DEVELOPMENT OF A HIGH DECELERATION FULL WIDTH FRONTAL IMPACT TEST FOR EUROPE

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ABSTRACT

To assess a vehicle's frontal impact crashworthiness an integrated set of test procedures is required that assesses both the car's self and partner (compatibility) protection. It has been recommended by the International Harmonisation of Research Activities (IHRA) frontal impact group that the set of test procedures should contain both full overlap and offset tests. Currently, in Europe only an offset test is used in regulation and consumer testing. In 2007, the European Enhanced Vehicle-safety Committee (EEVC) made a number of proposals for a set of test procedures, all of which contain full width and offset tests.

This paper presents the work performed by the European Commission 6th framework APROSYS project to develop a full width test procedure for Europe. It also describes an initial cost benefit analysis for its introduction into the European regulatory regime.

Accident analysis was performed using the UK CCIS and German GIDAS databases to help determine the test speed, what size dummies should be used and the relevance of including rear seated dummies in the test. A matrix of 12 full scale car crash tests was performed to determine the effect of including a deformable face, the effect of including rear seated occupants and to assess the test's repeatability and reproducibility. As all the tests were instrumented with a high resolution Load Cell Wall, the repeatability and reproducibility of proposed metrics to assess a car's compatibility were also assessed.

INTRODUCTION

In Europe, around 10,000 car occupants are killed in frontal impact crashes annually. To assess a vehicle's frontal impact crashworthiness, including its compatibility, an integrated set of test procedures is required that assesses both the car's self and partner (compatibility) protection. To minimise the burden of change to industry the set of procedures should contain a minimum number of procedures that are based on current procedures as much as possible. Also, the procedures should be internationally harmonised to reduce the burden further. The set of test procedures should contain both a full overlap test and an offset (partial overlap) test as recommended by the IHRA [1]. A full width test is required to provide a high deceleration pulse to control the occupant's deceleration and check that the vehicle's restraint system provides sufficient protection at high deceleration levels. An offset test is required to load one side of the vehicle to check compartment integrity, i.e. that the vehicle 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.

The European Enhanced Vehicle-safety Committee (EEVC) WG15 has helped co-ordinate work in Europe to understand and develop a set of test procedures to improve a vehicle's frontal impact crash performance. It has found that the main factors influencing a vehicle's compatibility are its structural interaction potential, its frontal force levels and its compartment integrity [2]. In 2007, EEVC WG15 made a number of proposals for potential sets of test procedures, all of which contain both full width and offset tests [3]. These were:

<u>Set 1</u>

- Full Width Deformable Barrier (FWDB) test to assess a vehicle's structural interaction potential and provide a high deceleration pulse to test the restraint system.
- Offset Deformable Barrier (ODB) test with EEVC barrier to assess a vehicle's compartment integrity and frontal force levels and also provide a softer deceleration pulse to test the restraint system.

<u>Set 2</u>

- Full Width Rigid Barrier (FWRB) test to provide a high deceleration pulse to test the restraint system.
- Progressive Deformable Barrier (PDB) test to assess a vehicle's structural interaction, frontal force levels and compartment integrity and also provide a softer deceleration pulse to test the restraint system.

<u>Set 3</u>

- Combination of FWDB and PDB

It should be noted that WG15 have formally investigated Sets 1 and 2, but have not explicitly investigated Set 3 to date.

Currently, in Europe only an offset test is used in regulation and consumer testing. This paper reports the work performed by the European Commission 6th framework APROSYS project to develop a full width test procedure for Europe. It also describes an initial cost benefit analysis for its introduction into the European regulatory regime.

The aim was that this test would be suitable for regulatory implementation in the short term and also have potential for further development to include measures to assess and control compatibility in the longer term.

APPROACH

The approach taken to develop the test procedure was to use review of similar procedures, accident analysis, sled and full scale testing to answer the questions to specify the procedure. The main questions and the work performed to answer them were:

- Test speed?
  An initial proposal for a test speed of 56 km/h was made on the basis that this was the speed used in similar tests. The Full Width Deformable Barrier (FWDB) test has a speed of 56 km/h. Also, a speed of 56 km/h is currently being phased in for the US FMVSS208 rigid barrier test. Accident analysis was performed to check the appropriateness of this proposal.

- Dummy specification?
  The questions to be answered to specify the dummies included: what size dummy (e.g. 5th percentile, 50th percentile) should be used in what seating positions; what injuries should the dummies be capable of assessing; should Hybrid III or THOR-NT dummies be used?
  Accident analysis was performed to provide information on the characteristics of the occupants injured and their injuries to help specify the dummy sizes and the type of injuries that should be assessed. Sled testing was also conducted to assess the repeatability and robustness of the THOR-NT dummy and compare its performance with the Hybrid III for a variety of restraint system types to help assess its suitability for its possible inclusion in the test.

- Assessment of rear seated position?
  At present it is usually assumed that the cost of providing improved protection for the rear seated occupant is likely to be greater than the value of the benefit because of the low occupancy rate. Despite this, assessment of the rear seated position may be required in the future because government policies may demand equivalent levels of protection for front and rear seated occupants and/or encourage car sharing which would increase the occupancy rate. To answer questions arising from this debate, accident analysis was performed to quantify the size of the rear seated injury problem and crash test work was carried out to investigate the feasibility of assessing the rear seated position.

- Deformable barrier face?
  EEVC WG15 has proposed three potential options for a set of test procedures to assess a vehicle's frontal impact crashworthiness. Set 1 and Set 3 contain a full width test with a 'deformable face' and Load Cell Wall (LCW) to take measures to help assess a vehicle's compatibility, whereas Set 2 does not. Because compatibility research was not advanced far enough to recommend a specific option and hence whether or not the test should have a deformable face, it was decided to use crash testing to evaluate the effect of including it to help inform future decisions.

- Repeatability and reproducibility?
  Full scale crash testing was performed to assess the repeatability and reproducibility of the test and to check for any practical or robustness problems. As all the tests were instrumented with a high resolution Load Cell Wall, the repeatability and reproducibility of proposed metrics to assess a car's compatibility were also investigated.

ACCIDENT ANALYSIS

Analysis of the UK CCIS (Co-operative Crash Injury Study) and German GIDAS (German In-Depth Accident Study) accident databases was performed to help answer questions to enable the specification of the draft test procedure [4]. The main criteria used to select cases for the analyses were: vehicles involved in frontal impact with no rollover and occupants belted. Additional criteria were used to select newer vehicles that were Regulation 95 compliant for the majority of the analyses, such as test speed, where including older vehicles was likely to have a significant influence on the results. The criteria used were: for analyses with the CCIS database, vehicles with build year 2000 onwards; for GIDAS, build year 1997 onwards. It was necessary to include a greater proportion of older vehicles in data set for the GIDAS analyses to ensure the sample size was large enough to give statistically meaningful results.

Test Configuration

The CCIS and GIDAS analyses both showed that distributed damage is the most frequent type of damage for all injury severities [Figure 1].

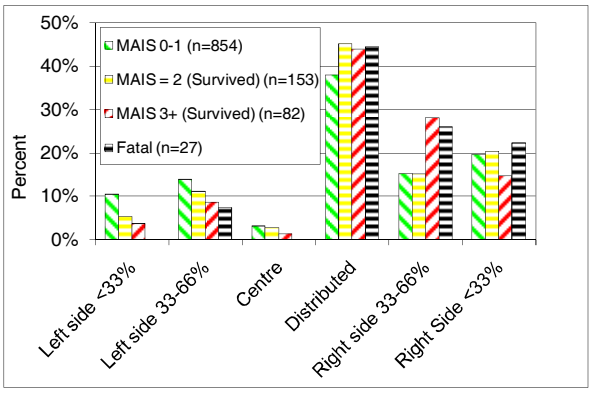

Figure 1. Location of damage by occupant injury severity for belted drivers (CCIS data).

The GIDAS analysis also showed that distributed damage has the highest MAIS 2+ injury risk [Figure 2]. This indicates the need for a full width test in Europe. The injury risk was not calculated for the CCIS analysis because it cannot be easily done because the CCIS data sample is biased.

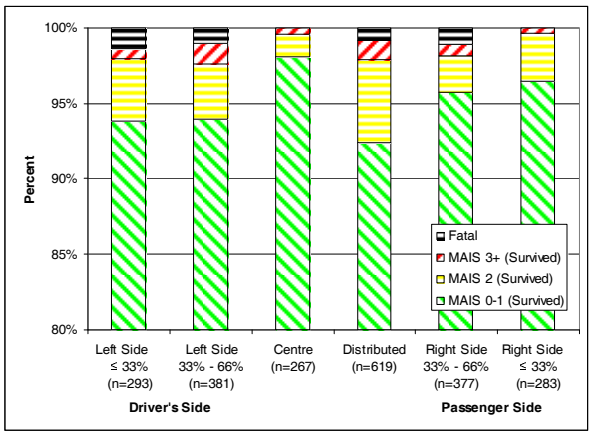

Figure 2. Risk of injury by location of damage for belted drivers.

The CCIS analysis showed that the principle direction of force for the majority of accidents was 0±15° for all injury severities and seating positions. The GIDAS analysis showed similar results. This indicates that a '0° head on' test configuration is the most representative.

Test Speed

The CCIS and GIDAS analyses showed that a test speed of 56 km/h would cover over 80% of MAIS 3+ injuries for belted casualties in frontal impacts with no rollover [Figure 3].

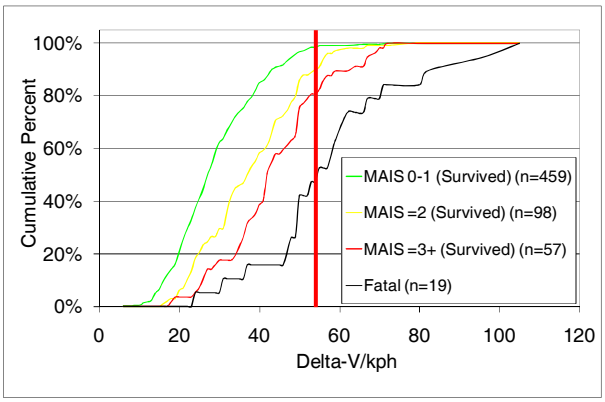

Figure 3. Cumulative frequency plot of distribution of injury against delta V (CCIS data).

Injury type

The CCIS analysis showed that the body regions most frequently injured at the AIS 2 level were the thorax, clavicle and legs for the driver and thorax and clavicle for the front seat passenger. Also, a high number of abdominal (internal organ and lumbar spine) injuries were seen for the front seat passenger. The nature of these injuries requires further investigation to understand why the driver does not also experience this. For the AIS 3+ level the regions were the thorax and legs (femur) for the driver and thorax for the front seat passenger [Figure 4].

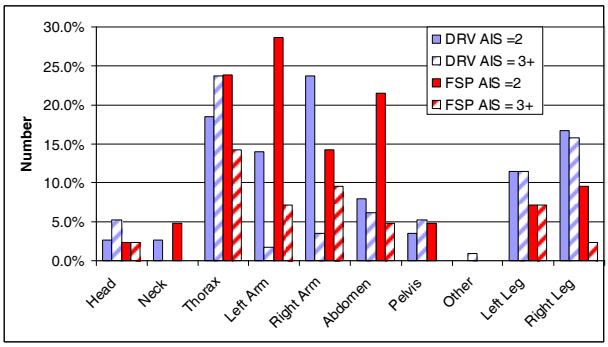

Figure 4. Body region injured for occupants with MAIS 2+ injuries (CCIS data). Note: clavicle injuries are included in arm classification.

The GIDAS analysis showed that the body regions most frequently injured at the MAIS 2+ level were the head and thorax. Further work is required to determine the reason why the GIDAS analysis showed a significantly

higher frequency of head injury than the CCIS analysis. However, it should be noted that the GIDAS data sample contained older vehicles than the CCIS sample (CCIS vehicles build year 2000 onwards, GIDAS 1998 onwards), which may have caused some of this difference.

Occupant characteristics

The GIDAS analysis showed that the driver was usually male (65-77% dependent on injury severity), the front seat passenger usually female (59-69% dependent on injury severity) and the rear seat passenger usually female [Figure 5]. The CCIS analysis gave similar results.

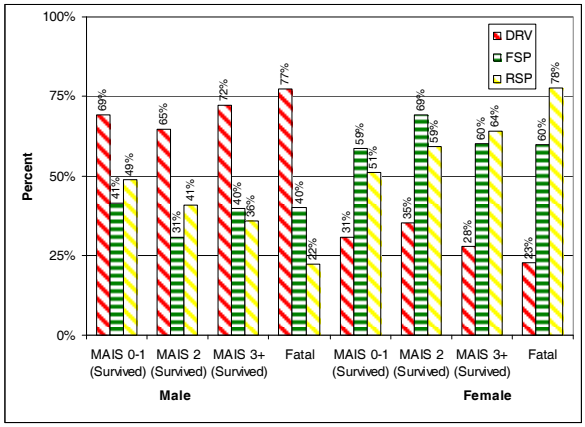

Figure 5. Gender ratio for belted occupants in frontal impacts (GIDAS data).

Further analysis of the GIDAS data showed that the 50th percentile driver was 34 years old, 175 cm tall and weighed 74 kg. The 50th percentile passenger was 30 years old, 169 cm tall and weighed 67 kg. From a choice of the 5th (150 cm, 49 kg) and 50th (175 cm, 78 kg) percentile dummies, the 50th percentile most closely matches these characteristics, indicating that this dummy is the more representative.

For rear seated occupants, the results were similar to those for the front seat passenger indicating that the 50th percentile dummy is the more representative for this position also. It should be noted that children under 12 were excluded from this analysis as it was assumed that they would use a Child Restraint System (CRS). There is a legal requirement in Europe that children under the age of twelve and less than 150 cm tall (135 cm for UK) have to use a CRS.

Rear seated position

Both the CCIS and GIDAS analyses showed that the proportion of occupants wearing a seatbelt was much lower for rear seated occupants compared to front seated ones [Figure 6]. This clearly indicates that there is a problem with the seat belt wearing rate in the rear.

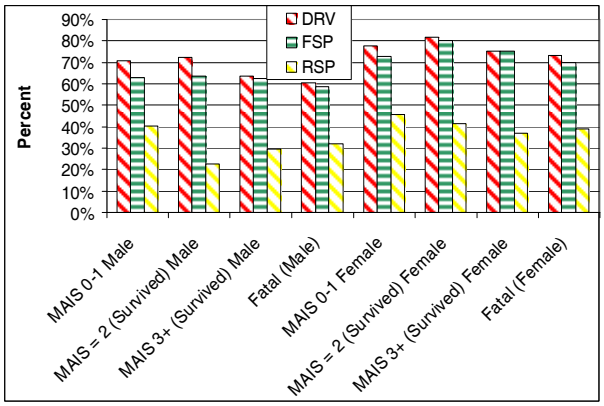

Figure 6. Seat belt usage by injury severity showing relatively low belt usage rate for rear seated occupants.

Further analysis of the GIDAS data showed that the rear seat occupancy rate in collisions was low, about 10% of all occupants involved in collisions are seated in the rear. Also, the analysis showed that if the seatbelt was worn, rear seated occupants have a lower risk of injury than front seated ones.

It was not possible to draw definite conclusions on the type of injury sustained by belted rear seat occupants because of small data sample size. However, the CCIS analysis showed that the body regions injured at the AIS 3+ level for the seven casualties with MAIS 3+ injuries were the thorax, abdomen and legs.

SLED TESTING

A series of sled tests was performed to compare the performance of the THOR-NT dummy to the HYBRID III from the point of view of its robustness, its repeatability and its response to different restraint systems [5]. Because of robustness problems with the THOR-NT dummy, most of which were subsequently solved, test data had to be discarded which resulted in a limited data set for comparison. In terms of injury risk prediction, the limited data showed no significant differences between the dummies. However, in terms of dummy kinematics, slight differences between the dummies were seen. On the basis that specific injury criteria were not available for the THOR-NT dummy and the problems that occurred with THOR-NT in this work, it was decided that the THOR-NT dummy was not well enough developed to include in a test procedure intended for implementation in the short term. Hence it was decided that development of the procedure should continue with the Hybrid III dummy

with an option to upgrade to the THOR-NT dummy in the future.

FULL SCALE CRASH TESTING

Twelve full scale crash tests as shown in Table 1 were performed to investigate the following issues [6]:

- Effect of deformable face compared to rigid wall
- Effect of the introduction of rear seated dummies
- Repeatability and reproducibility
- Practicality and robustness

Table 1. Full scale crash test matrix.

Vehicle	Test Configuration	
	Rigid Wall	Deformable Face
	Test Objective	Test Objective
Supermini 1	Baseline	Baseline
		Reproducibility
Supermini 2	Baseline	Baseline
		Rear occupants
Small Family 1	Baseline	Baseline
	Rear occupants	Rear occupants
		Repeatability
		Reproducibility

Effect of deformable face

The purpose of the deformable face is to make the test more representative of a vehicle to vehicle impact and to enable measures to be taken on a high resolution load cell wall (LCW) to assess a vehicle's compatibility, i.e. its partner protection [7]. The deformable face was designed to achieve this by ensuring that a vehicle's crossbeam structures are loaded in the test as they would be in a vehicle to vehicle impact and that the unrealistic high engine deceleration loads seen in a test with a rigid wall are attenuated, so that the structural loads can be assessed more easily.

Hence as expected, vehicle deformation was different in the tests with and without the deformable face, especially for the front of the lower rails and bumper crossbeam.

The vehicle's compartment deceleration at the start of the impact was slightly lower in the tests with the deformable face compared with those with the rigid wall [Figure 7]. This resulted in a later airbag firing time for the tests with Supermini 2 [Table 2], but made little difference for the other cars tested. This shows that a deformable face may be useful in a full width test to ensure a more realistic assessment of a vehicle's crash sensing capability.

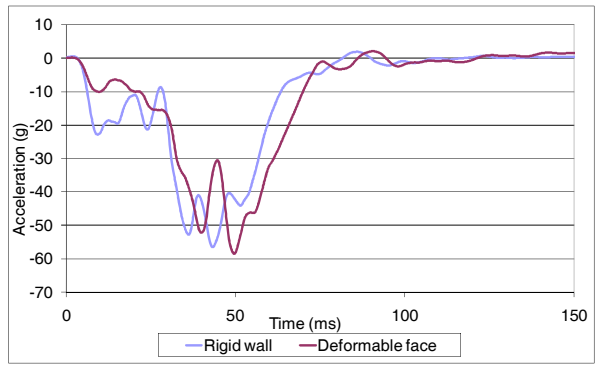

Figure 7. Compartment deceleration for test with 'Supermini 2'.

Table 2. Airbag firing time for test with 'Supermini 2'.

	Driver	Passenger
Rigid wall	12 ms	12 ms
Deformable face	33 ms	33 ms

The dummy injury criteria values were generally similar between the test with the deformable face and the rigid wall test, indicating that the deformable element had little effect on the overall severity of the test [Figure 8]. The exception was for Supermini 2, where the later airbag firing time resulted in substantially higher dummy injury values for the head.

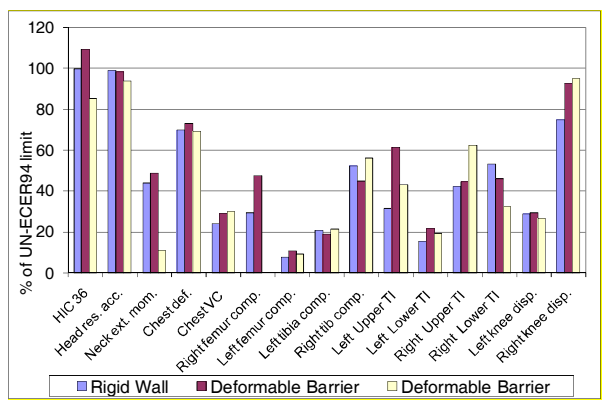

Figure 8. Driver dummy injury criteria values for tests with 'Small family 1'.

The Load Cell Wall (LCW) results also showed significant differences with the deformable face attenuating the engine inertial 'dump' loading seen in the rigid wall test, as expected [Figure 9].

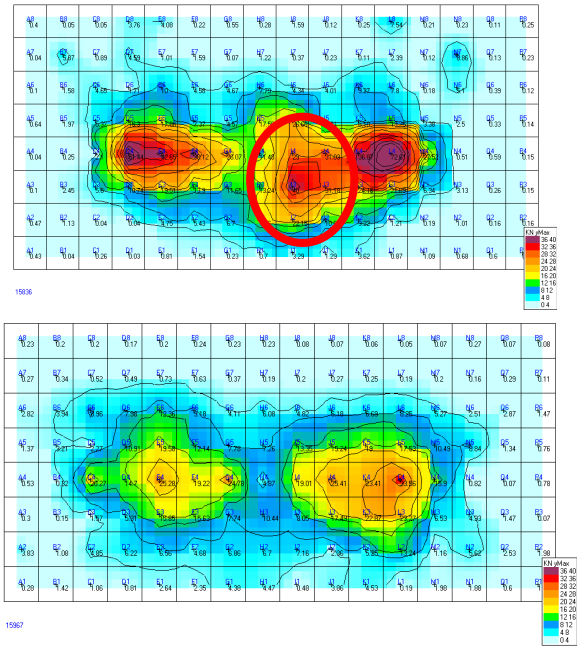

Figure 9. LCW force distribution for tests with 'Small family 1' for rigid wall (top) and deformable face (bottom) tests showing attenuation of engine dump loading for 'Small family 1' tests.

Effect of rear seated dummies

The performance of the front seated dummies did not vary significantly in the tests with and without the rear seated dummies [Figure 10]. Any differences seen could be explained by factors within the range of test repeatability, e.g. the difference between the knee slider values in the 'Small family 1' test was probably caused by the difference in knee interaction with the steering wheel column trim cover.

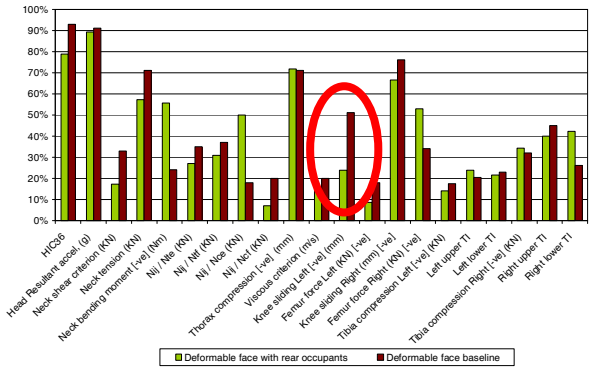

Figure 10. Driver dummy injury criteria values for tests with and without rear seated dummies for test with 'Small family 1'.

There were significant differences for the performance of the rear seated dummies compared to the front seated dummies [Figure 11].

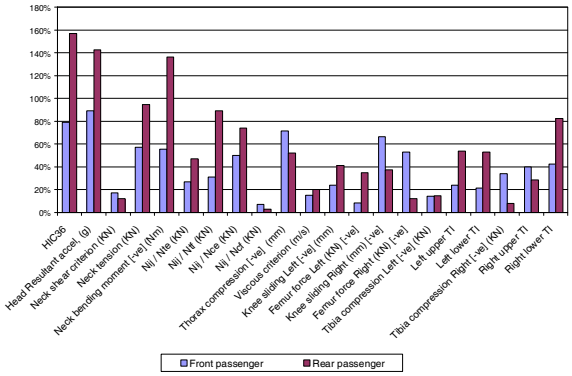

Figure 11. Comparison of front and rear seated dummy performance for driver side dummies for test with 'Small family 1'.

The main differences were the higher head, neck and tibia injury criteria values for the rear seated dummies, which were often substantially higher than the UNECE Regulation 94 performance limits. The higher head and neck values were probably caused by the lack of airbag support for the rear dummies as there was no evidence of interaction of the dummies' heads with the rear of the front seat in any of the tests. The higher tibia values were caused by the interaction of the dummies' lower legs with the rear of the front seat pan.

However, remarkably, even though the shoulder belt loads were substantially higher for the rear seated dummy [Figure 12] the thorax compression values were similar. This is an unexpected result as chest injury is known to be related to seat belt load [8, 9].

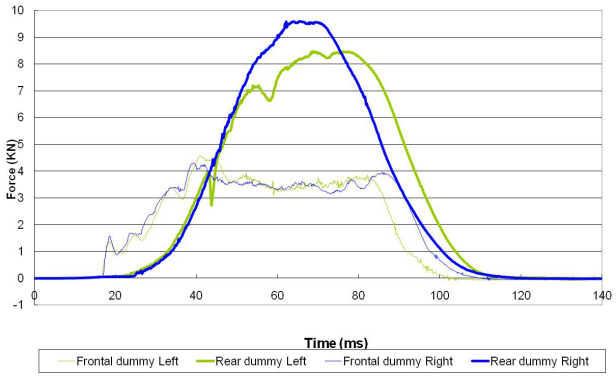

Figure 12. Shoulder belt loads in test with rear seated dummies for test with 'Small family 1'. Loads are substantially higher for rear seated dummies as rear belts do not have load limiters.

Possible contributory factors to this observation include:

- Submarining of the rear seated dummy leading to reduced upper body loading. Note that although there was strong evidence of submarining for the

test with the 'Small family 1' [Figure 13], there was no definite post test evidence of submarining for the test with the 'Supermini 2' However, there were no onboard cameras to monitor dummy motion or iliac load cells to monitor belt loading to the pelvis.

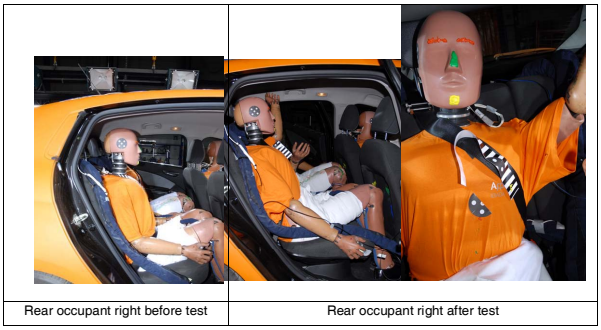

Figure 13. Comparison of belt positioning pre and post 'Small family 1' test for right seated dummy showing evidence of submarining, i.e. lap belt has ridden up off pelvis into abdomen area.

- Difference in routing of the belt for the front and rear seated dummies.
- Capability of Hybrid III dummy to assess thorax injury using the thorax deflection measure. Kent has shown that the relationship between Hybrid III thorax deflection and injury risk is substantially different for belt only, bag only and combined restraint conditions, whereas the injurious level of cadaver chest deflection is not highly sensitive to the load distribution on the chest (i.e. the type of restraint system) [10].

Repeatability and reproducibility

The repeatability and reproducibility of the test with the deformable face was assessed as the repeatability of the test with the rigid face is already well known. Repeatability is defined as the difference between identical tests performed at the same laboratory and reproducibility the difference between tests performed at difference laboratories.

Considering self protection measures, such as dummy injury criteria, it was found that the repeatability and reproducibility were at least as good as for the current UNECE Regulation 94 frontal impact test procedure [Figure 14].

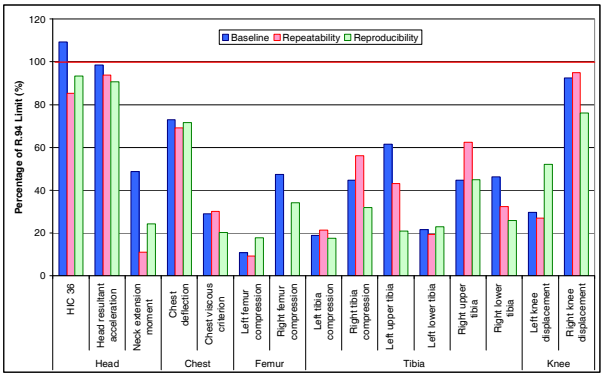

Figure 14. Driver dummy performance for tests with 'Small family 1'.

Considering compatibility (partner protection) measures, such as Load Cell Wall (LCW) force it was found that the global load cell wall force was repeatable and reproducible [Figure 15].

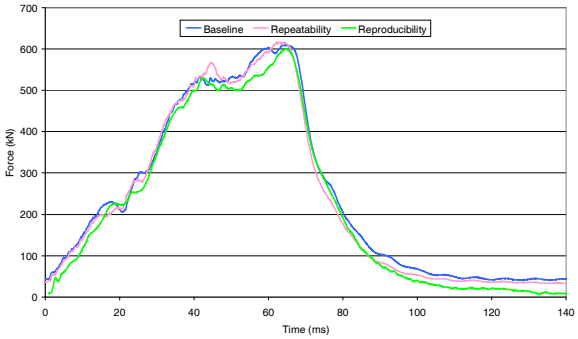

Figure 15. Load Cell Wall (LCW) total force for tests with 'Small family 1'.

For tests with 'Supermini 1' the LCW force distribution was repeatable. However, for the tests with 'Small family 1' the force distribution was not repeatable because of different collapse modes of the left main longitudinal rail [Figure 16].

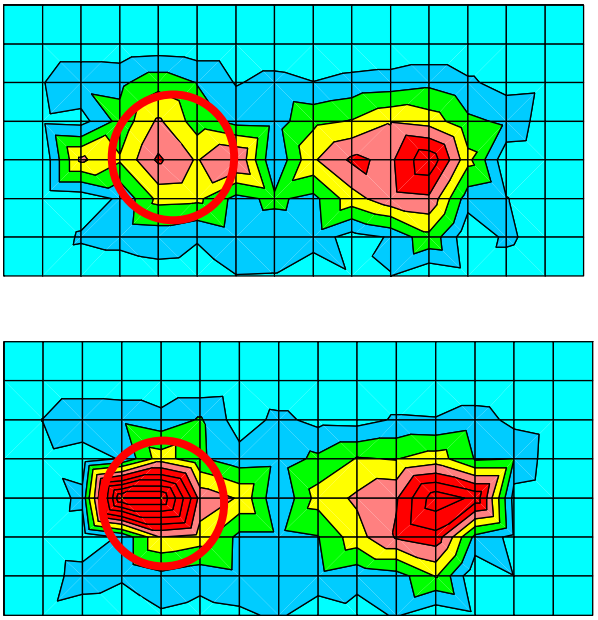

Figure 16. Difference in LCW force distribution in tests with 'Small family 1' caused by different collapse mode of left main longitudinal rail (Note: grid cross points represent centre of load cells).

Recently, the Structural Interaction (SI) metric has been proposed for the assessment of a vehicle's compatibility, in particular its structural interaction potential [11]. The SI metric consists of two components a vertical one (VSI) and a horizontal one (HSI). The repeatability of this metric was assessed for the tests with 'Supermini 1', in which the LCW force distribution was repeatable [Figure 17]. It was found that although the vertical component of the Structural Interaction (VSI) metric was repeatable, the horizontal component (HSI) was not [Table 3]. Note: Borderline value to distinguish between good and poor performing bumper crossbeams is somewhere between 2 and 4.

Table 3. Structural Interaction (SI) metric values for tests with 'Supermini 1'.

	VSI	HSI
Test 1	0.0	4.93
Test 2	0.0	3.26

Further investigation revealed that this was because of the high sensitivity of HSI to small variations (< 5 kN) in individual cell loads. Further development of the SI metric will be necessary to resolve this problem because good repeatability and reproducibility is required for regulatory application.

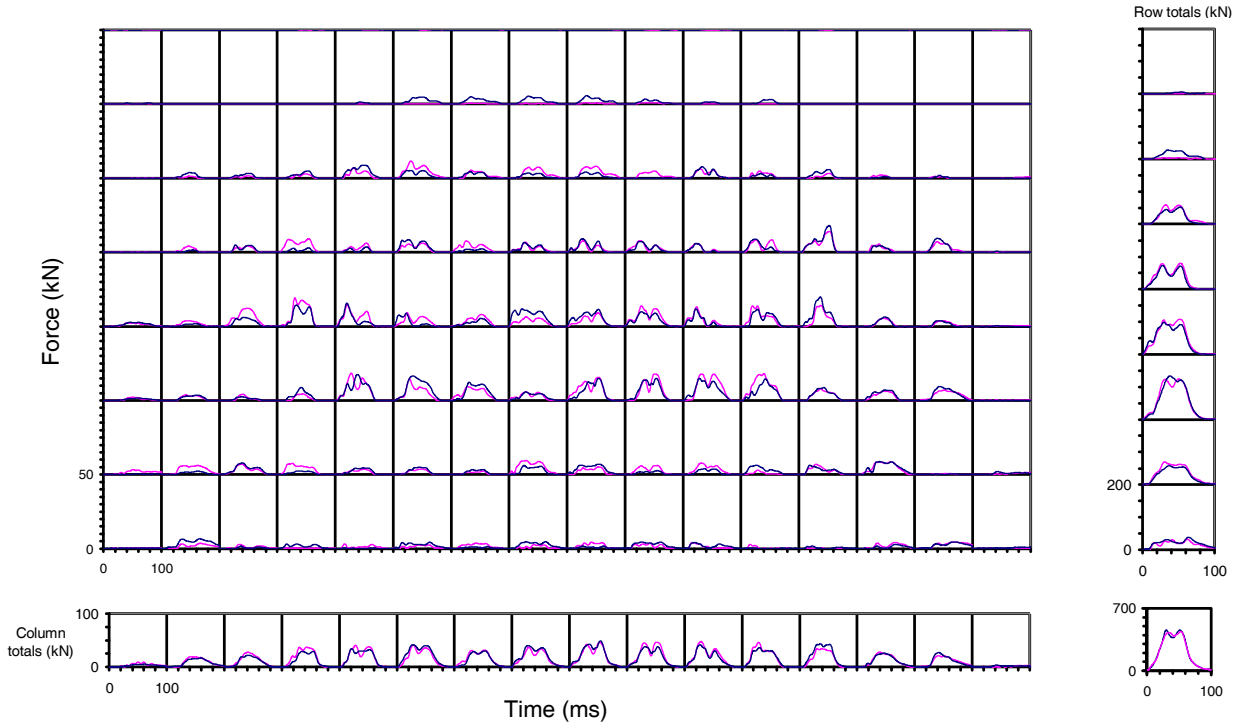

Figure 17. Load Cell Wall (LCW) force distribution for tests with 'Supermini 1'.

Practicality and robustness

No major practical or robustness problems were encountered in the test programme. However, from the experience gained positioning rear seated dummies in 5-door cars used in the test programme, it was thought that for 3-door cars there may be dummy access problems for taking measurements such as pelvic angle.

COST BENEFIT ANALYSIS

An initial cost benefit analysis was performed for the introduction of a full width test into the European regulatory regime [12].

Benefit analysis

The benefit for Europe was estimated by scaling the results from a study which estimated the benefit for GB [13]. Another study, based on German accident data, was also considered for use in this work. However, it was not used because a review of the analysis found that it did not take into account a key confounding factor which, most likely, significantly influenced the results [12].

It is known that a full width test produces a higher compartment deceleration in a car than the offset deformable barrier test, and so it is a more severe test for the restraint systems in the car. Following this argument, the GB benefit analysis was based on the assumption that the introduction of a full width test in Europe would encourage improved restraint systems, which would in turn reduce restraint-induced injury. It was assumed that the main body regions that would benefit from a reduction in restraint-induced injury would be those normally loaded by the webbing of a three-point seat belt, namely the thorax and abdomen. Restraint induced injuries were identified as those which occurred in impacts where the occupant was loaded by the restraint system only, i.e. those where there was little or no steering wheel or compartment intrusion.

The analysis could not be performed using the GB national accident database (STATS19) alone, because it did not contain sufficient information about the casualties' injuries. To resolve this problem, the detailed CCIS database, which contains information about the casualties' injuries for each body region by AIS, was used to estimate a proportional benefit which was scaled to calculate the national benefit.

The following steps were used to calculate the benefit:

- Identify target population in CCIS accident database.
- Calculate proportional benefit in terms of MAIS for casualties in target population.
- Transform benefit in terms of MAIS to police severity scale (fatal, serious, slight, non-injured).
- Scale proportional benefit calculated in CCIS to estimate national benefit.

The Target Population was identified as casualties who were belted and aged less than 65 years involved in frontal impacts with an impact severity less than the test severity (56 km/h) with little or no occupant compartment intrusion (< 5 cm).

The Proportional Benefit was calculated by assessment of the injuries sustained by individual casualties in the target population and how they would be reduced if an improved restraint system was present. The casualties were assessed in terms of both their overall MAIS level and the AIS injury levels sustained by the thorax and abdomen. The MAIS for these casualties was recalculated assuming that thorax and abdomen injuries would be reduced by a maximum of 2 AIS levels, with no injuries being reduced to a level lower than AIS 1 [Table 4].

Table 4. Change in MAIS levels for CCIS data set with restraint induced thorax and abdomen injuries reduced.

MAIS	Original data set (No. of occupants)	Data set with injury reduction (No. of occupants)	Change (No.)
0	296	296	0
1	1084	1174	+90
2	280	219	-61
3	135	115	-20
4	37	29	-8
5	35	34	-1
6	2	2	0
Total	1869	1869	0

This assumption was based on previous work by Cuerden [14] in which expert judgement was used to derive subjective estimates of potential reductions in the severity of an AIS injury to given body regions for the fitment of improved restraint systems. Examples of how this calculation works are given below:

If a casualty had an AIS 5 thorax or abdomen injury, it was reduced to AIS 3. However, if a casualty had an AIS 2 thorax or abdomen injury it was reduced to AIS 1 and there was no reduction for AIS 1 injuries. If the

casualty had an AIS 5 thorax injury and also an AIS 5 head injury even though the AIS 5 thorax injury was reduced to an AIS 3, there was no reduction for the head injury and thus the casualty's MAIS remained at 5.

The distribution of these 'new' MAIS levels was compared with the original MAIS distribution to give an estimated benefit in terms of reduction in MAIS for the casualties in the CCIS target population [Table 4].

Transformation of the Benefit calculated above into the police severity scale (fatal, serious, slight and uninjured) was performed. This was achieved by calculating the percentage distribution of fatal, serious and slight injuries for each MAIS level in the original target population, and using these figures to transform the proportional benefit in terms of MAIS into a proportional benefit in terms of the police injury severity scale.

The National Benefit was estimated by scaling the proportional benefit. This required the definition of equivalent data sets in the CCIS and national (STATS19) data samples to account for factors, such as seat belt use, which are not recorded in STATS19. The benefit for GB was estimated to be a reduction in annual car occupant fatalities of approximately 3 percent (47 occupants) and serious casualties of approximately 6 percent (812 occupants) [Table 5].

Table 5. Annual reduction in car occupant casualties for GB.

	GB National Benefit		
	Original number	Reduction No	Reduction %
Fatalities	1695	47	3
Serious Casualties	14,512	812	6

An additional interesting finding was that if the calculation was repeated using a target population that included elderly casualties, i.e. those over 65 years old, the benefit predicted increased substantially to a 5 percent reduction in fatalities and a 7 percent reduction in seriously injured casualties. This indicates a large potential benefit for restraint systems that could provide better protection to elderly occupants.

The Benefit for Europe (EU15, EU25, EU27) was estimated by simple scaling of the GB benefit. It should be noted that scaling of benefit in this manner will only give an order of magnitude estimate of the benefit for Europe. This is because the accident pattern varies considerably from country to country and hence this type of direct scaling can introduce large errors.

The Monetary Value of this benefit was calculated using GB quoted values for each life saved (£1,489,450) and serious injury avoided (£167,360) [15]. An exchange rate of 1.2 € per £ was assumed. It should be noted that, in general, the GB values are higher than those used for other European countries as they include a 'Willingness to Pay' element. However, they were still used for this analysis because other published values were not readily obtainable. For the EU15 countries the monetary value of the benefit was about €2,000 million per year [Table 6].

Table 6. Estimated benefit for Europe for introduction of full width test.

	Casualties Prevented		Financial Benefit (€Million)
	Fatal	Serious	
EU15	430	6,017	€1,976
EU25	574	8,038	€2,640
EU27	625	8,756	€2,876

Cost analysis

The analysis was based on the cost to modify a typical European car to meet either UNECE Regulation 94 or US FMVSS208 performance limits in a full width test [Table 7]. The 'Small family 1' car tested by APROSYS was assumed to represent a typical European car.

Table 7. Summary of UNECE Regulation 94 and US FMVSS208 performance limits.

Criteria	**Regulation 94 Limits**	**FMVSS208 Limits**
HIC_{36}	1000	1000
HIC_{15}		700
Head Acceleration (3 ms exceedence)	80g	
Neck Extension Moment	57 Nm	
Neck tension +Z		4.17 kN
Neck compression –Z		4.00 kN
N_{ij}		1.0
Chest Deflection	50 mm	63mm
Viscous Criterion	1.00	
Chest acceleration (3 ms exceedence)		60g
Femur Compression	9.7 kN	10.0 kN
Knee Displacement	15 mm	
Tibia Compression	8 kN	
Tibia Index	1.3	

The crash test results for 'Small family 1' were examined. It was seen that to consistently meet Regulation 94 performance limits the driver dummy head and knee injury criteria values would need to be reduced [Figure 18]. It should be noted that it was assumed that manufacturers would set a design target of around 80 to 85% of the performance limit to give a safety margin to allow for factors such as test repeatability.

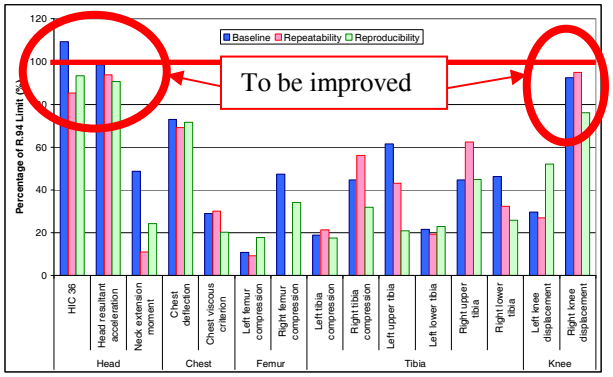

Figure 18. Driver dummy injury criteria values shown as a percentage of the UNECE Regulation 94 performance limits.

From further examination of the results and expert judgement, modifications to the driver restraint system to improve the dummy performance and meet the Regulation 94 performance limits were identified. These modifications included the introduction of a degressive load limiter to improve the head performance and introduction of a double pretensioner to improve the knee performance. This process was repeated for the passenger dummy to identify necessary modifications to the passenger restraint system. Following this, the cost of these modifications was estimated to determine the total cost per car to meet Regulation 94 limits in a full width test. This whole process was repeated to determine the costs per car to meet FMVSS208 limits in a full width test.

These costs were scaled to give an estimate of the total cost per year for the EU15 countries [Table 8]. This was achieved by multiplying the cost per car by the average number of new cars registered per year in the EU15 countries. ACEA data showed this to be 14,221,978 for the years 1999 to 2004 inclusive.

Table 8. Cost of restraint system modifications to meet US FMVSS208 or UNECE Regulation 94 performance limits per car and for the EU15 countries.

Performance limit	Cost per car (€)	Total Cost for EU15 per year (€)
FMVSS208	17	242 Million
UNECE R94	32	455 Million

Many cars sold in Europe are also sold in countries, such as the US, where a full width test is already part of the regulatory requirements. These cars are likely to perform better in a full width test than the typical European 'Small family 1' car on which the analysis was based and therefore require fewer modifications to meet the performance requirements. Hence the costs estimated are likely to be high.

Cost benefit

For EU15, a potential benefit of up to approximately €2,000 million per year was estimated for the introduction of a full width test. A cost of €242 million was estimated to meet FMVSS208 limits in the test and €455 million to meet Regulation 94 limits. Assuming that performance limits similar to the Regulation 94 ones are required to deliver the potential benefit, this results in a benefit to cost ratio of about 4:1. However, more stringent performance limits and other measures are likely to be needed to deliver all of the estimated benefit, which would require additional modifications to the car and inevitably increase the cost. These modifications may include adaptive restraint systems. Further work is required to determine appropriate performance limits and update the cost benefit analysis.

DISCUSSION

The decisions taken related to the main questions to help specify the full width test are discussed and summarised below.

- Test speed – 56 km/h.
  A test speed of 56 km/h was chosen for the following two reasons. Firstly, the accident analysis showed that it covered a large proportion of casualties with life threatening and fatal injuries (over 80% of MAIS 3+ injuries) for belted occupants in frontal impacts with no rollover. Secondly, it is the same speed as the US FMVSS208 test. This should help to harmonise crash tests worldwide to reduce the testing burden on manufacturers.

- Dummy specification – 50th percentile Hybrid III driver and passenger (front seat and rear seat).
  The Hybrid III dummy was chosen on the basis that specific injury criteria were not available for the THOR-NT and the limited data from the sled testing performed showed no significant advantage to using the THOR-NT dummy compared to the Hybrid III. However, an upgrade to the THOR-NT dummy could be considered at a later date if significant advances are made in its development, in particular regarding assessment of restraint induced thorax injury.

  50th percentile male dummies were chosen for driver and passenger (front and rear seated) occupant positions on the basis of the results from the analysis with the German GIDAS database. However, it is advised that further analysis is performed using data from European countries besides Germany to verify this choice. For the driver, the analysis showed that the gender median height and weight all corresponded well to the 50th percentile male. For the front and rear seat passengers, the analysis showed that a slightly shorter, lighter female dummy would be a better match to the median occupant, but the 5th percentile female dummy was too short and light to represent a median occupant.

  The accident analysis also indicated that key body regions to protect were the head, thorax, femur and clavicle, with emphasis on the head and thorax to reduce fatalities.

- Assessment of rear seated position – undecided.
  The crash testing work showed that the inclusion of rear seated dummies did not influence the assessment of the front seated position, indicating that testing this seat position is feasible. Comparison of the injury criteria values for the front and rear seated dummies showed that the main differences were higher head, neck and tibia values for the rear seated dummies. The tests with the 'Small family 1' car showed strong evidence of submarining. In addition, it was noticed that the thorax deflection values were similar for the front and rear seated dummies even though the belt loads were substantially higher for the rear seated dummies. Several possible contributory factors were identified to explain this observation, one of them being the different relationship between thorax deflection and injury risk for the Hybrid III dummy for belt only and combined airbag and belt restraint systems identified by Kent [10]. This factor has interesting consequences, namely if it was decided to test the rear seat position and to drive an equivalent level of safety protection for the thorax to that offered in the front, then different performance limits would be needed for the chest deflection for the rear dummies to account for the different injury risk functions for belt only and belt and airbag restraints.

  The main finding from the accident analysis was that the proportion of rear seated occupants wearing a seatbelt was much lower than for front seated occupants. This clearly indicates that there is a problem with the seat belt wearing rate in the rear. The accident analysis also found that the rear seat occupancy rate in collisions was low, about 10% of all occupants. The analysis with the GIDAS database showed that the risk of injury for belted occupants in the rear was lower than for the front. However, other recent studies have indicated that for the elderly the risk of injury is higher in the rear than the front [16].

  In summary, the crash tests performed showed no major technical obstacles to include rear seated dummies in the test. However, the accident analysis work showed that the seat belt wearing rate in the rear was substantially lower than for the front and the rear seat occupancy rate is currently low. One way to help improve the seat belt wearing rate could be the fitment of seat belt reminder systems for rear occupants. These and other factors need to be considered further, in particular from a cost benefit point of view, before a decision can be made whether or not to assess the rear seated position.

- Deformable barrier face – undecided.
  As mentioned previously, the main purpose of the deformable face is to help take measurements of a vehicle's compatibility potential and to make the test more representative of a vehicle to vehicle impact, in particular at the beginning of the impact [4]. EEVC WG15 has proposed three potential options for a set of test procedures to assess a vehicle's self and partner (compatibility) protection, two of which include a full width test with a deformable face. However, the research is not far enough advanced to decide which of these options should be taken forward and hence whether or not a deformable face is required to take compatibility measurements. If a full width test was to be introduced in the longer term it is expected that this research would be complete and hence the decision made. However, the aim of APROSYS was to develop a test that could be introduced in the short term and hence test work was performed to assess the effect of the deformable face on the assessment of a vehicle's self protection capability.

For the three cars tested the dummy injury criteria values were generally similar between the tests with and without the deformable face indicating that the deformable element had little effect on the overall severity of the test. However, for one car the airbag fired later in the test with the deformable face which resulted in substantially higher dummy injury values for the head. This was most likely caused by the lower compartment deceleration at the beginning of the impact, which is more representative of a vehicle to vehicle impact. This shows that a deformable face may be useful in a full width test in the short term to ensure a more realistic assessment of a vehicle's crash sensing capability. However, the author is not aware of studies showing that there is a problem with late airbag firing in these types of accidents in the real world. Moreover, it should be noted that current regulatory full width tests, such as FMVSS208, do not have a deformable face, so for harmonisation purposes it would be best not to include one in a test for Europe. To make a decision these advantages and disadvantages will have to be weighed up, most likely by governmental and/or regulatory bodies.

- Repeatability and reproducibility
  Full scale crash testing was performed to assess the repeatability / reproducibility of the test. As all the tests were instrumented with a high resolution Load Cell Wall, the repeatability and reproducibility of proposed metrics to assess a car's compatibility were also investigated.

  For self protection measures, such as dummy injury criteria, it was found that the repeatability and reproducibility were at least as good as for the current UNECE Regulation 94 test procedure.

  For partner protection measures, it was found that although the global Load Cell Wall (LCW) force was repeatable for all tests, the LCW horizontal force distribution was not because of different failure modes of the vehicle's main rail. For the Structural Interaction (SI) metric it was found that although the vertical component was repeatable, the horizontal one was not even when the LCW horizontal force distribution was repeatable. This indicates that although assessment of a vehicle's partner protection using LCW measurements and associated metrics shows promise, further development is required to improve repeatability to ensure suitability for regulatory application.

CONCLUSIONS

The APROSYS project has developed a full width test procedure suitable for regulatory application in Europe in the short term to assess a vehicle's self protection capability. An initial cost benefit analysis has also been performed.

However, some issues remain to be resolved to complete the specification of the procedure. These include:

- Definition of performance criteria and limits.
  The cost benefit analysis indicated a benefit to cost ratio of 4:1 assuming that performance limits similar to the Regulation 94 ones are required to deliver the estimated benefit. However, more stringent performance limits and other measures are likely to be needed to deliver all of the estimated benefit. These may include adaptive restraint systems and an improved dummy for the assessment of thorax protection. Further work is required to determine appropriate performance limits and update the cost benefit analysis.
- Deformable face
  The crash tests results showed that a deformable face could be useful to help ensure a more realistic assessment of a vehicle's crash sensing capability. However, a deformable face is not currently included in any worldwide regulatory or consumer testing and hence would be disadvantageous from the point of view of harmonisation. To decide whether or not to include a deformable face these advantages and disadvantages need to be weighed up, most likely by governmental and/or regulatory bodies.
- Rear seat position
  The crash tests performed showed no major technical obstacles to include rear seated dummies in the test. However, the accident analysis work showed that the seat belt wearing rate in the rear was substantially lower than for the front and the rear seat occupancy rate is currently low. These and other factors need to be considered further, in particular from a cost benefit point of view, to make a decision of whether or not the rear seat position should be tested.

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