compatibility

To estimate the benefit for the EU15 the benefit estimates for GB and Germany were scaled to give the following results, see [Table 2](#).

	Frontal car casualties	Predicted Reduction in EU-15 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

Table 2: Predicted reduction in EU-15 casualties

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, see [Table 3](#). 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 BAST (German Federal Highway Research Institute).

	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

Table 3: Value of EU15 Benefit

From this and the cost information presented above the cost / benefit ratio of improved frontal impact compatibility for the EU15 was estimated, see [Table 4](#).

	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

Table 4: Cost Benefit Ratio of improved compatibility for EU15

As a result of the analysis, the cost benefit ratio appears to be better than 1:1 if all the cost benefit results are considered as a group. These results are independent of any specific crash test procedure for

compatibility and only reflect the total expected benefit of improved compatibility. These estimates should be considered conservative since benefits to other crash configurations (side impact, single vehicle collisions, etc.) have not been included. In addition, the costs for vehicle modifications are likely overestimated, particularly for the worst case conditions.

Further analysis of accident data is needed to observe if other benefits of improved structural interaction can be detected in the current fleet. An improved interaction should provide more predictable crash pulses that facilitate the crash detection and safety system triggering algorithms. It is also expected that improved crash compatibility will lead to better coupling of the occupant and vehicle dynamics during the crash which facilitates the restraint system performance. It is important to use the existing accident data to begin identifying methodologies for analysing these characteristics.

Further accident data analyses are needed to allow the benefit (and cost) analyses to be reported to date updated and improved. In particular, the different analyses conducted with French and GB data identify how small changes to the approach will influence the result and a standardised benefit calculation for improved compatibility is not yet developed. Finally, the cost benefit analysis for a proposed crash test procedure must be recalculated to more accurately reflect the influence of the crash test procedure on vehicle designs. Future activities should be coordinated with EEVC WG21 (Accident Analysis) to ensure the best database and analysis procedures are used.

TEST PROCEDURE STATUS

Overall Development Strategy

To assess a car's frontal impact performance, including its compatibility, an integrated set of test procedures is required. The set of test procedures should assess both the car's partner and self protection. To minimise the burden of change to industry, the set of procedures should contain a minimum number of procedures which are based on current procedures as much as possible. Also, the procedures should be internationally harmonised to reduce the burden further. Above all, the procedures and associated performance limits should ensure that the current self protection levels are not decreased. Good self protection is required for car to car impacts. Also good self protection is required by all vehicles for impacts with road side obstacles.

The set of test procedures should contain both a full overlap test and an offset (partial overlap) test, as both of these tests are required to fully assess a car's frontal impact crash performance. In 2001, the IHRA frontal impact working group recommended the adoption of an offset deformable barrier and full width tests worldwide [3]. A full width test is required to provide a high deceleration pulse to control the occupant's deceleration and check that the car's restraint system provides sufficient protection at high deceleration levels. An offset test is required to load one side of the car to check compartment integrity, i.e. that the car can absorb the impact energy in one side without significant compartment intrusion. The offset test also provides a softer deceleration pulse than the full width test which checks that the restraint system provides good protection for a range of pulses and is not over-optimised to one pulse.

As mentioned previously, compatibility is a complex issue which consists of three major aspects, structural interaction, frontal force matching and compartment strength. To make vehicles more compatible, substantial design changes will be needed which will require some years to implement. Because of this the set of test procedures need to be designed so that compatibility requirements can be introduced in a stepwise manner over a time period of the order of years. This requirement is reflected in the current EEVC WG15 route map [1] which proposes that compatibility should be introduced in two steps which are:

Short term

- Improve structural interaction
- Ensure that force mismatch (stiffness) does not increase and compartment strength does not decrease from current levels

Medium term

- Improve compartment strength, especially for light vehicles
- Take first steps to improve frontal force matching
- Further improve structural interaction

In summary the strategy aims for development of the set of procedures is:

- Integrated set of test procedures to assess a car's frontal impact protection
 - o Address partner and self protection without decreasing current self protection levels
 - o Minimum number of procedures
 - o Internationally harmonised procedures
- Both full width and offset tests required

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

Based on the route map and the previous activities in WG 15, methods to fully assess frontal impact and compatibility can be divided into the following approaches:

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

Sets 1 and 2 have been formally investigated while Set 3 has not been explicitly investigated to date. Further details of the strategies for Sets 1 and 2 and the development of each approach are given in the following sections.

TEST PROCEDURE STATUS, FWDB APPROACH

The Full Deformable Barrier (FWDB) test forms part of an integrated set of two procedures proposed to assess a car's frontal impact crash performance, including its compatibility:

FWDB test:

- (1) To assess structural interaction potential.
- (2) To provide a high deceleration pulse to test the restraint system.

Offset Deformable Barrier (ODB) test with EEVC barrier:

- (1) To assess frontal force levels.
- (2) To load one side of the car to check its compartment integrity.
- (3) To provide a softer deceleration pulse than the FWDB test to check the restraint system performs over a range of decelerations.

Originally the approach also included a high speed (80 km/h) ODB test to measure compartment strength using a Load Cell Wall (LCW). This test is not currently included in the approach because it is thought that adequate control of the compartment strength should be possible using a lower speed (e.g. regulatory or EuroNCAP) ODB test or the PDB test.

FWDB Test

The FWDB test is effectively a modification of the US FMVSS208 test, the modifications being the addition of a deformable element and a high resolution Load Cell Wall. The LCW consists of cells of nominal size 125 mm by 125 mm. The load cells are mounted 80 mm above ground level so that the division line between rows 3 and 4 is at a height of 455 mm which is approximately mid-point of the US part 581 bumper beam test zone¹, see [Figure 2](#). The reason that this particular height was chosen was to be able to detect whether vehicles had structures in alignment with the top and bottom halves of the Part 581 zone by examining the loads on rows 3 and 4 of the LCW. The intention is to enable the test procedure to be used to encourage all vehicles to have crashworthy structures in a common interaction zone that spans the part 581 zone. This should ensure structural interaction between high SUV type vehicles and cars as most cars have their main longitudinal structures in the Part 581 zone to meet the US bumper beam requirement.

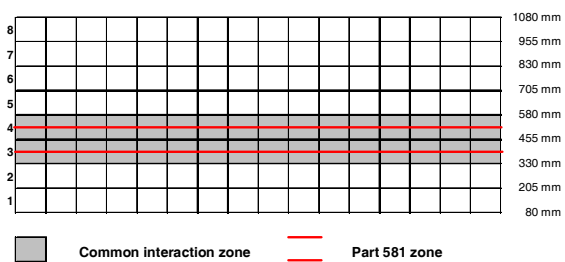


Figure 2: FWDB test LCW configuration showing row number and height above ground level.

¹ Part 581 zone: Zone from 16” to 20” above ground established by NHTSA in its bumper standard (49 CFR 581) for passenger cars.

The purpose of the deformable element has been discussed previously [3]; the main purpose being to improve detection of crossbeam structures which may not be strained in an impact with a rigid wall and to reduce engine dump loading that may otherwise confound the measured force distribution.

The FWDB Test Assessment intention is to control both self and partner protection. For self protection the occupants deceleration and restraint system performance will be assessed using dummy measures in a similar way to the current FMVSS208 test. For partner protection the car’s structural interaction potential will be assessed using the measures from the LCW.

A new criterion, called the Structural Interaction (SI) criterion, has been developed to resolve issues with the previous Homogeneity Criterion [4]. Its details are described in another paper presented at this conference [5], so only a brief description is given here. Its development was based on the following requirements:

- An ability to be applied in a stepwise manner to allow manufacturers to gradually adapt vehicle designs
- To encourage better horizontal force distribution (crossbeams).
- To encourage better vertical force distribution (multi-level load paths).
- To encourage a common interaction area with minimum load requirement.

It is calculated from the peak cell loads recorded in the first 40 ms of the impact. Compared to using peak cell loads recorded throughout the duration of the impact (as with the previous Homogeneity Criterion), this has the advantage of assessing structural interaction at the beginning of the impact when it is more important and minimising the loading applied by structures further back into the vehicle such as the engine. The 40 ms time interval allows detection of structures up to approximately 400 mm from the front of the vehicle, which aligns with a recent NHTSA proposal to assess the Average Height of Force (AHOF) over the initial 400mm vehicle displacement.

The SI criterion consists of two parts which assess the LCW force distribution over two different areas, Area 1 and Area 2. These parts could be applied in two phases to allow manufacturers to gradually adapt vehicle designs to become more compatible. The first part assesses over a common interaction area (Area 1) which is from 330 mm to 580 mm above ground level and consists of LCW rows 3 and 4. The intention of

