Mervyn Edwards, Marcus Wisch, Claus Pastor, Jennifer Price, Jeremy Broughton, Thorsten Adolph

FIMCAR
XIII – Cost Benefit Analysis

frontal impact and compatibility assessment research

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EXECUTIVE SUMMARY

Although the number of road accident casualties in Europe is falling the problem still remains substantial. In 2011 there were still over 30,000 road accident fatalities [EC 2012]. Approximately half of these were car occupants and about 60 percent of these occurred in frontal impacts. The next stage to improve a car's safety performance in frontal impacts is to improve its compatibility for car-to-car impacts and for collisions against objects and HGVs. Compatibility consists of improving both a car's self and partner protection in a manner such that there is good interaction with the collision partner and the impact energy is absorbed in the car's frontal structures in a controlled way which results in a reduction of injuries. Over the last ten years much research has been performed which has found that there are four main factors related to a car's compatibility [Edwards 2003, Edwards 2007]. These are structural interaction potential, frontal force matching, compartment strength and the compartment deceleration pulse and related restraint system performance.

The objective of the FIMCAR FP7 EC-project was to develop an assessment approach suitable for regulatory application to control a car's frontal impact and compatibility crash performance and perform an associated cost benefit analysis for its implementation.

This deliverable reports the cost benefit analysis performed to estimate the effect of the following potential changes to the frontal impact regulation:

- Option 1 – No change and allow current measures to propagate throughout the vehicle fleet.
- Option 2 – Add a full width (FW) test to the current offset Deformable Barrier (ODB) test.
- Option 3 – Add a full width test (FW) and replace the current ODB test with a Progressive Deformable Barrier (PDB) test.

The following conclusions were made:

- For the benefit analysis it was assumed that the introduction of a full-width test with appropriate compatibility and dummy metrics has the potential to address the frontal impact issues under/override related to structural alignment and restraint related acceleration type injuries. Limited potential of the full width test was expected for addressing fork effect issues. It was also assumed that the replacement of the ODB by the PDB/MPDB test procedure with an appropriate homogeneity metric had the potential to address the frontal impact issues under/override related to vertical load spreading, fork effect and low overlap as well as frontal force matching/compartment strength.
- The benefits of three potential changes to the frontal impact regulation were calculated for GB and Germany and scaled to give an indicative estimate for Europe.
    - For Option 1 'No change', a small benefit of about 2.0% or less of all car occupant Killed and Seriously Injured (KSI) casualties was estimated;
    - For Option 2 'Add FW test: Benefit of 5% to 12% of all car occupant KSI casualties was estimated. It was shown that this benefit consisted of:
        - Structural alignment (under/override related to structural alignment): 0.3% - 0.8%. However, it should be noted that the benefit related to structural alignment was likely to be under-estimated.
        - Restraint system: (restraint related deceleration related injuries): 5% - 11%

   - For Option 3 'Add FW test and replace ODB test with PDB test' 9% to 14% of all car occupant KSI casualties.
   - Note: Benefit percentages for Options 2 and 3 do not include the benefit of Option 1 'No change'.
- Break-even costs for options 2 and 3 were calculated. Comparison of these costs with costs estimated by previous projects indicated that the monetary value of the benefits of implementing Option 2 should be greater than the costs to modify the cars for restraint system changes. However, further work is needed to determine precisely what changes would be needed to deliver the injury reduction assumed for the benefit analysis and precisely what test configuration (in particular dummies) and performance limits would be needed to enforce these changes.

The following points should be noted:

- The benefit was calculated assuming the implementation of complete assessment procedures. However, appropriate dummy assessment values and dummy selection were not addressed by FIMCAR and appropriate PDB/MPDB metrics are not yet established.
- Possible further potential benefits from the definition of a common interaction zone related to truck underrun protection and roadside guard rails were not considered in the study.

1 INTRODUCTION

1.1 FIMCAR Project

Although the number of road accident casualties in Europe is falling the problem still remains substantial. In 2011 there were still over 30,000 road accident fatalities [EC 2012]. Approximately half of these were car occupants and about 60 percent of these occurred in frontal impacts. The next stage to improve a car's safety performance in frontal impacts is to improve its compatibility for car-to-car impacts and for collisions against objects and HGVs. Compatibility consists of improving both a car's self and partner protection in a manner such that there is good interaction with the collision partner and the impact energy is absorbed in the car's frontal structures in a controlled way which results in a reduction of injuries. Over the last ten years much research has been performed which has found that there are four main factors related to a car's compatibility [Edwards 2003, Edwards 2007]. These are structural interaction potential, frontal force matching, compartment strength and the compartment deceleration pulse and related restraint system performance.

The objective of the FIMCAR FP7 EC-project was to develop an assessment approach suitable for regulatory application to control a car's frontal impact and compatibility crash performance and perform an associated cost benefit analysis for its implementation.

Within the FIMCAR project off-set, full overlap and MDB test and assessment procedures were developed further with the ultimate aim to propose a compatibility assessment approach. This should be accepted by a majority of the involved industry and research organisations. The development work will be accompanied by harmonisation activities to include research results from outside the FIMCAR consortium and to disseminate the project results early, taking into account recent GRSP activities on ECE R94, Euro NCAP etc.

The FIMCAR project is organised in six different RTD work packages. Work Package 1 (Accident and Cost Benefit Analysis) and Work Package 5 (Numerical Simulation) are supporting activities for WP2 (Offset Test Procedure), WP3 (Full Overlap Test Procedure) and WP4 (MDB Test Procedure). Work Package 6 (Synthesis of the Assessment Methods) gathers the results of WP1 – WP5 and combines them with car-to-car testing results in order to define an approach for frontal impact and compatibility assessment.

1.2 Objective of this Deliverable

The main objective of the work for this deliverable was:

- Determine the benefits and costs of improved frontal impact compatibility for the following options:
  - Option 1: No change, i.e. progression to baseline
    - Baseline is defined to be a vehicle fleet in which all vehicles have safety performance level that is at least equivalent to that required to be UNECE Regulation 94 compliant. Legislation mandates that all new types of cars registered post 1st Oct 1998 shall be Regulation 94 compliant and all cars registered post 1st Oct 2003 shall be Regulation 94 compliant. It should be noted that the safety performance levels of many of these vehicles will be much higher than that required by Regulation 94 because of the influence of programmes such as Euro NCAP.
  - Option 2: Add Full Width (Deformable Barrier) test

- Option 3: Add Full Width test and replace the current Offset deformable Barrier (ODB) test with a Progressive Deformable Barrier (PDB) test.

Specific objectives were:

- Benefits
  - Identify casualty target populations for GB and Germany
  - Estimate benefits for GB and Germany and convert into a monetary value
  - Scale to give indicative estimate for Europe
- Costs
  - Derive 'break-even' costs per vehicle and compare with cost estimates from previous projects

Note: 'Break-even' costs are the costs when there is a cost to benefit ratio of one and are calculated by converting the benefit into a monetary value and dividing this value by the number of new cars registered annually.

It should be noted that some additional analyses were performed for GB to estimate:

- Benefit of Option 1 'No change' for casualties in side impacts.
- Target population of casualties in car struck on the side for car-to-car side impacts in which the side impact compatibility of the striking car has been improved.
- Benefits of different variants of Option 3, e.g. a PDB test that only addressed the fork effect structural interaction instead of all of the structural interaction issues, i.e. over/underride, fork effect and low overlap.

1.3 Structure of this Deliverable

This deliverable starts with a description of the approach followed for this study. It then describes the accident databases used. This is followed by sections describing the benefit analyses performed for GB, Germany and Europe, respectively. The next section describes the cost analysis. The final section summarises the conclusions of the study.

2 APPROACH

The overall approach was that separate analyses were performed to estimate the benefits for Great Britain (GB) and Germany (D) for each option. These results were scaled to give an indicative estimate of the benefits for Europe. Break-even costs per car i.e. a cost benefit ratio of one, were calculated by converting the benefit into a monetary value using published casualty costs for fatal, serious and slight injuries and dividing this value by the number of new cars registered annually. These costs were compared with costs calculated in previous projects such as VC-COMPAT [Cuerden 2006] and APROSYS [Edwards 2008] for other potential regulatory changes related to car crash compatibility. These steps are described in greater detail in the bullet points below:

- Estimate benefit of Option 1 'No change' to get to baseline which is the starting point for the estimate of the benefit of future changes
- Estimate target populations and benefits for Options 2 & 3 for GB and Germany and scale to give indicative estimate for Europe.
  - Both national and detailed accident databases were used for this work. National data will be used to determine high level information such as the number of car occupant casualties in frontal impacts. Detailed data will be used to obtain sufficient information to be able to estimate what level of injury reduction, if any, the casualty would experience if the potential regulatory changes being investigated were made.
- Convert benefits into monetary values using government published values for preventing, fatal, serious and slightly injured road accident casualties, calculate break-even costs and compare with cost estimates from previous projects such as:
  - VC-COMPAT FP5 project
  - APROSYS FP6 project.
  - EEVC WG13/21 costs and benefits study for improved side impact.

To ensure that the results were appropriate for use to identify compatibility issues in the current fleet and help develop changes to the current legislation (UN-ECE Regulation 94) as far as was possible only Regulation 94 compliant vehicles (or those with an equivalent safety level) were selected for this work. The legal situation for frontal impact type approval within the European Union is:

- Since 1 October 1998 the Frontal Impact Directive 96/79/EC (equivalent to Regulation 94) was mandated for type approval of new vehicle types within the European Union.
- Since 1 October 2003 an approval was mandated for the first registration of a vehicle.

As a result of 96/79/EC, all vehicles in the fleet registered since 1st October 2003 are Regulation 94 compliant and vehicles registered before this date may not be compliant. However, many vehicles registered between 1st Oct 1998 and 1st Oct 2003 may be compliant. In the accident data vehicle registration year information is available. Hence, this parameter was used to help select Regulation 94 compliant vehicles. The precise details of how this was achieved are given in following sections for each of the accident databases analysed.

Because of differences between the accident databases, slightly different methodologies were used for the GB and German benefit analyses. However, the spirit of the methodologies was kept as similar as possible. The accident databases, both methodologies and associated results are described in the sections below.

3 DESCRIPTION OF ACCIDENT DATABASES

A description of the accident databases used for this work is given below.

3.1 Great Britain

3.1.1 STATS19 National Accident Statistics

STATS19 data is comprised of the details of road traffic accidents attended by the police in Great Britain. In theory the police are required to attend every road traffic accident that involves an injury and whilst on scene officers fill out a series of standard forms. Details of the nature of the accident, the location, a crude classification of injuries and the overall accident severity are all collected. Officers make a judgement, often without further information from hospitals, and record the severity of the injured casualties and the overall accident as 'slight', 'serious' or 'killed'. This data is then collected, collated and analysed by the UK Department for Transport (DfT).

STATS19 is, in principle, the national database in which all traffic accidents that result in injury to at least one person are recorded, although it is acknowledged that some injury accidents are missing from the database and a few non-injury accidents are included. The database primarily records information regarding where the accident took place, when the accident occurred, the conditions at the time and location of the accident, details of the vehicles involved and information about the casualties. Approximately 50 pieces of information are collected for each accident [RRCGB 2010].

The severity of the casualties involved in the accident is assessed by the investigating police officer. Each casualty is recorded as being either slightly, seriously, or fatally injured. Fatal injury includes only casualties who died less than 30 days after the accident, not including suicides or death from natural causes. Serious injury includes casualties who were admitted to hospital as an in-patient. Slight injury includes minor cuts, bruises, and whiplash. The full definitions of these injury severities (and all other information recorded in STATS19) are given in the STATS20 document which accompanies the STATS19 form. These definitions are also available online at www.stats19.org.uk. Accidents that are recorded in STATS19 are summarised annually in the DfT "Reported Road Casualties Great Britain" (RRCGB) series.

Data for accidents from 2008 to 2010 inclusively were used for this analysis.

3.1.2 CCIS Detailed Accident Database

The Co-operative Crash Injury Study (CCIS) collected in-depth real world crash data from 1983 to 2010. Vehicle examinations were undertaken at recovery garages several days after the collision. Car occupant injury information was collected from hospitals and questionnaires sent to survivors. Multi-disciplinary teams examined crashed vehicles and correlated their findings with the injuries the victims suffered to determine how the car occupants were injured. The objective of the study was to improve car crash performance by developing a scientific knowledge base, which has been used to identify the future priorities for vehicle safety design as changes take place.

Accidents were investigated according to a stratified sampling procedure, which favoured cars containing fatal or seriously injured occupants as defined by the British Government definitions of fatal, serious and slight. In order for an accident to be included in the study, a "newer" car must have been involved – one that was 7 years old or younger at the time of the accident. CCIS data collected from June 2000 to March 2010 were used for this study.

The stratified sampling procedure means that CCIS records a relatively large number of fatal and serious accidents, which are often the most interesting from an injury prevention point of view.

CCIS data from phases 7 and 8, which encompass accidents collected from June 2000 to March 2010, were used for this analysis.

3.2 Germany

3.2.1 German National Accident Statistics

The statistical recording of all police reported traffic accidents in Germany is reported in the national statistics hosted by the German Federal Statistical Office. Survey records for the statistics of road traffic accidents are the copies of the standard traffic accident notices as used for the entire Federal Republic which are completed by the police officers attending the accident. After its transfer to data recording media, the information included in the accident notices is tabulated on a monthly and annual basis at the statistical offices at the states according to a standard programme for the entire Federal Republic. The state results are compiled to the federal result.

Data for accidents from 2005 to 2007 inclusively were used for this analysis.

3.2.2 GIDAS

GIDAS (German In-Depth Accident Study) is the largest and most comprehensive in-depth road accident study in Germany. Since mid 1999, the GIDAS project investigates about 2000 accidents in the areas of Hanover and Dresden per year and records up to 3000 variables per crash. The project is supported by the Federal Highway Research Institute (BASt) and the German Association for Research in Automobile Technology (FAT) [Otte 2003].

In GIDAS, road traffic accidents involving personal injury are investigated according to a statistical sampling process using the "on the scene" approach. That means, teams are called promptly after the occurrence of any kind of road traffic accident with at least one injured person which occurred in determined time shifts. Along with this method, severe accidents are recorded slightly more frequently than accidents with lower injury severities and this is mainly caused by a lower notification rate or late information. In order to avoid such biases in the database and to approach regional and national representativeness, comparisons are made regularly with the official accident statistics and e.g. the investigation areas were chosen accordingly to the national road network and built-up areas.

The detailed documentation of the accidents is performed by survey teams consisting of specialised students, technical and medical staff. The data scope includes technical vehicle data, crash information, road design, active and passive safety systems, accident scene details and cause of the accident. Surveyed factors include impact contact points of passengers or vulnerable road users, environmental conditions, information on traffic control and other parties (road users) involved. Additionally, vehicles are measured more in detail, further medical information is gathered and an extensive crash reconstruction is performed.

Data for accidents from 2000 to 2010 inclusively were used for this analysis.

3.3 European CARE Database

CARE contains basic data on all accidents as collected by most EU member states, i.e. data from national databases.

Data from 2008 were used for this analysis or nearest preceding year if not available.

4 GB ANALYSIS

This study used STATS19 data from road traffic accidents that occurred in the years 2008 to 2010 inclusive. It also used CCIS data from phases 7 and 8, which includes accidents collected from 2001 to 2010. Using the STATS19 data the numbers of fatally injured and seriously injured occupants by 'user type' and year are summarised in Table 1 and illustrated in Figure 4.1. Figure 4.1 also shows the breakdown of impact types (frontal, side or other) for fatally injured and seriously injured car users.

Table 1: STATS19 (national data) road accident casualties

User type	Number of fatalities				Number of seriously injured			
	2008	2009	2010	Average	2008	2009	2010	Average
Car users	1,257	1059	835	1050	10,711	10053	8914	9893
	50%	48%	45%	47%	41%	41%	39%	40%
Pedestrians	572	500	405	492	6070	5545	5200	5605
	23%	23%	22%	22%	23%	22%	23%	23%
Pedal cyclists	115	104	111	110	2450	2606	2660	2572
	5%	5%	6%	5%	9%	11%	12%	11%
Motorcycle users	493	472	403	456	5556	5350	4780	5229
	19%	21%	22%	21%	21%	22%	21%	21%
Bus / coach users	6	14	9	10	426	356	392	391
	0%	1%	0%	0%	2%	1%	2%	2%
Other users	95	73	87	85	821	780	714	772
	4%	3%	5%	4%	3%	3%	3%	3%
Total	2,538	2,222	1,850	2,203	26,034	24,690	22,660	24,461
	100%	100%	100%	100%	100%	100%	100%	100%

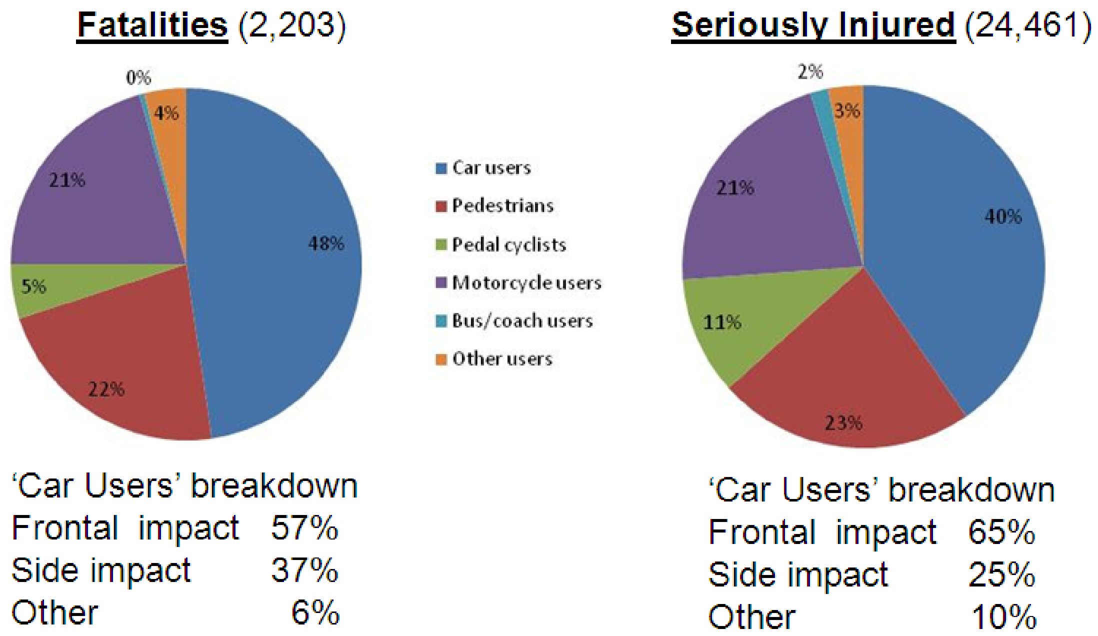


Figure 4.1: STATS19 (national data) road accident casualties (average 2008-2010).

4.1 Benefit of Option 1 'No change'

Only STATS19 national data from 2008 to 2010 inclusive was used for this part of the analysis. The benefit of this option arises from the natural replacement of old vehicles in the fleet which are not regulatory compliant with new vehicles which are regulatory compliant and may also have much higher safety performance levels as encouraged by Euro NCAP.

The legal situation for frontal impact within the European Union is:

- Since 1st October 1998: all new types of car are mandated to be Regulation 94/95 compliant.
- Since 1st October 2003: all cars are mandated to be Regulation 94/95 compliant.

Two types of analyses were undertaken. Both analyses were based on the assumption that the total number of casualties (killed plus seriously injured plus slightly injured will remain the same) but with newer vehicles the distribution will change. Firstly a simple proportion analysis was performed. Following this, a regression analysis was performed to remove some of the confounding factors present in the proportional analysis that may incorrectly influence the results such as older people drive newer cars.

Both analyses were performed for frontal and for side impacts for comparison.

4.1.1 Proportion Analysis

4.1.1.1 Methodology

The following methodology was used:

- Calculate distribution of car occupant casualties in frontal /side impacts for cars of all ages
  - Proportion of killed, seriously injured, slightly injured
- Calculate distribution of car occupant casualties in frontal/side impacts in Regulatory compliant / Euro NCAP-influenced cars, i.e. cars registered 1st Oct 2003 or later

- 1st Oct 1998 – all new types of car R94 / 95 compliant
- 1st Oct 2003 – all cars registered R94 / 95 compliant

- Estimate benefit of renewal of vehicle fleet by assuming that number of casualties remains the same and injury distribution changes to that for cars registered 1st Oct 2003 or later

4.1.1.2 Results

Frontal Impacts

The distribution of car occupant casualties in frontal impacts in all ages of cars average per year (2008-2010) by impact partner is shown in Table 2.

Table 2: Distribution of car occupant casualties in frontal impacts in all ages of cars average per year (2008-2010).

Impact type	Car occupant injury severity			Total
	Killed	Seriously injured	Slightly injured	
Car to Car front	137 0.80%	1727 10.11%	15215 89.09%	17,079 100.00%
Car to Car side/rear	21 0.12%	841 4.93%	16195 94.95%	17,057 100.00%
Car to HGV/PSV	65 2.97%	288 13.16%	1,835 83.87%	2,188 100.00%
Car to LGV	18 0.87%	194 9.34%	1,864 89.79%	2,076 100.00%
Car to Object	207 1.53%	1855 13.68%	11497 84.79%	13,559 100.00%
Car / Multiple (3+ vehicles)	113 1.02%	1,037 9.35%	9,939 89.63%	11,089 100.00%
Car to Other/Unknown	39 0.81%	475 9.88%	4291.3 89.30%	4,805 100.00%
Total	600 0.88%	6,417 9.46%	60,836 89.66%	67,853 100.00%

The distribution of car occupant casualties in frontal impacts in new cars (i.e. those registered after 1st Oct 2003) average per year (2008-2010) by impact partner is shown in Table 3.

Table 3: Distribution of car occupant casualties in frontal impacts in new cars average per year (2008-2010).

Impact type	Car occupant injury severity			Total
	Killed	Seriously injured	Slightly injured	
Car to Car front	23 1.06%	218 10.05%	1928 88.89%	2,169 100.00%
Car to Car side/rear	3 0.12%	119 4.88%	2317 95.00%	2,439 100.00%
Car to HGV/PSV	20 2.81%	83 11.67%	608 85.51%	711 100.00%
Car to LGV	3 0.43%	65 9.29%	632 90.29%	700 100.00%
Car to Object	65 1.55%	568 13.55%	3559 84.90%	4,192 100.00%
Car / Multiple (3+ vehicles)	33 0.83%	339 8.50%	3,615 90.67%	3,987 100.00%
Car to Other/Unknown	10 0.78%	127 9.93%	1142 89.29%	1,279 100.00%
Total	157 1.01%	1,519 9.81%	13,801 89.17%	15,477 100.00%

Application of the proportions for casualty distribution for new cars to all cars gives an estimate of the number of casualties in frontal impacts in all cars average per year (2008-2010) assuming all cars have crashworthiness performance of new cars as shown in.Table 4

Table 4: Estimate of car occupant casualties in all ages of cars assuming all cars have crashworthiness performance of new cars.

Impact type	Car occupant injury severity Killed	Seriously injured	Slightly injured	Total
Car to Car front	181 1.06%	1717 10.05%	15181 88.89%	17,079 100.00%
Car to Car side/rear	21 0.12%	832 4.88%	16204 95.00%	17,057 100.00%
Car to HGV/PSV	62 2.81%	255 11.67%	1871 85.51%	2,188 100.00%
Car to LGV	9 0.43%	193 9.29%	1874 90.29%	2,076 100.00%
Car to Object	210 1.55%	1837 13.55%	11512 84.90%	13,559 100.00%
Car / Multiple (3+ vehicles)	92 0.83%	943 8.50%	10054 90.67%	11,089 100.00%
Car to Other/Unknown	38 0.78%	477 9.93%	4291 89.29%	4,805 100.00%
Total	612 1.01%	6254 9.81%	60987 89.17%	67853 100.00%

The benefit was calculated by differencing the number of casualties in Table 4 and Table 2 (Table 5).It is interesting to note that overall and in particular for car front to car front impacts an increase in the number of fatalities is estimated. This result is unexpected and may be caused by confounding factors and hence is one of the reasons that a regression analysis was performed to try and remove the effect of some of these factors.

Table 5: Benefit of Option 1 'No change' for frontal impacts, expressed in casualties per year, note that a negative number represents a disbenefit, i.e. an increase in casualties.

Impact type	Car occupant injury severity			Total
	Killed	Seriously injured	Slightly injured	
Car to Car front	-44	10	34	0
Car to Car side/rear	0	9	-9	0
Car to HGV/PSV	3	33	-36	0
Car to LGV	9	1	-10	0
Car to Object	-3	18	-15	0
Car / Multiple (3+ vehicles)	21	94	-115	0
Car to Other/Unknown	1	-2	1	0
Total	-12	163	-151	0

Side Impacts

A similar process was followed as for frontal impacts to give the following results.

Table 6: Distribution of car occupant casualties in side impacts in all ages of cars average per year (2008-2010).

Impact type	Car occupant injury severity			Total
	Killed	Seriously injured	Slightly injured	
Car to Car front	181 1.06%	1717 10.05%	15181 88.89%	17,079 100.00%
Car to Car side/rear	21 0.12%	832 4.88%	16204 95.00%	17,057 100.00%
Car to HGV/PSV	62 2.81%	255 11.67%	1871 85.51%	2,188 100.00%
Car to LGV	9 0.43%	193 9.29%	1874 90.29%	2,076 100.00%
Car to Object	210 1.55%	1837 13.55%	11512 84.90%	13,559 100.00%
Car / Multiple (3+ vehicles)	92 0.83%	943 8.50%	10054 90.67%	11,089 100.00%
Car to Other/Unknown	38 0.78%	477 9.93%	4291 89.29%	4,805 100.00%
Total	612 1.01%	6254 9.81%	60987 89.17%	67853 100.00%

Table 7: Distribution of car occupant casualties in side impacts in new cars average per year (2008-2010).

Impact type	Car occupant injury severity			Total
	Killed	Seriously injured	Slightly injured	
Car to Car front	11 0.64%	90 5.24%	1616 94.12%	1,717 100.00%
Car to Car side/rear	2 0.21%	45 4.79%	892 94.99%	939 100.00%
Car to HGV/PSV	11 1.19%	45 4.88%	866 93.93%	922 100.00%
Car to LGV	5 0.97%	27 5.21%	486 93.82%	518 100.00%
Car to Object	42 2.92%	215 14.95%	1181 82.13%	1,438 100.00%
Car / Multiple (3+ vehicles)	16 1.17%	90 6.58%	1,261 92.25%	1,367 100.00%
Car to Other/Unknown	8 0.95%	63 7.46%	774 91.60%	845 100.00%
Total	95 1.23%	575 7.42%	7,076 91.35%	7,746 100.00%

Table 8: Benefit of Option 1 'No change' for frontal impacts, expressed in casualties per year.

Impact type	Car occupant injury severity			Total
	Killed	Seriously injured	Slightly injured	
Car to Car front	19	36	-54	0
Car to Car side/rear	0	-30	29	0
Car to HGV/PSV	6	22	-28	0
Car to LGV	1	18	-19	0
Car to Object	1	62	-63	0
Car / Multiple (3+ vehicles)	9	41	-49	0
Car to Other/Unknown	-1	34	-34	0
Total	35	184	-219	0

It is interesting to note that in contrast to frontal impacts an overall decrease in killed casualties (i.e. a benefit) was predicted for side impacts.

4.1.2 Regression Analysis

4.1.2.1 Methodology

As with the proportional analysis above, this analysis was based on the assumption that the total number of casualties (i.e. fatal plus serious plus slight) in a 'regulatory compliant / Euro NCAP influenced' fleet would be the same as in the current fleet, but the proportion of fatal, serious and slight casualties would be different. This effectively assumes that 'regulatory compliant / Euro NCAP influenced' cars have the same accident configurations as cars that are not 'regulatory compliant / Euro NCAP influenced'. It should be noted that primary safety features such as Electronic Stability Control (ESC) may alter the configurations of the accidents that cars have. This could be a confounding factor in the analysis performed which was not controlled for because appropriate data were not available to do this.

Regression modelling was used to determine the influence of the car's registration period on the casualty's injury severity for the different accident types, e.g. car-to-car accidents, car-to-object accidents etc. whilst taking into account confounding factors such as occupant age, gender and vehicle type. The analysis was most complex for car-to-car accidents because the registration period and type of both cars involved needed to be taken into account. The explanatory variables used were:

Type of the car	Minis/superminis', 'Small saloons', 'Medium saloons', 'Large saloons', Luxury saloons', 'Sports cars', '4x4s/MPVs', 'Taxis(black cabs)'
Registration period of the car	'to 12/93', '1/94 to 9/98', '10/98 to 9/03', 'from 10/03' and 'not known'
Driver age/sex	(male, female) x (0-25, 26-60, 61-99) and age or sex 'not known'

A Generalised Linear Model was fitted to the relationship:

$$\frac{K(i,j,k,l,m)}{C(i,j,k,l,m)} = \alpha(i).\beta(j).\gamma(k).\delta(l).\varepsilon(m) \qquad (1)$$

where $C(i,j,k,l,m)$= number of drivers of age/sex i of cars of type j and registration period k who are injured in collisions with cars of type l and registration period m

$K(i,j,k,l,m)$= number of these injured drivers who were killed or seriously injured

$\alpha, \beta, \gamma, \delta, \varepsilon$ are coefficients to be estimated

As K/C is a proportion, it was appropriate to fit model (1) using the logistic regression facility of the Generalised Linear Interactive Modelling (GLIM) programme [Francis 1993]. The GLIM programme requires a 'reference level' for each explanatory variable. The estimated coefficients show the effects for the other levels relative to the effect for this level, also the statistical significance of any differences. The benefit of changing to a 'regulatory compliant / Euro NCAP influenced' fleet was estimated from the effect of change in the car's registration period on the casualty outcome, whilst keeping all other factors such as casualty age and gender constant.

4.1.2.2 Results

Car-to-Car Accidents

Exploratory analyses were made of the casualty data from car-to-car accidents grouped according to the registration periods of the driver's car and the other car. These demonstrated the improvement in secondary safety in the car fleet: drivers of the older ('to 9/98' or pre-Directive) cars were more likely to be killed or seriously injured than drivers of newer ('from 10/03' or post-Directive) cars. It was also clear that the severity of the driver injuries was greater when in collision with a newer car than an older car, i.e. the newer cars were more aggressive.

Section 4.1.2.1 introduced the logistic regression analysis that can be used to identify the effects of registration period upon casualty severity, independent of the effects of the other variables such as car type. The results of this analysis that relate to registration period are presented in Table 9.

Table 9: Influence of registration period on driver casualty severity in car-car accidents, estimates from GLIM models.

Impact			killed all casualties proportion	t	serious casualties all casualties proportion	t
Front	Driver's car	to 12/93	1.04%	1.76	10.1%	1.69
		1/94 to 9/98	0.65%		8.8%	
		10/98 to 9/03	0.39%	-3.06	7.4%	-4.14
		from 10/03	0.44%	-2.26	6.8%	-5.68
	Other car	to 12/93	0.82%	0.61	8.5%	-0.32
		1/94 to 9/98	0.65%		8.8%	
		10/98 to 9/03	0.53%	-1.05	8.6%	-0.39
		from 10/03	0.85%	1.48	9.8%	2.43
Side	Driver's car	to 12/93	0.33%	-1.22	7.0%	1.80
		1/94 to 9/98	0.68%		5.3%	
		10/98 to 9/03	0.60%	-0.56	4.5%	-2.15
		from 10/03	0.37%	-2.75	4.2%	-3.00
	Other car	to 12/93	0.76%	0.22	6.2%	0.92
		1/94 to 9/98	0.68%		5.3%	
		10/98 to 9/03	0.89%	1.05	5.8%	1.15
		from 10/03	1.21%	2.34	5.9%	1.23

Estimates refer to reference levels for driver age and sex (men aged 0 - 25), for car type (Minis and Superminis) and for registration period (1/94 to 9/98)

The results output by the GLIM software from a logistic regression model can be tricky to interpret, so they have been illustrated using the reference level selected for the modelling, i.e. the table shows the proportions estimated by the fitted models for male drivers aged 0 - 25 of Minis and Superminis who were injured in frontal impacts with other Minis and Superminis. With the 'driver's car' results, the other car is taken to be of 'to 9/98' registration; with the 'other car' results, the driver's car is taken to be of 'to 9/98' registration. If other groups were selected for the illustration then the levels would differ but the relationship would not; the t-values would be unaffected. The Table shows that both casualty proportions are significantly lower when the driver's car is 'from 10/03' than when it is '1/94 to 9/98' in both frontal and side impacts.

The effect is reversed with respect to the other car, although it does not achieve significance some cases.

These results conform to the general trends seen in the exploratory analysis, and the trends for killed and serious casualties are similar. They do not show, however, the overall trade-off between the increase in aggressivity shown by the increased other car proportions for 'from 10/03' cars and the improvement of secondary safety shown by the reduced driver's car proportions for 'from 10/03' cars. This can be evaluated by considering in turn the groups of car-to-car accidents in the data set used to fit (1). When a car (driver's or other) is not from the 'from 10/03' registration period, the coefficients from the GLIM model are used to calculate the severity proportion that would be expected if it had been 'from 10/03'. This simulates the casualty outcome if the same set of accidents had occurred, but all cars had the characteristics of modern (from 10/03) cars. All GLIM coefficients are used, irrespective of their t-values.

Table 10 presents the results, which are not national figures but relate to the subset of data that is used to fit the GLIM models. This includes only driver casualties in accidents where the details of both cars and both drivers are known. These account for 69% of fatal casualties, 65% of serious casualties and 68% of slight casualties. The 'model' data are the values fitted by the regression model to the actual casualty data. The 'alternative' data show the changes to the 'model' data when the effects of changing to 'from 10/03' cars are simulated. Consider the column headed 'from 10/03' which shows the effects for drivers of modern cars; these cars are unchanged in the simulation but the cars with which they collide generally become more aggressive so the casualty numbers tend to increase. The 'from 10/03' rows, by contrast, show the effects of unchanged aggressivity of these new cars but improved secondary safety in the cars that they hit.

Table 10: Estimated driver casualty changes in frontal impacts if all cars had been regulatory compliant (from 10/03).

	Other car		Driver's car to 12/93	1/94 to 9/98	10/98 to 9/03	from 10/03	all
Frontal impacts							
Killed	to 12/93	model	0.8	2.2	2.7	2.3	8
		alternative	0.4	1.6	3.1	2.4	7
	1/94 to 9/98	model	3.1	11.7	13.4	12.8	41
		alternative	1.8	10.5	19.8	16.7	49
	10/98 to 9/03	model	4.8	19.3	24.1	22.8	71
		alternative	3.3	21.2	43.9	36.6	105
	from 10/03	model	9.3	31.8	41.9	42.1	125
		alternative	4.0	21.7	47.6	42.1	115
	all	model	18	65	82	80	245
		alternative	9	55	114	98	277
Serious casualties	to 12/93	model	5	21	35	27	88
		alternative	2	4	19	38	31
	1/94 to 9/98	model	27	148	240	191	605
		alternative	20	128	248	214	610
	10/98 to 9/03	model	51	299	527	422	1,299
		alternative	39	265	555	481	1,340
	from 10/03	model	64	341	635	523	1,562
		alternative	43	265	588	523	1,419
	all	model	146	809	1,436	1,163	3,554
		alternative	106	677	1,429	1,249	3,461
Side impacts							
Killed	to 12/93	model	0.1	0.9	1.9	1.1	4
		alternative	0.2	0.8	1.8	1.7	5
	1/94 to 9/98	model	0.4	4.7	9.7	5.1	20
		alternative	0.9	4.6	10.6	9.2	25
	10/98 to 9/03	model	1.1	13.0	27.2	15.6	57
		alternative	1.7	9.7	22.6	21.3	55
	from 10/03	model	1.3	19.3	40.1	23.2	84
		alternative	1.5	10.6	24.5	23.2	60
	all	model	3	38	79	45	165
		alternative	4	26	60	55	145
Serious casualties	to 12/93	model	3	8	16	13	41
		alternative	2	2	6	15	13
	1/94 to 9/98	model	10	45	89	74	218
		alternative	7	39	92	82	219
	10/98 to 9/03	model	20	101	208	186	516
		alternative	12	81	196	188	476
	from 10/03	model	17	100	205	191	514
		alternative	11	80	191	191	473
	all	model	51	254	519	465	1,289
		alternative	32	206	493	473	1,203

These estimates relate to the subset of the national data used for the GLIM models, i.e. those accidents for which details of both cars and both drivers are known.

Overall, it is estimated that if all cars had had the characteristics of modern cars, the number of drivers killed in car-to-car frontal impacts between 2008 and 2010 would have been 13% greater, 277 rather than 245; 12% fewer would have been killed in side impacts, 145 rather than 165. The number of serious casualties in frontal impacts would have been 3% less, 3,461 rather than 3,554, and in side impacts the number would have been 7% less, 1,203 rather than 1,289.

Single car accidents

This section considers driver casualties in frontal and side impacts that involve a single car and no other vehicle, irrespective of what objects might have been hit on or off the carriageway. The appropriate GLIM model is a simplified version of (1) as only details of one vehicle are included, and Table 11 is the equivalent of Table 9 for single vehicle accidents. There is a small reduction of the casualty proportions among modern cars that achieves statistical significance in one case.

Table 11: Influence of registration period on driver casualty severity in single car accidents, estimates from GLIM models.

Impact		killed / all casualties proportion	t	serious casualties / all casualties proportion	t
Front	to 12/93	1.46%	0.35	16.6%	1.94
	1/94 to 9/98	1.32%		14.0%	
	10/98 to 9/03	1.34%	0.07	13.6%	-0.73
	from 10/03	1.10%	-1.29	13.1%	-1.52
Side	to 12/93	4.07%	0.11	19.6%	0.57
	1/94 to 9/98	3.94%		18.2%	
	10/98 to 9/03	2.68%	-2.43	16.1%	-1.99
	from 10/03	3.15%	-1.34	15.1%	-2.71

Estimates refer to reference levels for driver age and sex (men aged 0-25), for car type (Minis and Superminis) and for registration period (1/94 to 9/98)

Table 12 now simulates the casualty outcome if the same set of accidents had occurred in 2008-10 but all cars had the characteristics of regulatory compliant (from 10/03) cars. The net effect is a small reduction in killed and serious casualties. Overall, it is estimated that if all cars had had the characteristics of modern cars, 49 fewer drivers would have been killed in single car frontal impacts between 2008 and 2010, a 12% reduction; the net effect is nil in side impacts. The number who were seriously injured would have reduced by 4% in frontal impacts and 8% in side impacts.

Table 12: Estimated casualty changes in single car accidents if all cars had been regulatory compliant.

Impact			Driver's car				
			to 12/93	1/94 to 9/98	10/98 to 9/03	from 10/03	all
Front	Killed	model	16.0	87.0	176.1	120.1	399
		alternative	12.1	72.5	145.3	120.1	350
	Serious	model	131	704	1,434	1,092	3,362
	casualties	alternative	103	657	1,380	1,092	3,233
Side	Killed	model	13.0	67.0	94.0	76.0	250
		alternative	10.1	53.6	110.4	76.0	250
	Serious	model	60	314	598	397	1,369
	casualties	alternative	46	260	562	397	1,265

These estimates relate to the subset of the national data used for the GLIM models, i.e. those accidents for which details of the car and the driver are known

These analyses have grouped together all casualties in single car accidents irrespective of the objects hit. They have been repeated with a subset of casualties, those whose cars hit an object off the carriageway (i.e. cases with 'first object hit off the carriageway'=none were excluded). It is estimated that if all cars were modern then, based on those accidents for which details of the car and the driver are known:

- the number of drivers killed would fall from 358 to 309 in frontal impacts and from 234 to 223 in side impacts
- the number of drivers seriously injured would fall from 2,813 to 2,732 in frontal impacts and from 1,157 to 1,091 in side impacts

Car-to-other Vehicle Accidents

Far fewer drivers were injured in accidents that involved one car and one other vehicle that was not a car than in the previous two groups of accidents, but it was still possible to separate the analysis by type of other vehicle. The analysis was restricted to accidents between cars and those vehicle groups that are appreciably heavier than cars: buses, coaches and goods vehicles. These accidents account for 11% of car drivers injured in frontal impacts involving two vehicles, but 33% of car drivers killed. 'Other vehicle' refers in the remainder of this section to these types of heavier vehicle.

The appropriate GLIM model is a simplified version of (1) as the type of the other vehicle is known but not its registration period. The diagnostic statistics confirm the importance of treating the four types of other vehicle separately. The results are presented in Table 13, which is the equivalent of Table 9 with the additional reference level of other vehicle=bus or coach. The results show a small reduction of the fatality proportion among modern cars in frontal impacts that does not achieve statistical significance and a larger reduction of the serious casualty proportion that does. This tends to suggest that the reduction of the fatality proportion is real, but does not appear to be significant because of the relatively small numbers. The reduction in side impacts did not achieve statistical significance.

Table 13: Influence of registration period on driver casualty severity in car-other vehicle accidents, estimates from GLIM models.

Impact		killed all casualties proportion	t	serious casualties all casualties Proportion	t
Front	to 12/93	0.95%	-0.65	21.5%	2.77
	1/94 to 9/98	1.35%		14.3%	
	10/98 to 9/03	1.62%	0.81	11.6%	-2.40
	from 10/03	1.07%	-0.97	11.3%	-2.59
Side	to 12/93	2.83%	-0.11	14.3%	1.32
	1/94 to 9/98	3.04%		10.2%	
	10/98 to 9/03	2.70%	-0.43	10.2%	0.00
	from 10/03	2.14%	-1.20	8.5%	-1.36

Estimates refer to reference levels for driver age and sex (men aged 0 - 25), for car type (Minis and Superminis), for registration period (1/94 to 9/98) and for other vehicle (bus or coach)

Table 14 now simulates the casualty outcome if the same set of accidents had occurred in 2008 - 2010 but all cars had the characteristics of regulatory compliant (from 10/03) cars. The net effect is a reduction in fatal and serious casualties. Overall, it is estimated that if all cars had had the characteristics of regulatory compliant cars, 29 (20%) fewer drivers would have been killed in car-to-other vehicle frontal impacts between 2008 and 2010, and the number who were seriously injured would have reduced by 9%. 14 (16%) fewer drivers would have been killed in side impacts and 50 (12%) would have been seriously injured.

These casualty reductions may be offset slightly by increased casualty numbers in the other vehicles as a result of the increased aggressivity of regulatory compliant cars that was identified above for car-to-car accidents, but a complementary data set for the casualties in these other vehicles would be needed to analyse this.

Table 14: Estimated casualty changes if all cars had been regulatory compliant, car-to-other vehicle accidents.

Impact			**Driver's car** to 12/93	**1/94 to 9/98**	**10/98 to 9/03**	**from 10/03**	**all**
Front	Killed	model	4.0	28.0	71.0	45.0	148
		alternative	4.5	22.2	47.1	45.0	119
	Serious	model	49	183	307	262	801
	casualties	alternative	26	145	299	262	732
Side	Killed	model	3.0	19.0	38.0	30.0	90
		alternative	2.3	13.4	30.2	30.0	76
	Serious	model	16	74	177	141	408
	casualties	alternative	9	61	146	141	358

These estimates relate to the subset of the national data used for the GLIM models, i.e. those accidents for which details of the car and its driver are known

Adjustment and Disaggregation

The previous sections have estimated the number of fatal and serious casualties in 2008 - 2010 for three groups of accident under the 'from 10/03' scenario, namely that all of the cars involved had the characteristics of the 'from 10/03' registration group. These estimates will now be combined to estimate changes to national casualty totals.

The first step is to adjust the earlier estimates to make allowance for the driver casualties that were excluded when the GLIM models were fitted, i.e. those with incomplete details. Adjustment factors are calculated for each of the three datasets by comparing the number of casualties with complete details and the total number. Table 15 presents the results. The final 'Total' column is the sum of the three 'Adjusted estimate' columns.

Table 15: Adjustment of driver casualty estimates.

Impact			**Accidents involve:** Single car		**Two cars**		**One car, one other vehicle**		
			Estimate from Table 12	**Adjusted estimate**	**Estimate from Table 10**	**Adjusted estimate**	**Estimate from Table 14**	**Adjusted estimate**	**Total**
Front	Killed	model	399	481	245	364	148	178	1,023
		alternative	350	422	277	411	119	143	976
	Serious	model	3,362	4,055	3,554	5,274	801	963	10,291
	casualties	alternative	3,233	3,899	3,461	5,136	732	880	9,915
Side	Killed	model	250	301	165	249	90	107	658
		alternative	250	301	145	219	76	91	611
	Serious	model	1,369	1,651	1,289	1,945	408	486	4,082
	casualties	alternative	1,265	1,525	1,203	1,815	358	427	3,767
Adjustment factor									
	Front		1.206		1.484		1.202		
	Side		1.206		1.509		1.192		

The estimates from the Total column were adjusted to take account of casualties in the accidents not included in sections above, principally those that involve three or more vehicles but also those that involve one car and one lighter vehicle. It would in principle be possible to make a basic analysis of these casualties similar to that for single car accidents but these data were not extracted. Instead, it was assumed that the effects will be a weighted mean of the effects of the three groups that have been studied. The results are shown in

Table 16, and indicate that if all cars in 2008-2010 had been to the 'from 10/03' standard then the number of car driver casualties would have been slightly reduced, 4.5% fewer fatalities and 3.7% fewer serious casualties.

Table 16: Final car driver casualty estimates, frontal impacts, 2008-2010.

Impact			Estimate from Table 15	Adjustment factor to allow for excluded accidents	Final estimate	Reduction
Front	Killed	model	1,023	1.233	1,261	
		alternative	976		1,204	4.5%
	Serious casualties	model	10,291	1.218	12,692	
		alternative	9,915		12,228	3.7%
Side	Killed	model	658	1.233	811	
		alternative	611		753	7.1%
	Serious casualties	model	4,082	1.218	5,034	
		alternative	3,767		4,646	7.7%

For the purposes of more detailed analyses required for this project, some of the results presented above need to be disaggregated. Firstly, the car-to-car results from Table 10 are split according to whether the first point of impact on the other car was frontal or side/rear. Separate sets of accident records have been extracted and GLIM models fitted as for the car-to-car accidents above

Table 17: Disaggregate casualty estimates, car-car accidents.

Impact			Other car hit on: front	side/rear	sum	all	Difference
Front	Killed	Model	198	24	222	245	9%
		Alternative	242	22	264	277	4%
		Reduction	-22%	8%	-19%	-13%	
	Serious casualties	Model	2,391	1,080	3,471	3,554	2%
		Alternative	2,332	1,096	3,428	3,461	1%
		Reduction	2%	-1%	1%	3%	
Side	Killed	Model	138	15	153	165	7%
		Alternative	121	17	138	145	5%
		Reduction	12%	-14%	10%	12%	
	Serious casualties	Model	877	376	1253	1289	3%
		Alternative	807	367	1174	1203	2%
		Reduction	8%	2%	6%	7%	

Note: a negative reduction is an increase

The fact that the first point of impact is sometimes recorded as 'did not impact' or 'not known' means that the sum of the two sets of estimates is slightly less than the earlier set. Table 17 compares the disaggregated results with the overall results from Table 10 (shown as 'all').

Next, the casualty reduction estimates in car-to-other vehicle accidents from

Table 14 are disaggregated. There are too few casualties involving the remaining groups of 'other vehicles' for analysis.

Table 18: Disaggregate casualty estimates, car-other vehicle accidents.

Impact			Other vehicle: Bus or coach	Van	HGV	All
Front	Killed	Model	14	33	101	148
		alternative	11	26	81	119
		Reduction	20%	20%	19%	20%
	Serious casualties	Model	103	333	365	801
		alternative	93	303	335	732
		Reduction	9%	9%	8%	9%
Side	Killed	Model	11	25	54	90
		alternative	9	21	46	76
		Reduction	16%	16%	16%	16%
	Serious casualties	Model	61	160	187	408
		alternative	53	141	164	358
		Reduction	13%	12%	12%	12%

Table 19: Final disaggregate car driver casualty estimates, frontal and side impacts, 2008-2010.

Impact		Killed model	Killed alternative	Killed reduction	Serious casualties model	Serious casualties alternative	Serious casualties reduction
Front	Car to car front	294	359	-22%	3,548	3,460	2%
	Car to car side/rear	36	33	8%	1,603	1,627	-1%
	Car to PSV/HGV	138	111	20%	563	515	8%
	Car to van	40	32	20%	400	365	9%
	Car to object (sva)	432	373	14%	3,393	3,295	3%
	Multiple-vehicle	237	229	3%	2,010	1958	3%
	Total	1,176	1,137	3%	9,507	9,262	3%
Side	Car to car front	208	182	12%	1,323	1,218	8%
	Car to car side/rear	23	26	-14%	567	554	2%
	Car to PSV/HGV	78	65	16%	296	259	12%
	Car to van	30	25	16%	191	168	12%
	Car to object (sva)	282	268	5%	1,396	1,315	6%
	Multiple-vehicle	156	143	9%	798	743	7%
	Total	777	710	9%	4,570	4,256	7%

Note: a negative reduction is an increase

The results from both these tables need to be adjusted to allow for the sampling in the GLIM data, and Table 19 makes these adjustments. Casualties in multiple-vehicle accidents have been included in the table although there has been no GLIM analysis for this casualty group.

The estimates were prepared as for Table 15, on the assumption that the effects will be a weighted mean of the effects of the groups that have been analysed.

Calculated benefits for frontal and side impact casualties are summarised in Table 20.

Table 20: Summary of benefits predicted by regression analysis for car occupant casualties in frontal and side impacts.

Benefit of Option 1, 'No change'	**% (No.) of car occupant casualties**	
	Killed	**Seriously injured**
Car occupant frontal impact casualties	2.0% (21)	1.7% (164)
Car occupant side impact casualties	3.1% (32)	1.7% (171)

4.1.3 Summary of Conclusions

- Frontal impact
  - Regression analysis estimates a benefit of 2.0% (21) of killed and 1.7% (164) of seriously injured car occupant casualties
  - However, for the car-to-car frontal impact subset both proportional and regression analyses show that the number of fatal casualties increases with newer cars. This may indicate that the increased self-protection of cars is being offset by their increased aggressivity.
- Side impact
  - Regression analysis estimates a benefit of 3.1% (32) of killed and 1.7% (171) of seriously injured car occupant casualties
  - For the car-to-car side impact subset both the proportional and regression analyses show that the number of fatal casualties decreases with newer (regulatory compliant / EuroNCAP influenced) cars.

4.2 Benefit of Option 2 ‘Add Full Width test’ and Option 3 ‘Add Full Width Test and Replace Current ODB Test with PDB Test’

4.2.1 Methodology

The five-step methodology described below was used to estimate target populations and benefits for Options 2 and 3. The methodology uses both national data and detailed accident data because there was insufficient information in the national data to be able to estimate the benefit. Hence the detailed accident data from CCIS was used to provide the information needed to estimate the benefit for a limited number of casualties and results scaled to estimate the benefit nationally. This approach is typical for the case when detailed information about the accident is needed to estimate the benefit.

1. Start with ‘baseline’ national data – Casualties in regulatory compliant / Euro –NCAP influenced vehicle fleet, i.e. Option 1 ‘No change’ baseline calculated above using regression analysis and national data
   2. Form equivalent ‘baseline’ dataset in detailed accident data
   3. Determine number/proportion of casualties in target population for each option
      – Remove casualties not likely to experience benefit, e.g. unbelted, etc.

  – For remaining casualties perform detailed case analysis to determine which ones likely to experience some benefit
4. Determine benefit for each casualty in target population for each option
  – Estimate injury reduction for each casualty in the target population using injury reduction model
5. Scale proportions from detailed analyses to obtain national target population and benefit

4.2.2 Representativeness of CCIS

CCIS data were examined to determine the proportion of (i) fatally injured casualties by impact partner compared with STATS19 data (Figure 4.2) and (ii) seriously injured casualties by impact partner compared with STATS19 data (Figure 4.3). This showed that HGV impacts are over-represented in CCIS and car-to-car front impacts are under-represented. To remove this bias, the analysis was performed for each impact partner type.

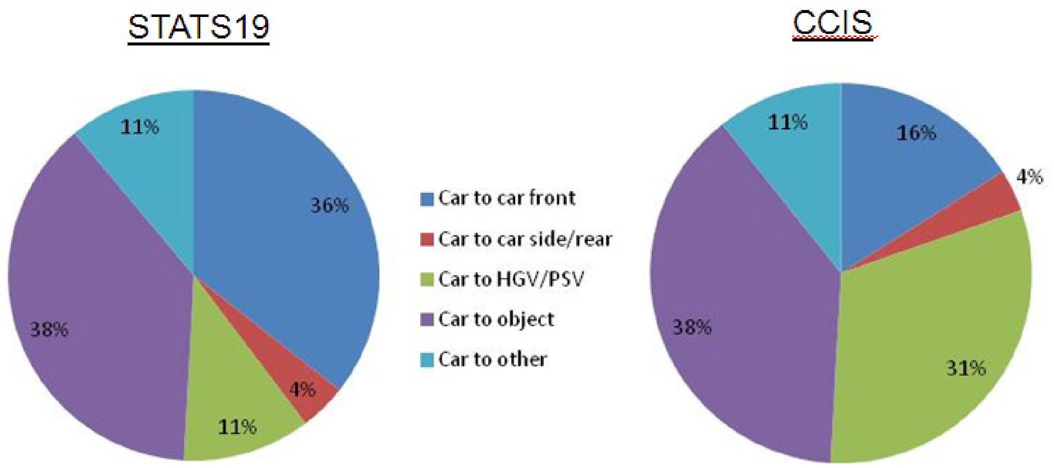


Figure 4.2: Representativeness of CCIS by impact partner (fatally injured occupants).

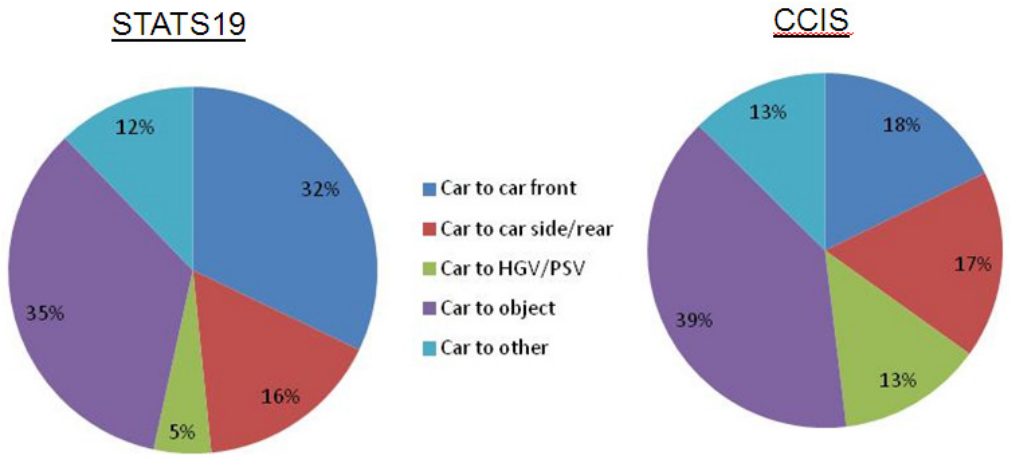


Figure 4.3: Representativeness of CCIS by impact partner (seriously injured occupants).

Secondly, CCIS data were examined to determine how representative CCIS data are of national (STATS19) data in terms of the age of (i) fatally injured occupants (Figure 4.4) and (ii) seriously injured occupants (Figure 4.5). This analysis showed a reasonable representation (although older (46-65 and >66 years of age) fatally injured occupants are slightly over-represented in CCIS and younger (12-25 years of age) fatally injured occupants are slightly under-represented). This slight bias was ignored because it was thought that it would not affect the validity of the analysis significantly.

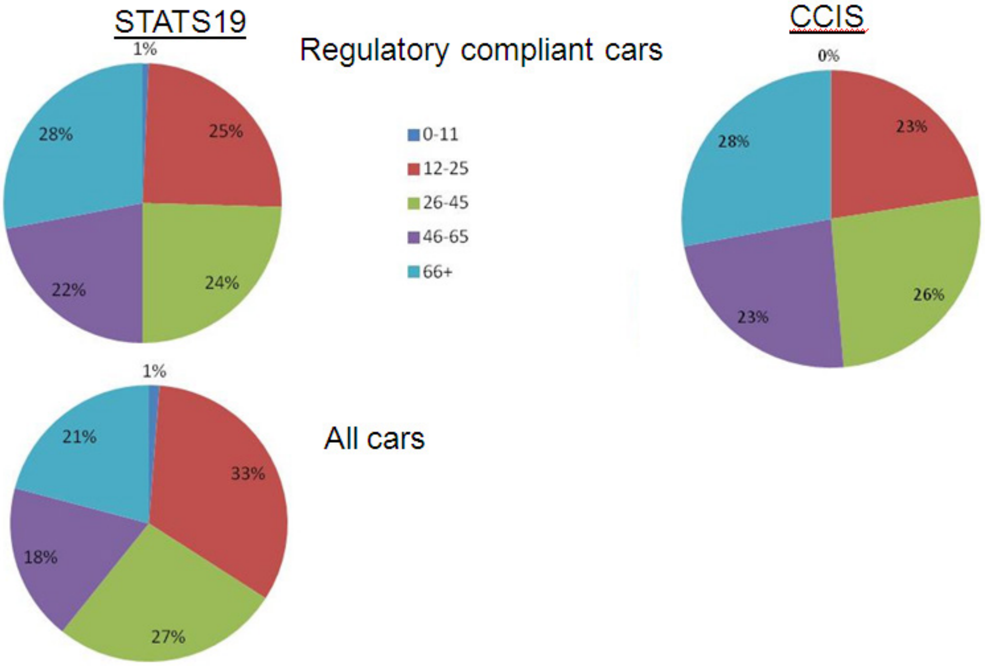


Figure 4.4: Representativeness of CCIS by age of occupant (fatally injured occupants).

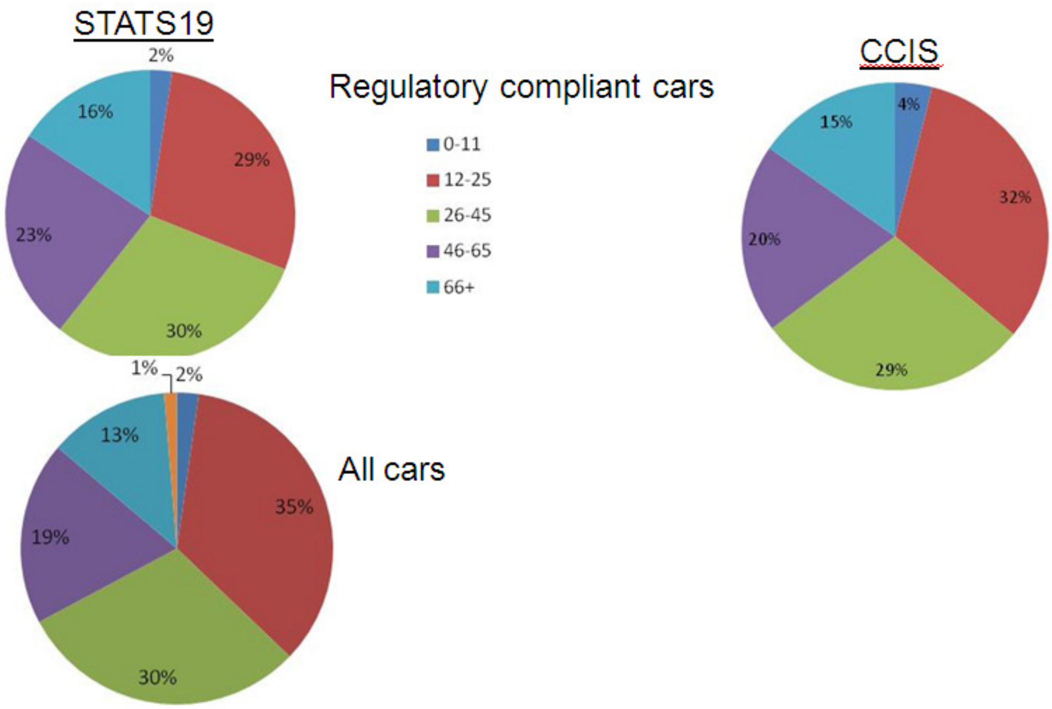


Figure 4.5: Representativeness of CCIS by age of occupant (seriously injured occupants).

4.2.3 Estimate of Target Population

Baseline and formation of equivalent datasets

The starting point for the analysis was the national baseline i.e. the number of casualties in frontal impacts in the regulatory compliant or Euro NCAP-influenced vehicle fleet calculated from STATS19 data. Table 21 summarises the number of fatally injured and seriously injured car occupant casualties in frontal impacts by impact partner type which was estimated as part of the work to derive the benefit of Option 1 'No change' described above.

Table 21: Road accident casualties in regulatory compliant / Euro NCAP-influenced vehicle fleet (frontal impacts).

Impact type	Car occupant casualties	
	Killed	Seriously injured
Car to car front	167	1684
Car to car side / rear	19	854
Car to HGV / PSV	52	263
Car to object	179	1801
Car to other / unknown	52	640
Car / multiple (3+ vehicles)	109	1010
Total	579	6253

Selection criteria were applied to the CCIS dataset to form equivalent CCIS baseline datasets for frontal impacts for different impact partner types. (As stated above, analysis was performed by impact partner type to remove the CCIS impact type sample bias i.e. over-estimation of HGV impacts). Cases meeting these selection criteria formed the comparison point with baseline national STATS19 data. The following criteria were applied to derive the CCIS baseline casualty datasets for frontal impacts:

- Accident occurred between 2000 and 2010 (inclusive).
- The casualty was killed or seriously injured.
- The casualty was a car occupant.
- A significant frontal impact occurred.
- The nature of the injury, the impact type and seatbelt use were all known.
- The casualty was in a regulatory compliant car or one which had an equivalent crash safety level.
    - Note: Initially to select cars that were regulatory compliant a criterion of 'those registered post 1 October 2003' was considered. However, it was found that with this approach the data sample size was not large enough to perform a meaningful analysis. Hence, the approach was modified to the one in which safety performance levels of vehicles registered between 2000 and 1st Oct 2003 were assessed further using type introduction date and Euro NCAP test data to determine whether or not they would have had a safety performance level sufficient to be regulatory compliant.

A further set of selection criteria was applied to casualties included in the CCIS baseline dataset to identify those casualties where a benefit may be achieved for the chosen options i.e. those casualties to be taken forwards for detailed analysis. For frontal impacts, the following criteria were applied:

- No rollover occurred before the first impact.
- Seatbelt was used by the casualty.
- No unbelted occupant was seated behind the casualty.

- The occupant was a front-seat occupant.

Where the above criteria were not met, it was assumed that the occupant would not experience a benefit from the measures proposed in Option 2 or Option 3. These cases were therefore excluded from the target population prior to detailed analysis. Cases meeting the above criteria were taken forwards for detailed case analysis to determine whether they should be included in the target population. The selection process for occupants in frontal impacts is illustrated in Figure 4.6.

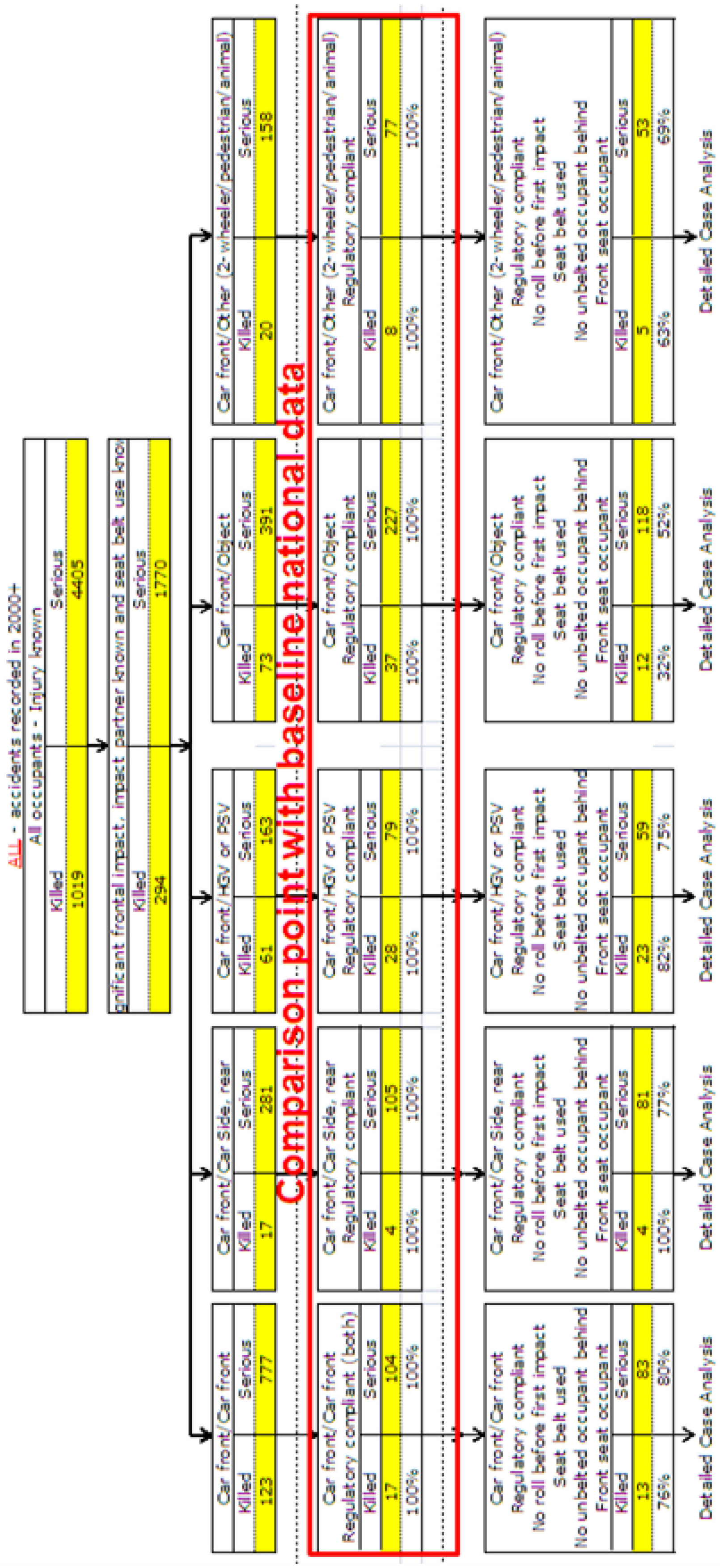


Figure 4.6: Formation of equivalent baseline CCIS dataset for frontal impacts.

Detailed Case Analysis

Detailed case analysis was undertaken for the casualties meeting all of the above criteria. This continued work started in the ‘Accident analysis’ task reported in FIMCAR Deliverable D1.1 [Thompson 2013]. The additional work involved a review of all cases analysed previously and the analysis of the additional cases included in the data sets used for the benefit analyses, Each case was assessed to identify (i) a structural interaction problem (over- / under-ride, fork effect, or low overlap), or (ii) a frontal force matching / compartment strength problem, or (iii) casualties with deceleration-related injuries (note: the absence of intrusion was used to help identify deceleration-related injuries). This enabled the target populations for Option 2 (full width test) and Option 3 (full width test and replace ODB with PDB test) to be identified as follows:

- Improved structural interaction (Options 2 and 3)
    - Casualties in vehicles for which a structural interaction problem has been identified.
        - Over- / under-ride – full width; PDB.
        - Fork effect – PDB.
        - Low overlap – PDB.
- Improved frontal force matching / compartment strength (Option 3)
    - Casualties in vehicles for which a frontal force matching / compartment strength problem has been identified – PDB.
- Improved restraint performance due to the introduction of the full width test (Options 2 and 3)
    - Casualties which have deceleration-related injuries in high overlap – full width.

In summary it was assumed that the introduction of a full-width test with appropriate compatibility and dummy metrics has the potential to address the frontal impact issues under/override related to structural alignment and restraint related acceleration type injuries. Limited potential of the full width test was expected for addressing fork effect issues. It was also assumed that the replacement of the ODB by the PDB/MPDB test procedure with an appropriate homogeneity metric had the potential to address the frontal impact issues under/override related to vertical load spreading, fork effect and low overlap as well as frontal force matching/compartment strength.

Each case was ‘flagged’ to show whether Option 2 and/or Option 3 was considered likely to provide a benefit for the occupant given the nature of the issue identified. Those casualties where a benefit was considered possible were included in the target population and taken forwards to the next stage (estimate of benefit – see section 4.2.4). Examples of the detailed case analysis are shown in Annex A.

Breakdown of the Issues Identified in the Target Population

A breakdown of the number of fatally injured or seriously injured (MAIS2+) casualties identified for each issue (overlap, fork effect or over- / under-ride) is shown in Figure 4.7. Fatally injured and seriously injured casualties are illustrated separately in Figure 4.8 and Figure 4.9 respectively. The bias in the CCIS dataset to HGV impact partner (described in section 4.2.2 above) is not taken into account in these figures. It should be noted that there was not sufficient information available for all cases to perform the detailed analysis; often there were not enough appropriate photographs to identify whether or not structural interaction problems were present. Therefore these casualties/cases were removed from the data set and the proportions used for scaling calculated from the remaining dataset. This is why the total number of casualties identified for detailed case analysis in Figure 4.6 above is greater than the total number included in the breakdown in Figure 4.7 below.

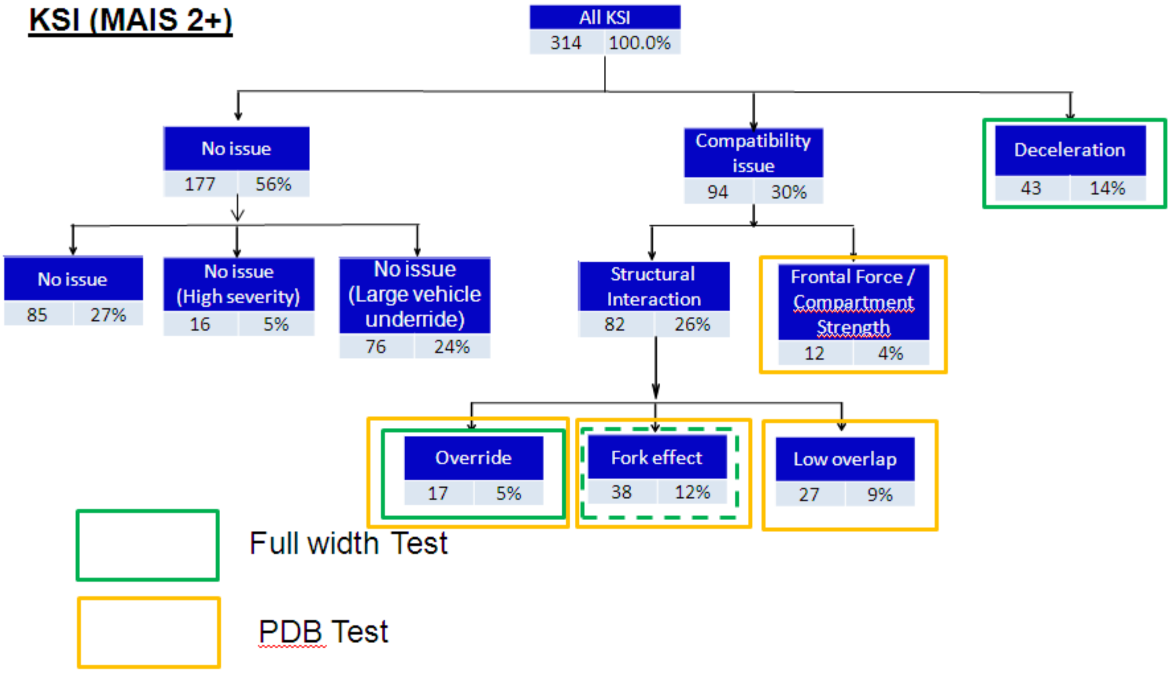


Figure 4.7: Detailed case analysis (target population) breakdown of killed or seriously injured casualties (MAIS 2+) casualties.

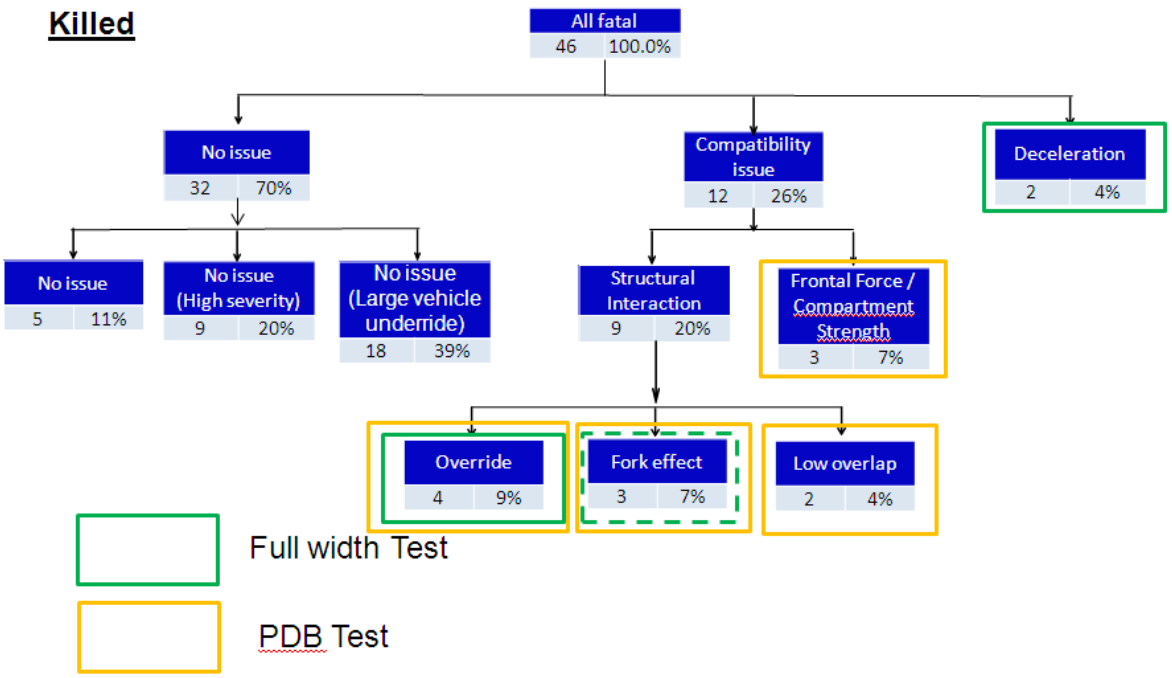


Figure 4.8: Detailed case analysis (target population) breakdown of killed casualties).

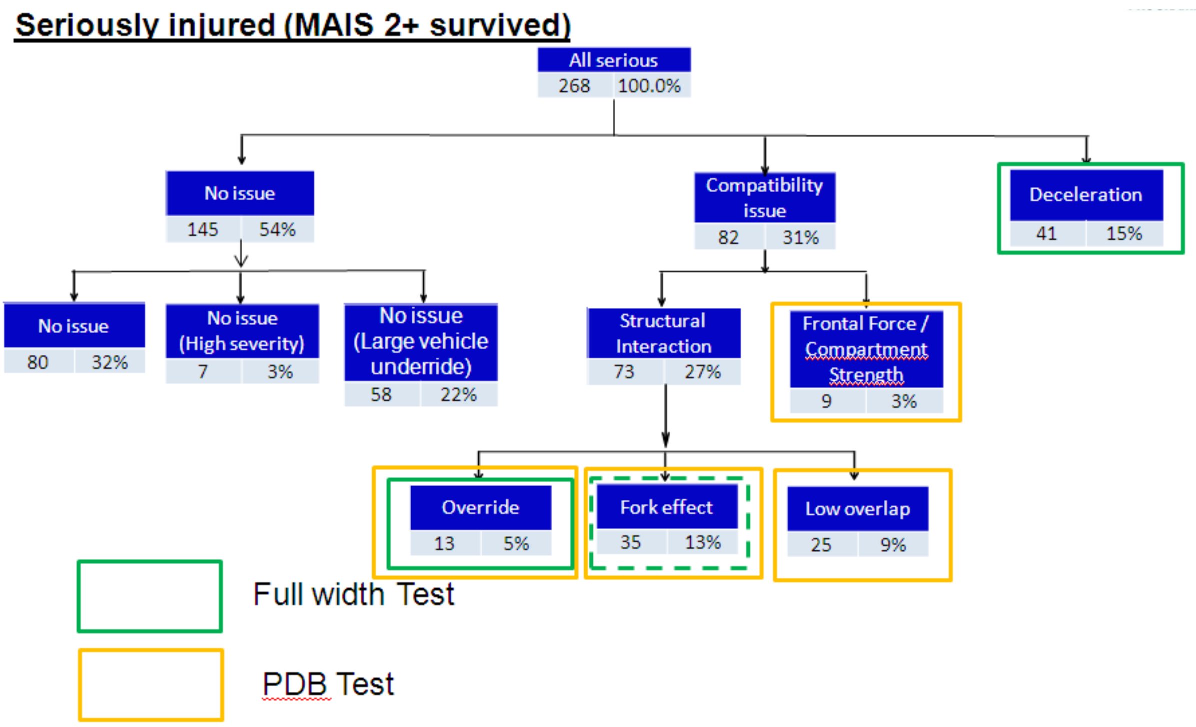


Figure 4.9: Detailed case analysis (target population) breakdown of seriously injured casualties.

CCIS Proportions and Scaling to the National Dataset

Table 22 shows the proportions of occupants included in the CCIS equivalent baseline datasets for whom a benefit was expected for Options 2 and 3. (Note: the proportion of casualties in the target population for the impact type 'car-to-multiple (3+ vehicles)' was calculated by estimating the number of casualties in multiple vehicle accidents in which the vehicle has a significant frontal impact and applying a weighted average of the proportions for other impact types to these casualties).

Table 22: CCIS target population proportions (frontal impacts).

Impact type	CCIS target population proportions			
	Killed		Seriously injured	
	Option 2	Option 3	Option 2	Option 3
Car-to-car front	0.353	0.529	0.436	0.499
Car-to-car side / rear	0	0	0.248	0.276
Car-to-HGV / PSV	0	0.046	0.046	0.046
Car-to-object	0.144	0.144	0.3	0.373
Car-to-other / unknown	0	0	0.098	0.147
Car /multiple (3+ vehicles)	0.072	0.099	0.176	0.209

These proportions were applied back to the national STATS19 baseline numbers to determine the number of casualties (killed and seriously injured) and the percentages of frontal impact car occupant casualties and all car occupant casualties included in the target populations for Options 2 and 3 (see Table 23).

Table 23: Target population for GB (frontal impacts).

Impact type	Car occupant casualties		Target population			
	Killed	Seriously injured	Killed		Seriously injured	
			Option 2	Option 3	Option 2	Option 3
Car-to-car front	167	1684	59	88	734	840
Car-to-car side / rear	19	854	0	0	212	236
Car-to-HGV / PSV	52	263	0	2	12	12
Car-to-object	179	1801	26	26	540	672
Car-to-other / unknown	52	640	0	0	63	94
Car / multiple (3+ vehicles)	109	1010	8	11	177	211
Total	**579**	**6253**	**93**	**127**	**1739**	**2065**
Percentage of frontal impact car occupant casualties			**16%**	**22%**	**28%**	**33%**
Percentage of all car occupant casualties			**9%**	**12%**	**18%**	**21%**

4.2.4 Estimate of Benefit

Further detailed case analysis was undertaken to determine the benefit for occupants included in the target populations for Options 2 and 3. The benefit was calculated using an 'injury reduction model', which considered a casualty's individual injuries.

Injury Reduction Model

Assumptions made in previous studies (VC-COMPAT [Cuerden 2006] and APROSYS [Edwards 2008]) were used to develop the model as follows:

- Improved compatibility will prevent compartment intrusion and improve the deceleration pulse in frontal impacts below test severity [Cuerden 2006]
    - Injury reduction models:
        - Pessimistic (lower): eliminate injuries caused by contact with an intruding front interior structure if ETS < 56 km/h.
        - Optimistic (upper): eliminate injuries caused by contact with the front interior (with or without intrusion) if ETS <56 km/h.
- Introduction of full width test will encourage improved restraint systems which will reduce restraint-related injury in frontal impacts [Edwards 2008]
    - Injury reduction models:
        - Model 1 (upper): reduce thorax and abdomen restraint-induced injuries to AIS 1 or by 2 AIS levels e.g. AIS 2 reduced to AIS 1; AIS 4 reduced to AIS 2.
        - Model 2: as Model 1 with ETS $\leq$ 56 km/h.
        - Model 3: as Model 2 with <5 cm intrusion on occupant's side of the vehicle.
        - Model 4: as Model 3 but assuming no benefit for occupants > 65 years of age.

The injury reduction model used to estimate the benefit of Options 2 and 3 is outlined below.

The following assumptions were made for the full width test:

- The full width test will improve structural alignment and hence prevent or reduce compartment intrusion and improve the deceleration pulse where structural alignment is an issue.
- The full width test will encourage fitment of improved restraint systems and hence reduce restraint-related thorax, abdomen, clavicle and leg/pelvic injuries. There will be no reduction of upper extremity (arm) injuries.

The injury reduction model for the full width test is described below:

- Structural alignment improvement: for casualties in the target population where a structural alignment issue (i.e. over-/under-ride caused by a difference in vehicle structural heights) is identified:
    - Pessimistic (lower): reduce casualty injuries associated with contact with intrusion by up to 3 AIS levels (but not less than AIS1).
    - Optimistic (upper): reduce casualty injuries associated with contact with intrusion by up to 3 AIS levels (but not less than AIS1) and reduce injuries caused by the deceleration and restraint system (thorax, abdomen, clavicle and leg/pelvic injuries) by up to 1 AIS level (but not less than AIS1).
- Restraint system improvement: for casualties in the target population where a deceleration pulse has been identified specifically, reduce restraint-related injuries (thorax, abdomen, clavicle and leg/pelvic) by:
    - Pessimistic: 1 AIS level (but not less than AIS1).
    - Optimistic: 2 AIS levels (but not less than AIS1).

The following assumptions were made for the PDB test:

- The PDB test will improve structural interaction and hence prevent or reduce compartment intrusion and improve the deceleration pulse where this is an issue.
- The PDB test will improve frontal force matching and hence prevent or reduce compartment intrusion where this is an issue.

The injury reduction model for the PDB test is described below:

- Structural interaction improvement: for casualties in the target population where a structural interaction issue (i.e. over-/under-ride, fork effect or low overlap) is identified:
    - Pessimistic (lower): reduce casualty injuries associated with contact with intrusion by 3 AIS levels (but not less than AIS1).
    - Optimistic (upper): reduce casualty injuries associated with contact with intrusion by 3 AIS levels (but not less than AIS1) and reduce injuries caused by the deceleration and restraint system (thorax, abdomen, clavicle and leg/pelvic injuries) by up to 1 AIS level (but not less than AIS1).

- Frontal force matching / compartment strength improvement: for casualties in the target population where a frontal force issue is identified:
    - Pessimistic (lower): reduce casualty injuries associated with contact with intrusion by 3 AIS levels (but not less than AIS1).
    - Optimistic (upper): reduce casualty injuries associated with contact with intrusion by 3 AIS levels (but not less than AIS1) and reduce injuries caused by the deceleration and restraint system (thorax, abdomen, clavicle and leg/pelvic injuries) by up to 1 AIS level (but not less than AIS1).

Options investigated

A number of options were investigated within Options 2 and 3. These were:

- Full width test (**Option 2**)
  - Full width – structural alignment (FW_SA)
  - Full width – deceleration/restraint system (FW_D)
  - Full width – above together (FW_All)
- PDB test – structural interaction fork effect only
  - PDB – structural interaction fork effect (PDB_FE_SI)
  - PDB – frontal force matching (PDB_FE_FF)
  - PDB – above together (PDB_FE_All)
- PDB test – structural interaction over-/under-ride, fork effect or low overlap
  - PDB – structural interaction (PDB_All_SI)
  - PDB – frontal force matching (PDB_All_FF)
  - PDB – above together (PDB_All_All)
- Full width and PDB (**Option 3**)
  - Full width and PDB – structural interaction over-/under-ride, fork effect or low overlap (FW_PDB_All) (Option 3a).
  - Full width and PDB – structural interaction fork effect only (FW_PDB_FE) (Option 3b).

The pessimistic (lower) and optimistic (upper) assumptions shown above for the full width and PDB tests were applied to identify an estimated MAIS for each casualty included in the target population for each of the above 11 options. This was achieved through detailed case analysis involving examination of the occupant's injuries and the injury causation. Each casualty was assessed on an individual basis to allow for the identification of controlling injuries i.e. those for which no benefit is predicted for any of the options (e.g. extremity (arm) injuries where no contact with intrusion has occurred on the occupant side) and the identification of limiting injuries where injuries of the same AIS and different causes occurred (where this AIS was also the MAIS). Detailed case analysis examples are included in Annex A.

Car front to car front

MAIS	No. of casualties Original	FW_Upper	FW_Lower
1	0	25	20
2	47	30	34
3	19	16	16
4	5	2	3
5	5	3	3
6	1	1	1
Total	**77**	**77**	**77**

Car front to HGV/PSV

MAIS	No. of casualties Original	FW_Upper	FW_Lower
1	0	1	1
2	26	25	25
3	23	23	23
4	4	4	4
5	5	5	5
6	9	9	9
Total	**67**	**67**	**67**

Car front to car side/rear

MAIS	No. of casualties Original	FW_Upper	FW_Lower
1	0	10	9
2	33	27	25
3	17	16	19
4	7	4	4
5	0	0	0
6	0	0	0
Total	**57**	**57**	**57**

Car front to object

MAIS	No. of casualties Original	FW_Upper	FW_Lower
1	0	34	25
2	48	25	32
3	21	12	14
4	8	6	6
5	3	3	3
6	0	0	0
Total	**80**	**80**	**80**

Car front to other

MAIS	No. of casualties Original	FW_Upper	FW_Lower
1	0	4	2
2	14	12	14
3	15	13	13
4	4	4	4
5	0	0	0
6	0	0	0
Total	**33**	**33**	**33**

Figure 4.10: Change in MAIS calculated for casualties in the target population for Option 2 'Full Width test' by impact partner.

Car front to car front

MAIS	No. of casualties Original	FW_PDB_Upper	FW_PDB_Lower
1	0	35	26
2	47	29	35
3	19	9	11
4	5	1	2
5	5	2	2
6	1	1	1
Total	**77**	**77**	**77**

Car front to HGV/PSV

MAIS	No. of casualties Original	FW_PDB_Upper	FW_PDB_Lower
1	0	2	2
2	26	25	25
3	23	23	23
4	4	4	4
5	5	4	4
6	9	9	9
Total	**67**	**67**	**67**

Car front to car side/rear

MAIS	No. of casualties Original	FW_PDB_Upper	FW_PDB_Lower
1	0	13	11
2	33	27	26
3	17	13	16
4	7	4	4
5	0	0	0
6	0	0	0
Total	**57**	**57**	**57**

Car front to object

MAIS	No. of casualties Original	FW_PDB_Upper	FW_PDB_Lower
1	0	44	34
2	48	21	29
3	21	8	10
4	8	5	5
5	3	2	2
6	0	0	0
Total	**80**	**80**	**80**

Car front to other

MAIS	No. of casualties Original	FW_PDB_Upper	FW_PDB_Lower
1	0	5	3
2	14	12	14
3	15	12	12
4	4	4	4
5	0	0	0
6	0	0	0
Total	**33**	**33**	**33**

Figure 4.11: Change in MAIS calculated for casualties in the target population for Option 3a (full width and PDB) by impact partner.

Car front to car front

MAIS	No. of casualties Original	FW_PDB(FE)_Upper	FW_PDB(FE)_Lower
1	0	27	20
2	47	30	36
3	19	14	14
4	5	2	3
5	5	3	3
6	1	1	1
Total	**77**	**77**	**77**

Car front to HGV/PSV

MAIS	No. of casualties Original	FW_PDB(FE)_Upper	FW_PDB(FE)_Lower
1	0	2	2
2	26	24	24
3	23	23	23
4	4	4	4
5	5	5	5
6	9	9	9
Total	**67**	**67**	**67**

Car front to car side/rear

MAIS	No. of casualties Original	FW_PDB(FE)_Upper	FW_PDB(FE)_Lower
1	0	11	9
2	33	27	26
3	17	15	18
4	7	4	4
5	0	0	0
6	0	0	0
Total	**57**	**57**	**57**

Car front to object

MAIS	No. of casualties Original	FW_PDB(FE)_Upper	FW_PDB(FE)_Lower
1	0	42	32
2	48	22	30
3	21	9	11
4	8	5	5
5	3	2	2
6	0	0	0
Total	**80**	**80**	**80**

Car front to other

MAIS	No. of casualties Original	FW_PDB(FE)_Upper	FW_PDB(FE)_Lower
1	0	5	3
2	14	12	14
3	15	12	12
4	4	4	4
5	0	0	0
6	0	0	0
Total	**33**	**33**	**33**

Figure 4.12: Change in MAIS calculated for casualties in the target population for Option 3b (full width and PDB fork effect) by impact partner.

<u>Conversion of Change in MAIS to the Police Severity Scale</u>

To convert the benefit expressed in terms of change in MAIS to a benefit expressed in terms of the police injury severity scale (*i.e.* fatal, serious and slight), conversion factors were developed by comparing the proportions of MAIS 1 to 6 injured casualties to the proportions of fatal, serious and slight casualties. This was done for casualties in the baseline datasets for each impact partner type. The proportion of MAIS 1 to 6 injured casualties is compared to the proportion of fatal and seriously injured casualties for car front to car front impacts is illustrated in Table 24 as an example. (MAIS1 injuries were assumed to be 'slight' on the police severity scale for all impact types). The resulting conversion factors were applied to the new MAIS distributions (taking into account the estimated benefit for each occupant) to estimate the benefit in terms of the police injury severity scale (fatal, serious and slightly injured).

Table 24: Conversion of MAIS to police injury severity scale (car front to car front impacts).

Original MAIS	Number of casualties			Conversion factors		
	Fatal	Serious	Total	Fatal	Serious	Slight
1	0	0	0	0.000	0.000	1.000
2	0	47	47	0.000	1.000	0.000
3	4	15	19	0.211	0.789	0.000
4	4	1	5	0.800	0.200	0.000
5	4	1	5	0.800	0.200	0.000
6	1	0	1	1.000	0.000	0.000

Injury reduction factors were calculated for each option by comparing the numbers of fatally injured, seriously injured and slightly injured casualties in the original CCIS datasets with the numbers of fatally injured, seriously injured and slightly injured casualties in the target population following application of the injury reduction model to reduce injury in terms of MAIS. This process was followed for each of the 11 options (with pessimistic (lower) and optimistic (upper) assumptions). Predicted injury reduction factors for each impact partner type are shown in Table 25.

Table 25: Predicted injury reduction factors for each option by impact type.

Option	Reduction factor									
	Car front to car front		Car front to car side / rear		Car front to HGV / PSV		Car front to object		Car front to other	
	Fatal	Serious	Fatal	Serious	Fatal	Serious	Fatal	Serious	Fatal	Serious
FW_SA_Upp	0.938	0.966	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FW_SA_Low	0.938	0.981	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
FW_D_Upp	0.705	0.700	0.571	0.829	1.000	0.980	0.806	0.546	0.947	0.867
FW_D_Low	0.767	0.766	0.571	0.847	1.000	0.980	0.806	0.673	0.947	0.938
FW_All_Upp	0.644	0.682	0.571	0.829	1.000	0.980	0.806	0.546	0.947	0.867
FW_All_Low	0.705	0.747	0.571	0.847	1.000	0.980	0.806	0.673	0.947	0.938
PDB_FE_SI_Upp	0.968	0.944	1.000	0.982	1.000	0.980	0.829	0.810	0.973	0.933
PDB_FE_SI_Low	0.984	0.988	1.000	1.000	1.000	1.000	0.926	0.911	0.973	0.969
PDB_FE_FF_Upp	0.968	0.975	1.000	1.000	1.000	1.000	0.903	0.998	1.000	1.000
PDB_FE_FF_Low	0.984	1.003	1.000	1.000	1.000	1.000	0.903	1.012	1.000	1.000
PDB_FE_All_Upp	0.919	0.923	1.000	0.982	1.000	0.980	0.731	0.809	0.973	0.933
PDB_FE_All_Low	0.968	0.991	1.000	1.000	1.000	1.000	0.829	0.923	0.973	0.969
PDB_All_SI_Upp	0.718	0.854	1.000	0.893	0.944	0.980	0.731	0.696	0.973	0.933
PDB_All_SI_Low	0.845	0.907	1.000	0.964	0.944	1.020	0.926	0.883	0.973	0.969
PDB_All_FF_Upp	0.796	0.963	1.000	0.982	1.000	1.000	0.903	0.998	1.000	1.000
PDB_All_FF_Low	0.906	0.988	1.000	1.000	1.000	1.000	0.903	1.012	1.000	1.000
PDB_All_All_Upp	0.608	0.798	1.000	0.893	0.944	0.980	0.634	0.694	0.973	0.933
PDB_All_All_Low	0.751	0.894	1.000	0.964	0.944	1.020	0.829	0.895	0.973	0.969
FW_PDB_FE_Upp	0.611	0.657	0.571	0.811	1.000	0.959	0.634	0.455	0.920	0.836
FW_PDB_FE_Low	0.673	0.754	0.571	0.847	1.000	0.959	0.634	0.596	0.920	0.907
FW_PDB_All_Upp	0.407	0.574	0.571	0.776	0.944	0.980	0.634	0.427	0.920	0.836
FW_PDB_All_Low	0.501	0.695	0.571	0.811	0.944	0.980	0.634	0.567	0.920	0.907

<u>CCIS Proportions</u>

Benefit proportions of fatally injured and seriously injured casualties estimated for the CCIS dataset are illustrated for the target population and Option 2 (full width), Option 3a (full width and PDB full) and Option 3b (full width and PDB fork effect) for all impact types in Table 26 (fatally injured casualties) and Table 27 (seriously injured casualties), including pessimistic (lower) and optimistic (upper) assumptions.

Table 26: Target population and benefit proportions estimated for CCIS dataset for Options 2, 3a and 3b (fatally injured casualties).

Impact type	CCIS benefit proportions							
	Target population		Option 2		Option 3a		Option 3b	
	Option 2	Option 3	Upper	Lower	Upper	Lower	Upper	Lower
Car-to-car front	0.353	*0.529*	0.272	0.225	0.453	0.381	0.297	0.250
Car-to-car side / rear	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Car-to-HGV / PSV	0.000	0.046	0.000	0.000	0.046	0.046	0.000	0.000
Car-to-object	0.144	0.144	0.063	0.063	0.119	0.119	0.119	0.119
Car-to-other / unknown	0.000	0.000	0.033	0.033	0.050	0.050	0.050	0.050
Car / multiple (3+ vehicles)	0.072	0.099	0.011	0.008	0.032	0.023	0.015	0.011

Table 27: CCIS proportions (target population and Options 2, 3a and 3b) (seriously injured casualties).

Impact type	CCIS benefit proportions							
	Target population		Option 2		Option 3a		Option 3b	
	Option 2	Option 3	Upper	Lower	Upper	Lower	Upper	Lower
Car-to-car front	0.436	0.499	0.254	0.202	0.340	0.243	0.274	0.196
Car-to-car side / rear	0.248	0.276	0.132	0.118	0.173	0.146	0.146	0.118
Car–to-HGV / PSV	0.046	0.046	0.015	0.015	0.015	0.015	0.030	0.030
Car-to-object	0.300	0.373	0.236	0.170	0.298	0.225	0.283	0.210
Car-to-other / unknown	0.098	0.147	0.092	0.043	0.113	0.064	0.113	0.064
Car / multiple (3+ vehicles)	0.176	0.209	0.024	0.014	0.041	0.022	0.031	0.017

<u>Estimated Benefit</u>

The CCIS dataset benefit proportions above were used to scale the national data to estimate the benefit for GB. The estimated benefit (in terms of casualties saved) for each impact type is shown for Option 2 (full width), Option 3a (full width and PDB full) and Option 3b (full width and PDB fork effect) in Table 28 (fatally injured casualties) and Table 29 (seriously injured casualties), including pessimistic (lower) and optimistic (upper) assumptions.

Table 28: Benefit for GB (in terms of casualties saved) for Options 2, 3a and 3b for fatally injured casualties.

Impact type	**Car occupant casualties**	**Target population**		**Benefit (casualties saved)**					
				Option 2		**Option 3a**		**Option 3b**	
		Option 2	**Option 3**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Car-to-car front	167	59	88	46	38	76	64	50	42
Car-to-car side / rear	19	0	0	0	0	0	0	0	0
Car-to-HGV / PSV	52	0	2	0	0	2	2	0	0
Car-to-object	179	26	26	11	11	21	21	21	21
Car-to-other / unknown	52	0	0	2	2	3	3	3	3
Car / multiple (3+ vehicles)	109	8	11	1	1	3	3	2	1
Total	**579**	**93**	**127**	**60**	**52**	**105**	**93**	**75**	**67**
Percentage of all car occupant casualties		**9%**	**12%**	**6%**	**5%**	**10%**	**9%**	**7%**	**6%**

Table 29: Benefit for GB (in terms of casualties saved) for Options 2, 3a and 3b for seriously injured casualties.

Impact type	**Car occupant casualties**	**Target population**		**Benefit (casualties saved)**					
				Option 2		**Option 3a**		**Option 3b**	
		Option 2	**Option 3**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Car-to-car front	1684	734	840	428	340	573	410	461	331
Car-to-car side / rear	854	212	236	3	2	3	3	3	2
Car-to-HGV / PSV	263	12	12	4	4	4	4	8	8
Car-to-object	1801	540	672	425	307	537	405	511	379
Car-to-other / unknown	640	63	94	59	27	72	41	72	41
Car / multiple (3+ vehicles)	1010	178	211	24	14	41	22	32	17
Total	**6253**	**1739**	**2065**	**943**	**694**	**1231**	**885**	**1086**	**777**
Percentage of all car occupant casualties		**18%**	**21%**	**10%**	**7%**	**13%**	**9%**	**11%**	**8%**

Table 30: Breakdown of benefit for Option 2 'full width test' for fatally injured casualties.

Impact type	**Car occupant casualties**	**Target population**		**Benefit (injury reduction)**					
				Option 2		**Option 2 - SA**		**Option 2 - D**	
		Option 2	**Option 3**	**Upper**	**Lower**	**Upper**	**Lower**	**Upper**	**Lower**
Car to car front	167	59	88	46	38	8	8	38	30
Car to car side / rear	19	0	0	0	0	0	0	0	0
Car to HGV / PSV	52	0	2	0	0	0	0	0	0
Car to object	179	26	26	11	11	0	0	11	11
Car to other / unknown	52	0	0	2	2	0	0	2	2
Car / multiple (3+ vehicles)	109	8	11	1	1	0	0	1	1
Total	**579**	**93**	**127**	**60**	**52**	**8**	**8**	**52**	**43**
Percentage of all car occupant casualties		**8.9%**	**12.1%**	**6%**	**5%**	**0.8%**	**0.8%**	**5%**	**4%**

A breakdown of the benefit resulting from Option 2 (full width) structural alignment improvement and restraint system improvement is shown in

Table 30 (fatally injured casualties) and Table 31 (seriously injured casualties). These results show that the majority of the benefit predicted for Option 2 is from the restraint system improvement (with a resulting reduction in the severity of deceleration-related injuries).

Table 31: Breakdown of benefit for Option 2 'full width test' for seriously injured casualties.

Impact type	Car occupant casualties	Target population		Benefit (injury reduction)					
				Option 2		Option 2 - SA		Option 2 - D	
		Option 2	Option 3	Upper	Lower	Upper	Lower	Upper	Lower
Car to car front	1684	734	840	428	340	46	25	403	314
Car to car side / rear	854	212	236	3	2	0	0	3	2
Car to HGV / PSV	263	12	12	4	4	0	0	4	4
Car to object	1801	540	672	425	307	0	0	425	307
Car to other / unknown	640	63	94	59	27	0	0	59	27
Car / multiple (3+ vehicles)	1010	178	211	24	14	0	0	23	13
Total	**6252**	**1739**	**2065**	**943**	**694**	**46**	**25**	**916**	**667**
Percentage of all car occupant casualties		**17.7%**	**21%**	**10%**	**7%**	**0.5%**	**0.3%**	**9%**	**7%**

4.3 Target Population for Side Impact

The above analysis focused on car occupants involved in frontal impacts. It was assumed that if lower load paths are fitted to car fronts to improve their compatibility in frontal impacts, this will also help compatibility in side impacts and hence could reduce the number of casualties in cars impacted on the side by the fronts of other cars. This is because a lower load path should enable better interaction with the sills of cars impacted on the side.

The analysis started with the baseline i.e. Option 1 'No change' (calculated as described above using regression analysis and STATS19 data) with Killed or Seriously Injured (KSI) car occupant casualties in side impacts in a regulatory compliant and/or Euro NCAP-influenced vehicle fleet Table 32 summarises the number of killed and seriously injured car occupant casualties in side impacts by impact partner type.

Table 32: Car occupant casualties in car side impacts in a regulatory compliant / Euro NCAP influenced vehicle fleet.

Impact type	Car occupant injury severity	
	Killed	Seriously injured
Car side hit by car front	80	656
Car side hit by car side / rear	14	309
Car side hit by HGV / PSV	29	120
Car side hit by object	143	732
Car side hit by other / unknown	40	282
Car side hit by multiple (3+ vehicles)	40	226
Total	**346**	**2325**

An equivalent baseline CCIS dataset (i.e. the comparison point with baseline national STATS19 data) for occupants in side impacts was derived by applying the following selection criteria:

- Accident occurred between 2000 and 2010 (inclusive).
- The casualty was killed or seriously injured (MAIS 2+)
- The casualty was a car occupant.
- A significant side impact occurred.
- The car side was hit by the car front.
- The nature of the injury was known.
- The occupant was in a regulatory compliant car.

A further set of selection criteria was applied to each dataset to identify those casualties who may experience a benefit if the vehicle's front end was modified to improve its compatibility in side impacts. The following criteria were applied:

- No rollover occurred before the first impact.
- Damage to the passenger compartment occurred.
- The direction of force was between 1 and 5 or between 7 and 11.

The selection process to determine the target population in the detailed CCIS dataset is illustrated in Figure 4.13.

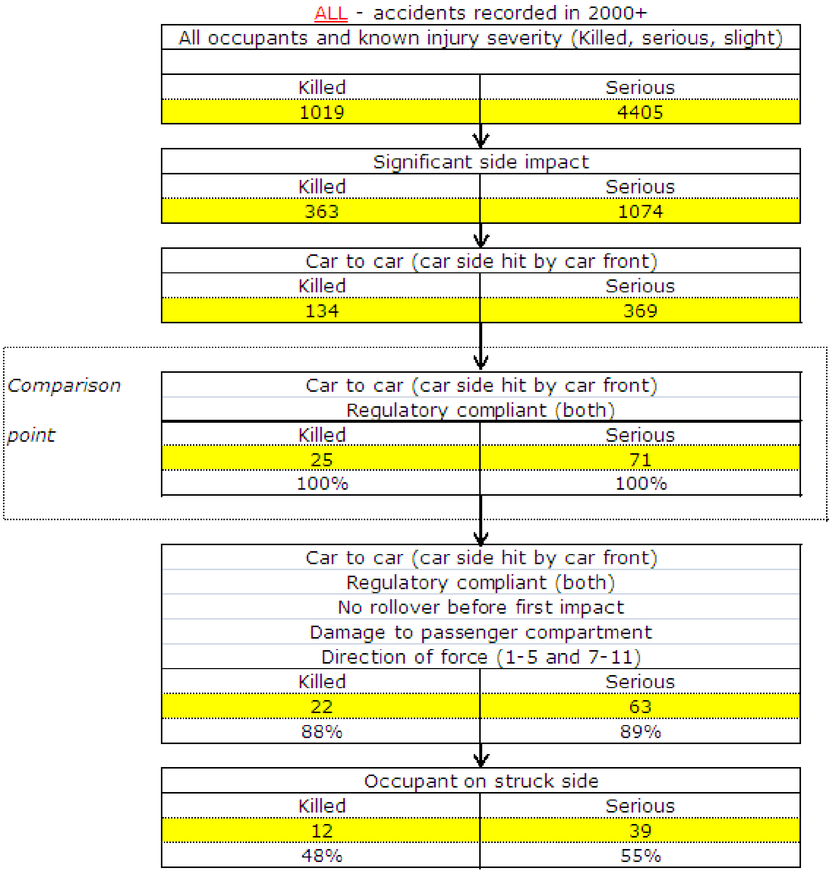


Figure 4.13: Formation of equivalent baseline CCIS dataset for side impacts.

<u>CCIS Proportions and Scaling to the National Dataset</u>

Table 29 shows the proportions of casualties in the CCIS equivalent baseline datasets included in the target population for side impacts. (Note: the proportion of casualties in the target population for the impact type 'car / multiple (3+ vehicles)' was calculated by estimating the number of casualties in multiple vehicle accidents in which the vehicle has a significant side impact and applying a weighted average of the proportions for other impact types to these casualties). The proportions were calculated for occupants on the struck side of the vehicle only and for occupants on either the struck or non-struck side.

Table 30: CCIS target population proportions (side impacts).

Impact type	CCIS target population proportions			
	Killed		Seriously injured	
	Struck and non-struck side	Struck side only	Struck and non-struck side	Struck side only
Car side hit by car front	0.88	0.48	0.89	0.55
Car side hit by car side / rear	0	0	0	0
Car side hit by HGV / PSV	0	0	0	0
Car side hit by object	0	0	0	0
Car side hit by other / unknown	0	0	0	0
Car side hit by multiple (3+ vehicles)	0.079	0.043	0.126	0.078

These proportions were applied to the national STATS19 baseline numbers to determine the number of casualties (killed and seriously injured) and the percentages of side impact car occupant casualties and all car occupant casualties in the target population (see Table 31).

Table 31: Target population for GB for side impact.

Impact type	Car occupant injury severity		Target population			
	Killed	Seriously injured	Killed		Seriously injured	
			Struck and non-struck side	Struck side only	Struck and non-struck side	Struck side only
Car side hit by car front	80	656	71	39	584	361
Car side hit by car side / rear	14	309	0	0	0	0
Car side hit by HGV / PSV	29	120	0	0	0	0
Car side hit by object	143	732	0	0	0	0
Car side hit by other / unknown	40	282	0	0	0	0
Car side hit by multiple (3+ vehicles)	40	226	3	2	28	18
Total	**346**	**2325**	**74**	**40**	**613**	**379**
Percentage of side impact car occupant casualties			**21%**	**12%**	**26%**	**16%**
Percentage of all car occupant casualties			**7%**	**4%**	**6%**	**4%**

The overall benefit of improved compatibility for casualties in the target population (side impacts) is summarised in Table 32.

Table 32: Target population for side impact.

Option	% (Number) of car occupant casualties			
	Killed		Seriously injured	
	Struck and non-struck side	Struck-side only	Struck and non-struck side	Struck-side only
Target population for side impact casualties	7.1%	3.8%	6.2%	3.9%
	(74)	(40)	(613)	(379)

4.4 Summary of Conclusions

4.4.1 Benefit of Option 1 'No change'

The benefits for Option 1 'No change' for casualties in frontal and side impacts were:

- Frontal impact
  - Regression analysis estimates a benefit of 2.0% (21) of killed and 1.7% (164) of seriously injured car occupant casualties
  - However, for the car-to-car frontal impact subset both proportional and regression analyses show that the number of fatal casualties increases with newer cars. This may indicate that the increased self-protection of cars is being offset by their increased aggression
- Side impact
  - Regression analysis estimates a benefit of 3.1% (32) of killed and 1.7% (171) of seriously injured car occupant casualties
  - For the car-to-car side impact subset both the proportional and regression analyses show that the number of fatal casualties decreases with newer (regulatory compliant / Euro NCAP influenced) cars.

4.4.2 Target Populations and Benefits for Option 2 'Full Width Test' and Option 3 'Full Width and PDB Tests'

The target populations and benefits predicted for Option 2 'Full Width test', Option 3a ' Full Width and PDB Tests' and Option 3b 'Full Width and PDB test – fork effect only' is summarised in Table 33 (Note: this does not include the benefit of Option 1 'no change').

Table 33: Summary of target population and benefits for GB for implementation of Options 2, 3a and 3b.

Option		% (No.) of car occupant casualties			
		Killed		Seriously injured	
Target population	Option 2 'Full width test'	8.9% (93)		17.7% (1739)	
	Option 3 'Full width & PDB tests'	12.1% (127)		21.0% (2065)	
Benefit	Option 2 'Full width test'	**Upper**	**Lower**	**Upper**	**Lower**
		6% (60)	5% (52)	10% (943)	7% (694)
	Option 3a 'Full width & PDB test full'	**Upper**	**Lower**	**Upper**	**Lower**
		10% (105)	9% (93)	13% (1231)	9% (885)
	Option 3b 'Full width & PDB test fork effect only'	**Upper**	**Lower**	**Upper**	**Lower**
		7% (75)	6% (67)	11% (1086)	8% (777)

The benefit for Option 2 'Full Width test' was examined further and the proportion of it related to improvements in structural alignment and improvements to the restraint system were estimated as shown in Table 34.

It should be noted that the target populations and benefits estimated in this section do not include the benefit of Option 1 'No change'. Also, the benefit related to structural alignment is likely to be under estimated because misaligned vehicles were difficult to identify in the accident data.

Table 34: Breakdown of the benefit for Option 2 'Full Width test'.

Option		% (No.) of car occupant casualties			
		Killed		Seriously injured	
Target population	Option 2 'Full width test'	8.9% (93)		17.7% (1739)	
Benefit	Option 2 'Full width test'	**Upper**	**Lower**	**Upper**	**Lower**
		6% (60)	5% (52)	10% (943)	7% (694)
	Option 2 'Full width test - structural alignment'	**Upper**	**Lower**	**Upper**	**Lower**
		0.8% (8)	0.8% (8)	0.5% (46)	0.3% (25)
	Option 2 'Full width test - deceleration'	**Upper**	**Lower**	**Upper**	**Lower**
		5% (52)	4% (43)	9% (916)	7% (667)

4.4.3 Target Population for Side Impact

The target population was estimated for casualties in car side impacts in which the car was struck by another car which had improved compatibility. Two estimates were made, the first (optimistic/upper) assumed that occupants seated on the struck and non-struck side may experience benefit, the second (pessimistic/lower) that only occupants seated on the struck may experience benefit (Table 35).

Table 35: Target population for side impacts.

Option	% (Number) of car occupant casualties			
	Killed		Seriously injured	
	Struck and non-struck side	Struck-side only	Struck and non-struck side	Struck-side only
Target population for side impact casualties	7.1%	3.8%	6.2%	3.9%
	(74)	(40)	(613)	(379)

5 GERMAN ANALYSIS

As for GB, the German analysis was performed in two parts; the first part estimated the benefit for Option 1 (No change) and the second part the benefits and break-even costs for Option 2 (FW test) and Option 3 (FW and PDB tests).

5.1 Benefit of Option 1 'No change'

5.1.1 Methodology

German national accident data with personal injury from years 2005 to 2007 were used for this analysis, which were presented in Geneva in 2009 [Pastor 2009/1, Pastor 2009/2]. The high importance of two-car-accidents can be illustrated as follows. Two-car-accidents deliver more than half of the accidents with personal injury to a passenger car driver and about a quarter of all passenger car driver fatalities. Among those accidents, front-to-front accidents are of particular high importance. Front-to-front two-car-accidents make up about 12 % of all two-car-accidents, but produce more than 50 % of all-two-car accidents driver fatalities (***Figure 5.3***). For this reason – and because other categories of frontal car impacts were difficult to identify in police accident data – only front-to-front two-car-accidents were considered in this analysis.

For this investigation a matched pairs approach was chosen. In contrast to other methods - e.g. analysing indicators like Severity Rate, which is defined as the ratio of the count of driver fatality plus seriously injured drivers and the count of all personally injured drivers – this kind of statistical approach does not neglect the possible correlation of two road users that are involved in the same accident (no independent observations).

The method used was the "Bradley Terry Model". This model deals with the area of paired comparisons, where ranking takes place between members drawn from a group two at a time. Whereas the method has often been used to establish rankings and predictions for sports competitions, the method was now used to establish crashworthiness rankings for passenger cars.

Whereas the winner in a sports duel is easy to see, the winner in a car-to-car crash was defined as the car which received less injury to its driver. The model can be formulated as follows:

$p_{ij} = \alpha_i / (\alpha_i + \alpha_j)$; $Odds_{ij} = \alpha_i / \alpha_j$; (2), (3)

with: P_{ij} *: Winning Probability car i against car j;*

α_i *: Crashworthiness of car i*

The model can alternatively be formulated as a log linear model where independent (explanatory) parameters can be introduced.

The parameters selected were primarily age and gender of the passenger car driver, frontal impact Euro NCAP rating and the mass of the car. Secondary, parameters as the wheelbase/total length, total width and height, the specific power and the manufacturer were considered. Based on these factors the crashworthiness (CW) was calculated.

Finally the injury risk for a car occupant was estimated. The injury risk for the driver of one particular car was considered to be a function of

- (1) the accident severity in general,
- (2) the partner protection of the other car and
- (3) the self protection/crashworthiness of the reference or case car

The general accident severity (1) will probably depend on accident related parameters such as, e.g. “location of accident”. Rural accidents are for instance in general more severe than urban accidents because of higher driving speeds.

Any given general accident severity can be made more severe by an aggressive collision opponent, or vice versa can be made less severe by some smart collision opponent. This partner protection term (2) was easily constructed to be the difference in crashworthiness between the partners. A collision opponent with identical crashworthiness (basically a car with the same mass, the same NCAP rating) will not make the accident more or less severe.

Finally the given accident severity was taken into account (absorbed) in the cars’ crashworthiness (3), as it was estimated by the Bradley Terry Model. The injury risk of car A was then calculated using a standard logistic regression approach.

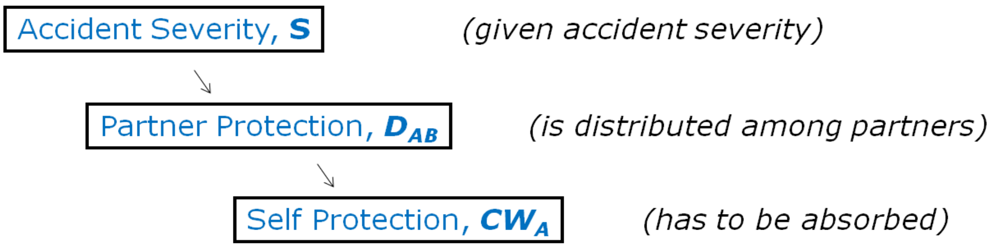


Figure 5.1: Input for the estimation of injury risk of a car-to-car accident.

The final statistical model, using the inputs shown in Figure 5.1, is able to fully explain the current injury severity distribution of passenger car drivers involved in car–to-car front to front collisions. It is now of particular interest to see how this injury severity distribution may be modified by different future scenarios.

One of the options being of interest is the “do nothing option”. Here it is assumed that no changes to the current frontal impact regulation will be introduced. The car fleet will develop without applying additional constraints. It has been assumed that the newer cars will become heavier, simply because the older cars will leave the fleet and will be substituted by more modern cars, which have shown to have a greater mass (by a factor of around 1.3). In addition the frontal safety level of new cars, substituting the old ones, was considered to be 9-12 points in terms of NCAP rating.

5.1.2 Results

5.1.2.1 Overview of Car Occupant Casualties in Germany

Figure 5.2 shows road accident casualties by user type for Germany for the average of years 2005 - 2007. It can be seen that approximately half of the fatally injured people were car users, similar to GB. ***Figure 5.3*** shows the breakdown by impact type for car occupant fatalities for 2008. Single car accidents are the biggest group of fatalities with 42%, with nearly half of them being frontal collisions. Car-to-car accidents make the second biggest group of fatalities with 24%, with about half of them being car front-to-front accidents and half car-to-other impact types.

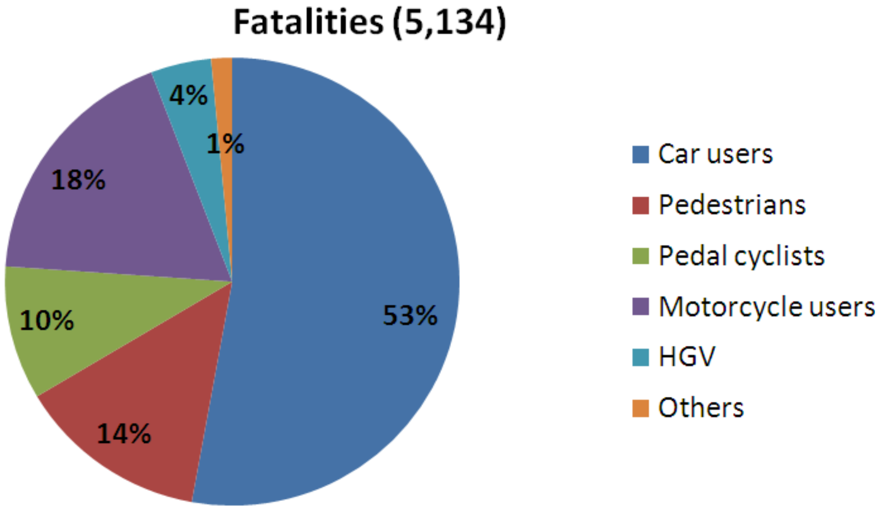
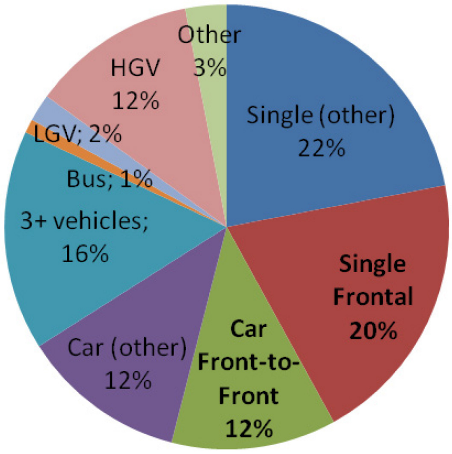


Figure 5.2: Road accident fatalities in Germany by user type average 2005-2007.



5.1.2.2 Figure 5.3: Car occupant fatalities in year 2008 (German National Accident Data).Matched pairs analysis

The statistical model as described in the methodology part was applied to 21,764 two car front-to-front accidents. The statistical model outlined, describing the injury severity risk for some driver is visually shown in Figure 5.4. The statistical significance and effects of “partner protection”, “self protection” and “accident severity in general” as driving factors determining the injury severity risk is given in terms of Odds Ratio. Odds Ratios of 1 describe factors which do not influence the injury risk (roughly speaking the Odds Ratio is fifty/fifty, which is identical to 1). This is, for example, true for the effect of the self protection term in the model, where the Odds Ratio is nearly 1. The bars in different grey shadings attached to the calculated Odds Ratio shows the confidence interval of the estimate. In particular, if the bars cross the Odds Ratio line at 1, no significant effect can be seen.

It is somehow surprising that the self protection term did not show up to have a significant effect. It has to be mentioned that some “self protection” term is already integrated in the definition of the “partner protection” term. The “partner protection” term is highly relevant and significant. However, the right interpretation/reading of the minor “self protection” effect is, that – provided there is no dangerous collision opponent and the accident severity in general is similar – the injury risk for the driver does not depend heavily on the crashworthiness of the car they are in. This result is in line with conclusions from some frontal impact research work recently done by TRL for the European Commission [Richards 2010]. In the paper (Tables 11, 12 and 13) it is shown that the risk for getting fatally injured in a front to front car-to-car crash is primarily dependent on the model year of the collision opponent, but independent of the model year of the reference car.

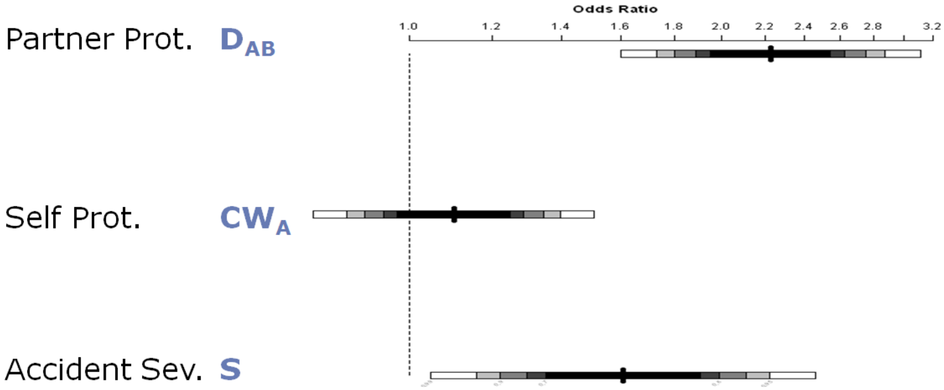


Figure 5.4: Importance of factors driving injury risk for car A.

5.1.3 Estimate of Benefit and Conclusions

The factors mentioned were used to calculate the benefit of changing to a regulatory compliant / Euro NCAP influenced fleet (defined as vehicles registered 2000+ with a Euro NCAP frontal score of 9-12) as shown in Table 36 and Table 37 for option 1 ‘no change’.

Table 36: Outcome of Option 1 ‘No change’ based on 21,764 front-to-front two car accidents.

	Fatalities	Seriously injured	Slightly injured	Uninjured
Current situation	100.0 %	100.0 %	100.0 %	100.0 %
Option 1	98.2 %	100.1 %	100.0 %	100.4 %

Table 37: Benefit of Option 1 ‘No change’ for car-to-car frontal impacts (Germany).

Benefit of Option 1, ‘No change‘	% of car occupant casualties	
	Killed	Seriously injured
Casualties	-1.8 %	0.1 %

It is interesting to note that a benefit is estimated for two-car frontal accidents for killed casualties in contrast to the GB analysis which predicts a disbenefit. However, the German analysis did consider some additional factors for the evolution of the car fleet (higher masses of new cars and some better self protection as a result of the general technical improvement). This could be a reason for such differing results.

5.2 Benefit of Option 2 ‘Add Full Width Test’ and Option 3 ‘Add Full Width Test and Replace Current ODB Test with PDB Test’

5.2.1 Methodology

For this analysis, the GIDAS database was used because the detailed information necessary to perform the analysis was not available in the German national statistics.

The selection of the dataset and the identification of the target population were performed in a similar manner as for the CCIS dataset for the GB analysis apart from the necessity of a different data handling process. In detail, the data query from the accident data analysis (see

Deliverable 1.1) [Thompson 2013] to extract car frontal collisions was used as for the GB analysis. The following criteria were applied to derive the dataset:

- Accident occurred between 2000 and 2010 (inclusive).
- The casualty was killed or seriously injured.
- The casualty (driver and/or front passenger) was a car occupant and older than 12 years.
- A significant frontal impact occurred with the frontal force direction (11, 12 or 1 o'clock), main damage to the front and no rollover.
- The nature of the injury, the impact type and seatbelt use were all known.
- Cars with first registration of years 2000 to 2009.

A further set of selection criteria was applied to identify those casualties where a benefit may be achieved for the chosen options, such as the known usage of the belt. The focus of the analysis was then focused on fatalities and seriously injured people (MAIS 2+). The associated accidents were categorised on a casualty level by a case-by-case analysis to the defined compatibility issues or to the category 'no issue' (see section 4.2.3):

- Structural interaction (scope)
- Front End Force / Deformation
- Compartment integrity
- Restraint system
- No issue

The alignment to these categories was done mainly by investigating photos, described accident causation, the injury overview (single injuries were summarised per body region; for each body region (highest AIS) main injury causation is assigned), driver behaviour and expert judgment. In general, if the compartment integrity failed, then it was likely that a compatibility issue occurred. 'No issue' was assigned if e.g. the car was totally destroyed by extreme speeding and hence, these high severity damages could not be assigned to certain compatibility issues impacts or addressed by resolving them.

The benefit was estimated for each option separately for each casualty in the target population by the use of an injury-shifting-method. Major steps for the assignment of injured people to the target population with regard to their injuries were:

- Consideration of all injuries
- Determination of highest AIS level per body region and its causation
- Assignment of those injuries to compatibility issues / no issues.

However, for the benefit analysis a different injury reduction model was used compared to the CCIS analysis. Initially each person's most seriously injured body region (expressed by MAIS) was determined. Following this, it was determined if the MAIS injury(ies) were caused by, or related to, a compatibility issue. They were then considered for the injury reduction model as described below. Due to the low number of fatalities in the GIDAS dataset, the killed and seriously injured (KSI) casualties were treated as one group to ensure statistically meaningful results.

The following injury reduction model (injury severity shifting method) was applied to calculate the casualty injury reduction to estimate the benefit of Options 2 and 3:

- MAIS reduction for casualties in target population:
  - Killed:
    - Full-width: MAIS minus 1 -> considered seriously injured if MAIS 4 or less
    - PDB: MAIS minus 1 -> considered seriously injured if MAIS 4 or less
  - Seriously injured:
    - Full-width: MAIS minus 1, but minimum MAIS 1 -> considered slightly injured if MAIS less than 2
    - PDB: MAIS minus 1, but minimum MAIS 1 -> considered slightly injured if MAIS less than 2
  - Slightly injured (MAIS 1) stay slightly injured
- Optimistic estimate for upper limit: all killed and seriously injured in target population have their injuries reduced as above.
- Pessimistic estimate for lower limit: half of all killed and seriously injured in target population have their injuries reduced as above.

Finally, the national benefit was estimated as the change of the proportion of killed and seriously injured casualties scaled to the national level.

5.2.2 Estimate of Target Population

The analysis of GIDAS passenger car frontal collisions of the years 2000 to 2010 included all kinds of collision partners and impact configurations to other vehicles or objects (Frontal-frontal, Frontal-side, Frontal-rear, Frontal-object/others). The dataset contained:

- Number of cases: 2862
- Number of cars involved: 2950
- Number of people in those cars: 3650

Table 41 shows an overview of people involved in the final dataset, whereby a distinction was chosen into the collision partner groups CAR_CAR (car-to-car), CAR_HGV (car-to-heavy good vehicles), CAR_OBJ (car-to-objects) and CAR_OTH (car-to-others). It can be seen that most KSI injured people (56%) were involved in car-to-car crashes, but a higher proportion of killed cases occur in car-to-object (e.g. tree) and car-to-heavy good vehicles accidents.

Table 38: GIDAS dataset used (person level, seatbelt use known)

	KSI	Slightly injured	Uninjured	Unknown	Total	Killed
CAR_CAR	111 (56%)	623	958	35	1727	4
CAR_HGV	22 (11%)	69	21	8	120	3
CAR_OBJ	64 (32%)	162	305	22	553	6
CAR_OTH	2 (1%)	15	816	0	833	0
TOTAL	199 (100%)	869	2100	65	3233	13

The process was followed by a reduction of four potential cases due to missing information. Thus, the GIDAS data sample for the detailed case analysis was reduced to 195 killed or seriously injured car occupant casualties. Due to the low numbers of cases no further distinctions have been made in the following work in terms of collision partner groups. The result of this analysis to determine the target populations is shown in Figure 5.5. Casualties were identified in which there were compatibility problems and restraint performance issues in the accident as described in the methodology section above. The relationship of the problem to the test is shown by the green and orange boxes, e.g. there is a green box around deceleration because the full width test should help reduce deceleration restraint related injuries. Nearly half of all cases were assigned to the category 'No issues', while 41% were assigned to 'Deceleration' related injuries and 13% to 'Compatibility issues'.

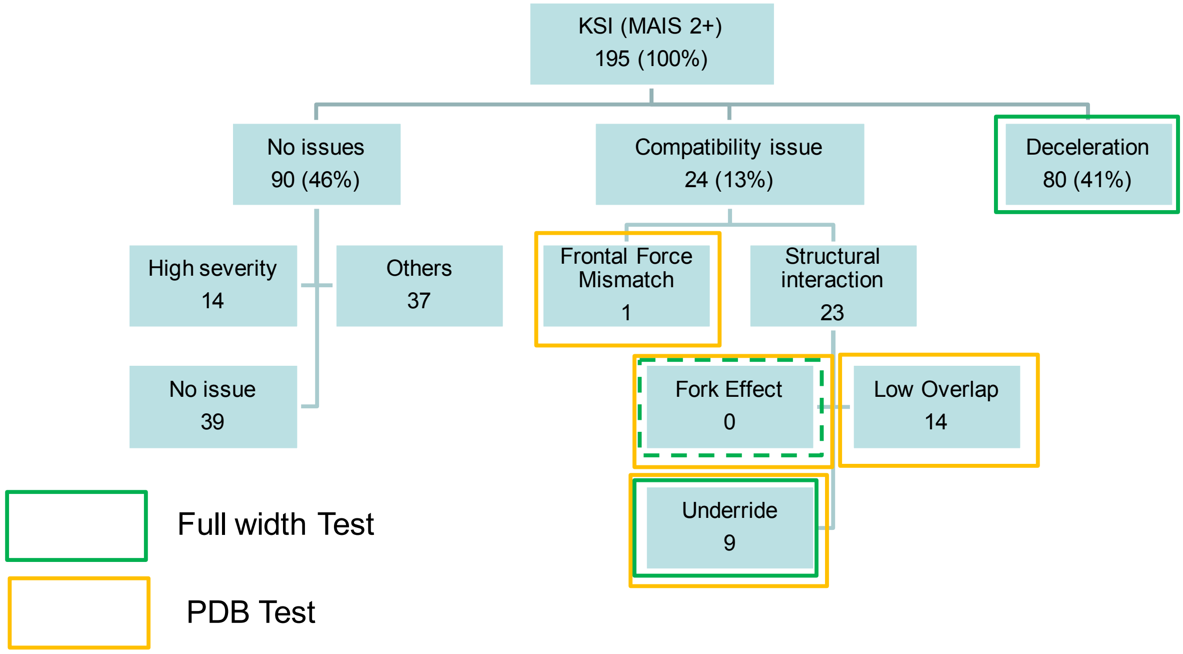


Figure 5.5: German (GIDAS) detailed data sample target population breakdown KSI (MAIS 2+).

These results were then scaled up to national level. An assumption taken to scale to national data level was that 42% of all killed and seriously injured people in cars occur in frontal collisions in Germany. The proportions for the target population for the options 2 and 3 can be seen in Table 42.

5.2.3 Estimate of Benefit

The target populations and benefits for Germany are shown below in a similar manner as for GB, see Table 33. Target populations and benefits shown do not include the benefit of Option 1 'No change'.

Table 39: Target populations and benefits for Options 2 and 3 (Germany).

Option		% (No.) of car occupant casualties Killed and seriously injured	
Target population	Option 2 'Full-width test'	16% (5085)	
	Option 3 'Full-width & PDB test'	19% (5942)	
Benefit	Option 2 'Full-width test'	**Upper** 12% (3771)	**Lower** 6% (1886)
	Option 3 'Full-width & PDB test'	**Upper** 14% (4343)	**Lower** 7% (2171)

The target population for Option 2 was calculated to be16% and for Option 3 to be 19% of car occupant casualties with at least serious injuries, respectively. The benefit varies, for Option 2 between 6% and 12% and for Option 3 slightly higher between 7% and 14%. The breakdown of the benefit of Option 2 shows that a major part of it would be addressed by an improved restraint system for car occupants, see Table 43.

Table 40: Breakdown of the benefit of Option 2 (Germany).

Option		% (No.) of car occupant casualties Killed and seriously injured	
Target population	Option 2 'Full-width test'	16% (5085)	
Benefit	Option 2 'Full-width test'	**Upper** 12% (3771)	**Lower** 6% (1886)
	Option 2 'Full-width test - structural alignment'	**Upper** 0.7% (229)	**Lower** 0.4% (114)
	Option 2 'Full-width test - deceleration'	**Upper** 11% (3543)	**Lower** 6% (1771)

5.3 Summary of Conclusions

- The benefit for option 1 'No change' was estimated to 1.8% less fatalities and 0.1% more seriously injured people by a matched pairs analysis of national data from 2005-2007. The benefits for option 2 'Add full width test to ODB test' and for option 2 'Add full-width test and replace ODB by PDB test' were estimated to be within the ranges of 6 - 12% of KSI (killed and seriously injured car occupants) and 7 - 14%, respectively.
- Compared to the GB analysis, the German analysis for Options 2 and 3 only states joint results for killed and seriously injured people, because a further distinction and hence scaling was not reasonable for the small number of fatalities within the selected GIDAS data set. Nevertheless, proportions for the target populations as well as for the benefits calculated are quite similar for GB and Germany.
- It should be noted that the case-by-case analysis of CCIS and GIDAS data in terms of identifying defined compatibility issues was mainly similar but there were some small differences due to subjective judgements (e.g. frontal tree collisions were mainly assigned to 'Fork effect' by TRL but to 'Deceleration' or 'No issue' by BASt).

6 EUROPEAN ANALYSIS

This work involved scaling the benefit proportions estimated for Great Britain (GB) and Germany (D) described above to give an indicative estimate of the benefits for Europe for each option. The approximate nature of this estimate should be remembered because it was assumed that the accident scene in GB and Germany is representative of that across the whole of Europe which is not accurate.

Fatal and seriously injured casualty data for all casualties and car occupant casualties were extracted from CARE [EC 2013.] for each country in the EU by year (Table 41). Points to note are:

- Fatal casualties were defined as those killed within 30 days of the collision. In a number of countries, the time period is much shorter, so an adjustment was made to account for this.
- 'Seriously injured' does not have a common definition across Europe; there may be differences in the classification of casualties between countries.
- 2008 data were the most recent data available for all countries in EU-15; as a result, these data was used. A number of countries have shown casualty reductions since 2008, so benefit figures calculated may be an overestimate.
- EU-27 excludes Bulgaria and Lithuania as data were not available from CARE for these countries.
- Data for Cyprus were only available for 2004, so these data were used.
- Seriously injured casualty data were not available for a number of countries (Cyprus, Estonia, Finland and Italy). As a result, the ratio of seriously injured to killed casualties was calculated for the remaining 21 countries; this was then averaged and an estimate of the number of seriously injured casualties, in those countries where the figures were not available, was obtained. This was done separately for 'all casualties' and 'car occupant casualties' to account for any difference between these groups. It should be noted there was large variation in the individual ratios for each country and hence, the average ratio may not be representative of the country in question; estimates obtained may be over or under representations of the true seriously injured casualty figure.

Table 41: Killed and seriously injured casualties in Germany, GB and Europe by casualty type, 2008 (Source: CARE database).

	Killed within 30 days		**Seriously injured**	
	All casualties	**Car occupant casualties**	**All casualties**	**Car occupant casualties**
Germany	4,477	2,368	70,644	30,589
Great Britain	2,538	1,250	26,034	10,643
EU-15	**25,420**	**12,497**	**225,990**	**96,075**
EU-27 (excluding Bulgaria & Lithuania)	**37,384**	**18,029**	**268,062**	**114,581**

Using the benefit proportions estimated for GB and Germany described in the sections above, European casualty data from CARE and simple scaling, upper and lower estimates of the benefit for Europe were made for each of the options (Table 42). The upper and lower estimates were obtained by scaling with the highest or lowest benefit proportion from either the GB or German analysis. The killed proportions were taken from the GB analysis only because it was only the GB analysis that estimated these proportions separately from the seriously injured proportions. Similarly, the proportions for Option 3b 'Full Width and PDB test fork effect only' were taken from the GB analysis only.

Table 42: Benefits for Europe for all options.

Option	No of car occupant casualties in EU27		% (No) of car occupant casualties			
	Killed	Seriously injured	Killed		Seriously injured	
			Upper	Lower	Upper	Lower
Option 1 'No change'	**18,029**	**114,581**	2.0%	1.8%	1.7%	0.1%
			361	325	1,948	115
Option 2 'Full width test'	**18,029**	**114,581**	6%	5%	12%	6%
			1,034	901	13,750	6,875
Option 3a 'Full width & PDB test all'	**18029**	**114581**	10%	9%	14%	7%
			1,810	1,623	16,041	8,021
Option 3b 'Full width & PDB test fork effect only'	**18029**	**114581**	7%	6%	11%	8%
			1,293	1,155	12,641	9,044

7 COSTS

The benefits predicted for GB, Germany and Europe above were converted in monetary values using the costs of killed, seriously injured and slightly injured road accident casualties published by the UK and German governments. Break-even costs, i.e. the cost per car for a cost / benefit ratio of one, were calculated by dividing the monetary value of the benefit by the number of new cars registered per year. These costs were compared with costs estimated in previous projects to give some idea of the cost effectiveness of the options analysed.

7.1 Previous Cost Analysis Studies

In previous studies cost analyses have been made, the results of which are summarised below:

- APROSYS: estimate of cost to improve restraint system for Full Width test [Cuerden 2006]
  - To meet R94 limits in Full Width test € 32 per car based on Fiat Bravo.
- Add collapsible steering column, degressive load limiter and double pretensioner
  - To meet FMVSS208 limits in FW test € 17 per car based on Fiat Bravo
- Add collapsible steering column and degressive load limiter

Note: Items such as a collapsible steering column and double pretensioner may be present already on many of today's vehicles.

- VC-COMPAT: estimate of cost to improve structural interaction for enhanced compatibility[Edwards 2007]
  - Add second load path € 102 per car
  - Add second load path and reinforce compartment € 222 per car
- EEVC WG13/21: estimate of costs to improve structure and introduce airbags for pole test [Edwards 2010]
  - Between € 297 and € 386 depending on original safety performance level of car
- NHTSA 2007: Final impact assessment to add oblique pole test [NHTSA 2007]
  - Assume add two or four sensor curtain airbag system
  - Between $ 243 (€ 182) and $ 280 (€ 210) ($ 1 = € 0.75€)

7.2 Costs for GB

The UK DfT published the following costs per casualty (Table 43) in 'Reported Road Casualties Great Britain: 2010 Annual Report' [RRCGB 2010].

Table 43: UK costs per casualty [RRCGB 2010]

		£ June 2009
Accident/casualty type	Cost per casualty	Cost per accident
Fatal	1,585,510	1,790,200
Serious	178,160	205,060
Slight	13,740	21,370
Average for all severities	47,740	68,320
Damage only	-	1,880

Using ACEA data [ACEA 2012] it was found that the number of registered cars in UK on average per year for 2008 to 2010 was 2,333,792 (Table 44).

Table 44: Number of new cars registered in UK 2008 - 2010.

Country	2008	2009	2010	Average
UK	2,485,258	2,222,542	2,293,576	2,333,792

From this information and an exchange rate of £1=€1.2, break-even costs for Options 2 and 3 were calculated for GB (Table 48).

Note: it was assumed that total number of casualties remained the same so the decrease in number of killed and seriously injured casualties equalled an increase in slightly injured casualties, the cost of which was taken into account in the calculation.

Table 45: Break-even costs for GB for Options 2 and 3.

Option	% (No) of car occupant casualties				Monetary Value (€M)		Break-even costs (€)	
	Killed		Seriously injured		Upper	Lower	Upper	Lower
	Upper	Lower	Upper	Lower				
Option 2 'Full width test'	6%	5%	12%	6%				
	60	52	943	694	299	235	128	101
Option 3a 'Full width & PDB test all'	10%	9%	14%	7%				
	105	93	1,231	885	441	350	189	150
Option 3b 'Full width & PDB test fork effect only'	7%	6%	11%	8%				
	75	67	1,086	777	356	280	152	120

7.3 Costs for Germany

German published monetary values for saving a casualty of fatal € 1,010,907, serious € 112,296 and slight € 4,437 [Bast 2011] were used for this calculation instead of the GB ones. These values are considerably less than the GB ones (Table 46). A probable cause of this is that the GB values contain a 'willingness to pay' element whereas the German values do not.

Table 46: Comparison of government published casualty costs for GB and Germany.

Casualty severity	GB Cost (€)	German cost (€)
Killed	1902612	1010907
Seriously injured	213792	112296
Slightly injured	16488	4437

Applying the same methodology as for GB and assuming that the number of new cars registered in Germany per year for 2008 to 2010 was 3,271,167 [Statistisches Bundesamt 2011], break-even costs for Options 2 and 3 were calculated for Germany, see Table 47.

Table 47: Break-even costs for Germany for Options 2 and 3.

Option	Break-even costs (€)	
	Upper	Lower
Option 2 'Full-width test'	175	84
Option 3 'Full-width & PDB test'	203	97

7.4 Costs for Europe

The number of new cars registered in the EU27 (excluding Bulgaria and Lithuania) average per year 2008-2010 was estimated to be 15,838,011 [ACEA 2012] (Table 48).

Table 48: Number of cars registered in EU27 excluding Bulgaria and Lithuania.

Country	2008	2009	2010	Average
Bulgaria	55,236	29,247	18,857	34,447
Lithuania	28,885	8,918	10,369	16,057
EU15	15,293,804	14,804,292	14,202,042	14,766,713
EU27*	16,730,630	15,793,939	15,140,977	15,888,515
EU27* (excluding Bulgaria and Lithuania)	16,646,509	15,755,774	15,111,751	**15,838,011**

*Data for Malta and Cyprus not available

Using this value, the ranges of the break-even costs for Options 2 and 3 for Europe were calculated using the benefits estimated for Europe in Section 6 and the highest (GB) and lowest (German) monetary values for saving a casualty.

Table 49: Break-even costs for Europe for Options 2 and 3.

Option	% (No) of car occupant casualties in EU27 (excluding Bulgaria and Lithuania)				Monetary Value (€M)		Break-even costs (€)	
	Killed		Seriously injured		Upper	Lower	Upper	Lower
	Upper	Lower	Upper	Lower				
Option 2 'Full width test'	6%	5%	12%	6%				
	1,034	901	13,750	6,875	4,663	1,649	294	104
Option 3a 'Full width & PDB test all'	10%	9%	14%	7%				
	1,810	1,623	16,041	8,021	6,579	2,498	415	158
Option 3b 'Full width & PDB test fork effect	7%	6%	11%	8%				
	1,293	1,155	12,641	9,044	4,932	3,963	311	250

7.5 Discussion and Conclusions

Comparing the costs estimated by previous projects with the break-even costs for Option 2 above shows the costs estimated by the APROSYS project for modifications to the restraint system are much lower. This indicates that the costs of introducing the improved restraint systems necessary to deliver the benefit predicted for Option 2 are likely to be less than the monetary value of the benefits, i.e. a cost benefit ratio of less than one. However, at present it is not known what vehicle restraint system changes would be needed to deliver the injury reduction assumed for this benefit analysis. It is likely that substantial changes will be needed, e.g. adaptive restraint systems. Also, it is not known what dummy performance limits will be needed in the Full Width test to enforce the fitment of appropriate restraint systems, and indeed whether or not the current HYBRID III dummy is sufficient for this purpose. More work is needed to address these issues but at present indications are that the benefits of implementing Option 2 should be greater than the costs.

8 DISCUSSION

It is interesting to note that, even though different injury reduction models had to be used for the GB and German analyses because of the different natures of the databases, the proportions calculated for the target populations and benefits were quite similar. The only significant difference of note was in the break-down of the target population. In the German data a larger proportion of the target population had injuries related to restraint performance issues and a smaller proportion had injuries related to the fork effect compared to the GB data (Figure 4.7 and Figure 5.5). It is believed that this difference is in the accident data because a great deal of care was taken to perform the GB and German analyses in a similar way although a somewhat subjective approach had to be used. It should be noted that because of this subjective approach there were some small differences, e.g. frontal tree collisions were mainly assigned to ‘Fork effect’ in the GB analysis but to ‘Deceleration’ or ‘No issue’ in the German analysis.

As an outcome of the German GIDAS analysis additional issues were identified, which may warrant further investigation in the future. These included the observation that often the front passenger injury severity was higher than the driver’s even though the impact was on the driver’s side and a large number of underride issues were seen in crashes of passenger cars against heavy goods vehicles.

Finally it should be noted that the dummy performance limits for a full width test need to be reviewed by future working groups in order to achieve the injury reduction assumed in the benefit analysis. It is likely that more stringent performance limits than the current R94 will be needed or indeed perhaps additional tests with different dummy sizes and/or tests at lower speeds with even more stringent performance limits. For reference, a non-exhaustive overview of dummy readings from full-width deformable barrier tests in the FIMCAR crash test data base is included in Annex B.

9 SUMMARY OF CONCLUSIONS

- For the benefit analysis it was assumed that the introduction of a full-width test with appropriate compatibility and dummy metrics has the potential to address the frontal impact issues under/override related to structural alignment and restraint related acceleration type injuries. Limited potential of the full-width test was expected for addressing fork effect issues. It was also assumed that the replacement of the ODB by the PDB/MPDB test procedure with an appropriate homogeneity metric had the potential to address the frontal impact issues under/override related to vertical load spreading, fork effect and low overlap as well as frontal force matching/compartment strength.
- The benefits of three potential changes to the frontal impact regulation were calculated for GB and Germany and scaled to give an indicative estimate for Europe.
    - For Option 1 'No change', a small benefit of about 2.0% or less of all car occupant Killed and Seriously Injured (KSI) casualties was estimated;
    - For Option 2 'Add FW test: Benefit of 5% to 12% of all car occupant KSI casualties was estimated. It was shown that this benefit consisted of:
        - Structural alignment (under/override related to structural alignment): 0.3% - 0.8%. However, it should be noted that the benefit related to structural alignment was likely to be under-estimated.
        - Restraint system (restraint related deceleration related injuries): 5% - 11%
- For Option 3 'Add FW test and replace ODB test with PDB test' 7% to 14% of all car occupant KSI casualties.
    - Note: Benefit percentages for Options 2 and 3 do not include the benefit of Option 1 'No change'.
- Break-even costs for options 2 and 3 were calculated. Comparison of these costs with costs estimated by previous projects indicated that the monetary value of the benefits of implementing Option 2 should be greater than the costs to modify the cars for restraint system changes. However, further work is needed to determine precisely what changes would be needed to deliver the injury reduction assumed for the benefit analysis and precisely what test configuration (in particular dummies) and performance limits would be needed to enforce these changes.

The following points should be noted:

The benefit was calculated assuming the implementation of complete assessment procedures. However, appropriate dummy assessment values and dummy selection were not addressed by FIMCAR and appropriate PDB/MPDB metrics are not yet established.

Possible further potential benefits from the definition of a common interaction zone related to truck underrun protection and roadside guard rails were not considered in the study.

The conclusions for the GB additional analysis that was performed were:

- The benefit of 'No change' for car occupant casualties injured in side impacts was estimated to be approximately 3 percent of all killed car occupant casualties and 2 percent of all seriously injured car occupant casualties.
- The target population for casualties in car side impacts in which the car was struck by another car which had improved compatibility ranged from 4 to 7 percent of all killed car occupant casualties and 4 to 6 percent of all seriously injured car occupant

casualties depending on whether just struck side or struck side and non-struck side occupants were assumed to experience benefit.

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12 GLOSSARY

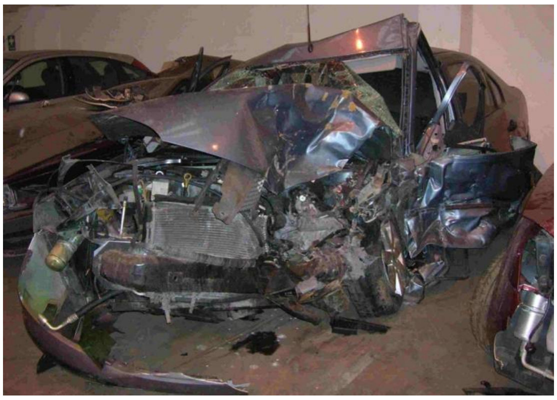
AIS:	Abbreviated Injury Severity Scale, describing the mortality rate of an injury ranging from 0 (not injured) to 6 (medical treatment today impossible), AIS 1 injuries and sometimes also AIS 2 injuries are reported to be superficial; Injuries above a certain level are often described as AIS X+ (e.g., AIS 2+ meaning injuries with severity levels 2, 3, 4, 5 and 6). In the databases AIS 9 is often coded for unknown severity level
Deceleration injuries	injuries related to the restraint system caused by loading of the occupant by the seatbelt or airbag to decelerate him and prevent greater injuries by contact with other car interior structures. Deceleration injuries are sometimes referred to as 'restraint' or 'restraint related' injuries.
delta-v	velocity change following a collision
DRV:	driver
DV	delta-v
EES:	Energy Equivalent Speed describing the deformation energy by a velocity that would create this deformation with $E_{def} = ½\, m\, EES^2$
ETS:	Estimated Test Speed; test speed of the vehicle against a rigid fixed barrier that would cause the same deformation. Note: similar to EES.
FSP:	Front Seat Passenger
FPS:	Front Passenger Seat
FW:	Full-width test including FWDB and FWRB
HGV:	Heavy Goods Vehicle / large truck (within GIDAS study also including coaches and buses
KSI:	Killed or seriously injured people
MAIS:	Maximum AIS coded injury, i.e. the most severe injury
Mass ratio:	relationship between the mass of two vehicles with mass ratio larger than one meaning the opponent vehicle is heavier than the case vehicle
MPDB:	Movable Deformable Barrier test using the PDB barrier face
ODB:	Off-set Deformable test (used for current ECE R94)
PDB:	Progressive Deformable Barrier test
PSV:	Public Service Vehicle (buses and coaches)

ANNEX A: EXAMPLE CASES

Examples of detailed case analyses to identify casualties in target population and estimate benefit of implementing Options 2 and 3 are given in the following.

Case Example 1 (CCIS data set: Structural interaction issue, over/underride): Ford Mondeo (2002) vs. Ford Mondeo (2001)

Accident description



Vehicle 1 (Mondeo 2002)   Vehicle 2 (Mondeo 2001)

Figure A.1: Frontal deformation of vehicles showing that the vehicles over/underrode each other.

The accident consisted of a head-on collision between a 2002 Ford Mondeo (vehicle 1) and a Ford 2001 Ford Mondeo (Vehicle 2). The overlap was estimated to be 50%. Other accident parameters are shown in Table A1.

Table A1: Mondeo vs. Mondeo accident parameters.

Parameter	Vehicle 1 (Mondeo 2002)	Vehicle 2 (Mondeo 2001)
ETS (km/h)	26	46
DV (km/h)	37	38
Intrusion	o/s (driver) None	o/s (driver) steering wheel 19cm lateral, 8 cm longitudinal Facia at knee contact area 18 cm A-pillar / top of facia 0 cm Footwell 5 cm

The 32 year old male driver in Vehicle 1 was seriously injured (MAIS 2, shoulder – principal injuries caused by seatbelt loading) and the 53 year old male driver in Vehicle 2 was fatally injured (MAIS 5, chest- principal injuries caused by contact with front intruding structure). Examination of the frontal deformation of the vehicles shows that they over/underrode each other in the collision – vehicle 1 overrode vehicle 2. This is seen from the vertical deformation profiles; there is more deformation lower down on vehicle 1 and less deformation higher up and vice-versa for vehicle 2.

Occupant injuries and benefit analysis

Vehicle 1 Driver MAIS 2

1. Displaced break to right clavicle (AIS2) *caused by seatbelt (belt webbing)*

Target population

It was considered that it was reasonable to assume that with better structural interaction and an improved restraint system the casualty injuries would have been less severe and hence this casualty was included in the target population for Options 2 and 3.

Benefit assessment

From application of injury reduction models for FW and PDB tests described in GB methodology section above.

FW test – structural alignment – no injury reduction Structural alignment will not be improved because vehicles in accident already have their structures in alignment with the common interaction zone, hence no benefit from this aspsect of the FW test.

FW test – improved restraint system – decrease injury to MAIS 1 (pessimistic and optimistic). Improved restraint system should reduce seatbelt loading.

PDB test all – structural interaction - no injury reduction because no intrusion related injuries (pessimistic), decrease injury to MAIS 1 due to improved deceleration pulse (optimistic).

PDB test fork effect only – no fork effect issue identified – no injury reduction.

Benefit

- Option 2 (FW) – MAIS 2 to 1 (pessimistic and optimistic).
- Option 3a (FW & PDB all) – MAIS 2 to 1 (pessimistic and optimistic).
- Option 3b (FW & PDB fork effect only) – MAIS 2 to 1 (pessimistic and optimistic).

Vehicle 2 Driver MAIS 5

1. Multiple rib breaks: left 1, 2, 5, 6 laterally, 5 - 10 posteriorly & right 4 - 8 posteriorly (with left haemothorax & bilateral pneumothoraces) (AIS5) *Caused by steering wheel (intruded)*
2. Massive retroperitoneal haematoma (AIS3). *Caused by seatbelt*
3. Rupture to spleen (AIS3). *Caused by seatbelt*
4. Rupture to left diaphragm producing communication between abdominal & thoracic cavities (AIS3). *Caused by seatbelt (belt webbing).*
5. Break to left clavicle (AIS2). *Caused by steering wheel (rim) (intruded)*
6. Extensive break to left posterior pelvis in region of sacroiliac joint with extensive (surrounding pelvic) haemorrhage (AIS3). *Caused by facia (intrusion)*
7. Break to left anterior pubic ramus, left superior & inferior pubic ramus and right superior pubic ramus (AIS2). *Caused by facia (intrusion).*
8. Haemopneumothorax (AIS5). *Caused by steering wheel rim. (intruded).*

Target population

It was considered that it was reasonable to assume that with better structural interaction, intrusion would have been less and the casualty injuries would have survived with less injuries and hence this casualty was included in the target population for Options 2 and 3.

Benefit assessment

From application of injury reduction models for FW and PDB tests described in GB methodology section above.

FW test – structural alignment – no injury reduction Structural alignment will not be improved because vehicles in accident already have their structures in alignment with the common interaction zone, hence no benefit from this aspect of the FW test.

FW test – improved restraint system – no injury reduction; improved restraint system will not reduce main injuries caused by intrusion.

PDB test all – structural interaction - MAIS 5 to 3 (pessimistic) and MAIS 5 to 2 (optimistic). Improved structural interaction should prevent intrusion and hence remove intrusion related injuries (pessimistic) and reduce deceleration induced injuries (optimistic).

PDB test fork effect only – no fork effect issue identified – no injury reduction

Benefit

- Option 2 (FW) – no injury reduction.
- Option 3a (FW & PDB all) – MAIS 5 to 3 (pessimistic), MAIS 5 to 2 (optimistic).
- Option 3b (FW & PDB fork effect only) – no injury reduction.

Case example 2: CCIS data set: Structural interaction issue (over/under-ride): Vauxhall Corsa (2002) vs. Mitsubishi Shogun (2003)

Accident description

Vehicle 1 (Corsa 2002) Vehicle 2 (Shogun 2003)

Figure A.2: Frontal deformation of vehicles showing that the vehicles over/underrode each other.

The accident consisted of a head-on collision between a 2002 Vauxhall Corsa (vehicle 1) and a 2003 Mitsubishi Shogun (vehicle 2). The overlap was estimated to be 55%, the mass ratio 1.91. Other accident parameters are shown in Table A2.

Table A2: Corsa vs Shogun accident parameters.

Parameter	Vehicle 1 (Corsa 2002)	Vehicle 2 (Shogun 2003)
ETS (km/h)	46	33
DV (km/h)	53	28
Intrusion	Facia at knee contact area 19 cm A-pillar/top of facia 27 cm Footwell 11 cm	Facia at knee contact area 3 cm A-pillar/top of facia 1 cm Footwell 12 cm

The driver of vehicle 1 (Vauxhall Corsa 2002) was fatally injured (MAIS5) with principal injuries caused by contact with the steering wheel. The driver of vehicle 2 (Mitsubishi Shogun) was seriously injured (MAIS2) with principal injuries caused by contact with the footwell. Examination of the frontal deformation of the vehicles shows that they over/underrode each other in the collision – vehicle 2 overrode vehicle 1. This is seen from the vertical deformation profiles, there is much more deformation (and compartment intrusion) higher up on vehicle 1 and vice versa for vehicle 2.

Occupant injuries and benefit analysis

Vehicle 1 (Vauxhall Corsa)

The driver of vehicle 1 (49 year old male) sustained the following injuries:

- Flail chest on right (AIS4) caused by contact with the intruded steering wheel.
- # to right forearm (AIS2) caused by contact with the intruded A-Pillar.

- # to neck of right femur (as a result of knee into facia femur loaded, classed as facia) (AIS3) caused by contact with the intruded facia panel.
- Blood in subdural space – haemorrhage (AIS4) caused by contact with the intruded facia panel.
- Extensive subarachnoid haemorrhage (AIS3) caused by contact with the intruded facia panel.
- Extensive #s of both rib cages, particularly ribs 5-12 on right anteriorly & posteriorly with right haemothorax & bilateral haemothoraces (AIS5) caused by contact with the intruded steering wheel.
- Transection of spinal cord through T5/6 level (AIS5) caused by contact with the intruded steering wheel.
- # to C4 cervical spine (spinal cord uninjured at this level) (AIS2).
- Multiple surface lacerations to liver (AIS2) caused by contact with the intruded steering wheel.
- 9cm laceration to spleen (AIS2).

Target population

It was considered reasonable to assume that improved structural interaction would have reduced intrusion and hence injuries associated with contact with intrusion. Therefore The driver of vehicle 1 was included in the target population for Options 2 and 3.

Benefit

From application of injury reduction models for FW and PDB tests described in GB methodology section above.

- FW test - structural alignment improved – would help prevent under/override and remove intrusion related injuries (pessimistic)and reduce deceleration related injuries because of improved pulse (optimistic) (pessimistic and optimistic MAIS 5 to 2)
- FW test – improved restraint system - no decel pulse issue identified – no injury reduction
- PDB test (all) – improved structural interaction (over/underride) – remove intrusion related injuries (pessimistic) and reduce deceleration related injuries because of improved pulse (optimistic) (pessimistic and optimistic MAIS 5 to 2)
- Option 2 (full width) – MAIS5 to MAIS2 (pessimistic and optimistic).
- Option 3a (full width and PDB full) – MAIS5 to MAIS2 (pessimistic and optimistic).
- Option 3b (full width and PDB fork effect only) – MAIS5 to MAIS2 (pessimistic and optimistic).

<u>Vehicle 2 (Mitsubishi Shogun)</u>

The driver of vehicle 2 (29 year old male) sustained the following injuries:

- Comminuted # to posterior talus, left foot (AIS2) caused by footwell (intruded)
- # through anterior body of calcaneum, left foot (AIS2) caused by footwell (intruded)

Target population

Reasonable to assume that improved structural interaction (alignment) would have reduced footwell intrusion and hence injuries associated with contact with intrusion, hence casualty included in target population for Options 2 and 3.

Benefit

- FW test - structural alignment improved – would help prevent under/override and remove intrusion related injuries (pessimistic)and reduce deceleration related injuries because of improved pulse (optimistic) (pessimistic and optimistic MAIS 2 to 1)
- FW test – improved restraint system - no deceleration pulse issue identified – no injury reduction
- PDB test (all) – improved structural interaction (over/underride) – remove intrusion related injuries (pessimistic) and reduce deceleration related injuries because of improved pulse (optimistic) (pessimistic and optimistic MAIS 2 to 1)
- PDB test (fork effect only) – no fork effect issue identified – no injury reduction
- Option 2 (full width) – MAIS2 to MAIS1 (pessimistic and optimistic).
- Option 3a (full width and PDB full) – MAIS2 to MAIS1 (pessimistic and optimistic).
- Option 3b (full width and PDB fork effect) – MAIS2 to MAIS1 (pessimistic and optimistic).

Case example 3: CCIS data set: Frontal force mismatch / compartment strength: Toyota Yaris (2008) vs Vauxhall Astra (2007)

Accident description

Vehicle 1 (Yaris 2008)

Vehicle 2 (Astra 2007)

Figure A.3: Deformations of vehicles showing much greater compartment deformation of Yaris compered to Astra showing frontal force matching / compartment strength compatibility problem.

The accident consisted of a head-on collision between a 2002 Vauxhall Corsa (vehicle 1) and a 2003 Mitsubishi Shogun (vehicle 2). The overlap was estimated to be 60%, the mass ratio 1.41. Other accident parameters are shown in Table A3.

Table A3: Yaris vs. Astra accident parameters.

Parameter	Vehicle 1 (Yaris 2008)	Vehicle 2 (Astra 2007)
ETS (km/h)	57	46
DV (km/h)	60	43
Intrusion	Steering wheel 0 cm vertical, 3 cm lateral, 14 cm longitudinal Facia at knee contact area 13 cm A-pillar/top of facia 16 cm Footwell 8 cm	No intrusion

The driver of vehicle 1 (Toyota Yaris) was seriously injured (MAIS3) with principal injuries caused by seatbelt and contact with facia/footwell. The driver of vehicle 2 (Vauxhall Astra) was seriously injured (MAIS2) with principal injuries caused by seatbelt and pedals Examination of the frontal deformation of the vehicles shows that although structural interaction was reasonable there was much greater compartment intrusion for the Yaris than the Astra. This indicates a frontal force matching / compartment strength problem.

Occupant injuries and benefit analysis

Vehicle 1 (Toyota Yaris)

The driver of vehicle 1 (29 year old female) sustained the following injuries:

- # posterior portion L 1st rib (AIS3) caused by seatbelt
- small apical L pneumothorax (AIS3) caused by seatbelt
- 3 part distal tibial # with a long spiral into shaft and medial malleolar fragment pilon # (AIS3) caused by footwell (intruded)
- comminuted # L proximal fibula (AIS2) caused by facia panel (intruded)

Target population

It was considered reasonable to assume that with improved frontal force matching intrusion would have been reduced and hence injuries associated with contact with intrusion. Also, with an improved performance of the restraint system the severity of the deceleration related injuries caused by the seatbelt would have been reduced. Therefore the driver of vehicle 1 was included in the target population for Options 2 and 3.

Benefit

From application of injury reduction models for FW and PDB tests described in main report above.

- FW test - structural alignment improved – no issue identified – no injury reduction.
- FW test – improved restraint system – reduce seatbelt related injuries to AIS 2 (pessimistic) 1 (optimistic) – however overall no MAIS injury reduction because of AIS2 injury caused by pedals.
- PDB test (all and fork effect only) – improved frontal force matching – reduce intrusion related injuries to AIS 1 and seatbelt related injuries to AIS 2 (optimistic only).
    - Option 2 (Full width) – no injury reduction (MAIS) because AIS 3 injury caused by intrusion
    - Option 3a (Full width & PDB all) – MAIS 3 to 2 (pessimistic) and MAIS 3 to 1 (optimistic)
    - Option 3b (Full width & PDB Fork effect only) – MAIS 3 to 2 (pessimistic) and MAIS 3 to 1 (optimistic)

Vehicle 2 (Vauxhall Astra)

The driver of vehicle 2 (55 year old male) sustained the following injuries:

- compression # L1 anterior superior endplate (AIS2) caused by seatbelt
- weber A # R fibula (AIS2) caused by pedals

Target population

Fibula AIS2 injury not caused by intrusion and unlikely to be reduced with an improved restraint system. However, thorax injury caused by seatbelt which improved restraint system should help reduce. Hence casualty included in target population for Options 2 and 3.

Benefit

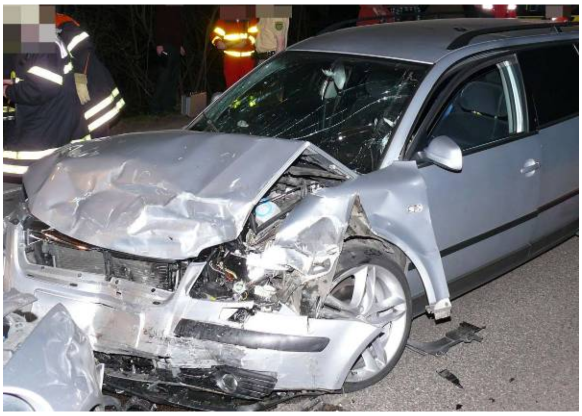
- FW test - structural alignment improved – no structural alignment issue identified so no injury reduction.

- FW test – improved restraint system – reduce thorax AIS 2 injury to AIS 1. However, no MAIS injury reduction because of fibula AIS 2 injury.
- PDB test (all) – improved structural interaction – no structural interaction issue identify so no injury reduction
- PDB test (all) – improved frontal force matching – no compartment intrusion so no improvement and hence no injury reduction
- PDB test (fork effect only) – improved frontal force matching – no compartment intrusion so no improvement and hence no injury reduction
- Option 2 (full width) – no injury reduction in terms of MAIS.
- Option 3a (full width and PDB full) – no injury reduction in terms of MAIS..
- Option 3b (full width and PDB fork effect) – no injury reduction in terms of MAIS.

Case Example 4 (GIDAS data set: Restraint performance issue):

<u>VW Passat (2003) vs VW Passat (2006)</u>

Accident description



Vehicle 1 (Passat 2003)

Vehicle 2 (Passat 2006)

Figure A.4: Frontal deformation of vehicles showing that the front structures hit aligned.

The accident consisted of a head-on collision between a 2003 VW Passat (vehicle 1) and a 2006 VW Passat (vehicle 2). The overlap was estimated to be >75%. Other accident parameters are shown in Table A4.

Table A4: Passat vs. Passat accident parameters.

Parameter	Vehicle 1 (Passat 2003)	Vehicle 2 (Passat 2006)
ETS (km/h)	42	43
DV (km/h)	48	47
Collision speed (km/h)	45	44
Intrusion	Passenger compartment stable	Passenger compartment stable

The 28 year old male driver in Vehicle 1 was seriously injured (MAIS 2, Sternum fracture – principal injuries caused by seatbelt loading), the 22 year old female front passenger was also seriously injured (MAIS 3, Contusion of superior lobe) and the 31 year old male driver in Vehicle 2 was slightly injured (MAIS 1, Bruise of soft tissue thorax and pelvis - principal injuries caused by seatbelt loading). Examination of the frontal deformations of both vehicles shows that cross and longitudinal beams hit each other in alignment. No important intrusions in the passenger compartments were investigated.

Occupant injuries and benefit analysis

<u>Vehicle 1 Driver MAIS 2, male, 28 years old</u>

1. Bruise of soft tissue Thorax (AIS 1) *caused by seatbelt (belt webbing)*
2. Distortion of cervical vertebrae NOS (AIS 1) *caused by body motion*
3. Fracture of sternum (AIS 2) *caused by seatbelt (belt webbing)*

Target population

It was considered that it was reasonable to assume that with an improved restraint system the casualty injuries would have been less severe and hence this casualty was included in the target population for Options 2 and 3.

Benefit assessment

From application of injury reduction models for FW and PDB tests described in methodology section above.

FW test – improved restraint system – decrease injury to MAIS 1 (optimistic). Improved restraint system should reduce seatbelt loading.

FW test – structural alignment – no injury reduction. Structural alignment will not be further improved because vehicles in accident already had their structures in alignment with the common interaction zone, hence no benefit from this aspect of the FW test.

PDB test – structural interaction - no injury reduction because no intrusion related injuries, decrease injury to MAIS 1 due to improved deceleration pulse (optimistic).

Benefit

- Option 2 (FW) – MAIS 2 to 1 (optimistic), no MAIS change (pessimistic)
- Option 3 (FW & PDB) – MAIS 2 to 1 (optimistic and pessimistic)

<u>Vehicle 1 Front Passenger MAIS 3, female, 22 years old</u>

1. Fracture of 20th vertebra (L1) (AIS 2) *caused by (not assigned)*
2. Fracture of 22nd vertebra (L3) (AIS 2) *caused by (not assigned)*
3. Fracture of sternum (AIS 2) *caused by (not assigned)*
4. Contusion of heart (AIS 1) *caused by seat belt (belt webbing)*
5. Contusion of superior lobe (AIS 3) *caused by seat belt (belt webbing)*
6. Rupture of intestinum jejunum (AIS 3) *caused by seat belt (belt webbing)*

Target population

It was considered that it was reasonable to assume that with an improved restraint system the casualty injuries would have been less severe and hence this casualty was also included in the target population for Options 2 and 3.

Benefit assessment

From application of injury reduction models for FW and PDB tests described in methodology section.

FW test – improved restraint system – decrease injury to MAIS 2 (optimistic). Improved restraint system should reduce seatbelt loading by the assumption of also avoiding submarining effects.

FW test – structural alignment – no injury reduction. Structural alignment will not be further improved because vehicles in accident already had their structures in alignment with the common interaction zone, hence no benefit from this aspect of the FW test.

PDB test – structural interaction - no injury reduction because no intrusion related injuries, decrease injury to MAIS 2 due to improved deceleration pulse (optimistic).

Benefit

- Option 2 (FW) – MAIS 3 to 2 (optimistic and pessimistic)
- Option 3 (FW & PDB) – MAIS 3 to 2 (optimistic and pessimistic)

Vehicle 2 Driver MAIS 1, male, 31 years old

1. Bruise of thoracic soft tissue (AIS 1) *caused by seat belt (belt webbing)*
2. Bruise of pelvic soft tissue (AIS 1) *caused by seat belt (belt webbing)*
3. Distortion of cervical vertebrae NOS (AIS 1) *caused by body motion*
4. Abrasion of hands (each AIS 1) *caused by (not assigned)*

Target population

This casualty was not included in the target population because it was not believed that additional compatibility measures (improved restraint system, structural interaction, etc.) would have decreased the level of MAIS 1 (slightly injured) to MAIS 0 (uninjured).

Case Example 5 (GIDAS data set: Small Overlap as compatibility issue):

<u>Ford Focus Turnier (2004)</u>

Accident description

Figure A.5: Frontal deformations (left) of the vehicle hitting a tree (right).

The accident consisted of a small overlap collision between a Ford Focus (2004) and a tree located on the pathway. The driver left the road (light left bend) due to the speeding to the right side. The driver drove under the influence of alcohol. The overlap was estimated to be <25%. Other accident parameters are shown in Table A5.

Table A5: Ford Focus accident parameters.

Parameter	Vehicle 1 (Focus 2004)
ETS (km/h)	63
DV (km/h)	49
Collision speed (km/h)	76
Intrusion	Deformation of the right front including e.g. a-pillar, sill, door, partly dashboard, windscreen and roof

The 37 year old male driver in Vehicle 1 was seriously injured (MAIS 2, Scull-brain-trauma – principal injuries caused by the contact with the windscreen). The examination of the frontal deformations of the vehicle shows that the longitudinal beams were not hit in a sufficient manner and hence, the car was ripped on the right side, the compartment collapsed and started to rotate. Intrusions were investigated on the front passenger side within the compartment (seat was not used) and partly on the driver's side.

Occupant injuries and benefit analysis

<u>Vehicle 1 Driver MAIS 2, male, 37 years old</u>

1. Laceration (contusion wound) of scalp (AIS 1) *caused by contact with windscreen*
2. Laceration of forehead (AIS 1) *caused by contact with windscreen*
3. Scull-brain-trauma (AIS 2) *caused by (not assigned)*

Target population

It was considered that it was reasonable to assume that with an improved structural interaction (compartment integrity) the casualty injuries would have been less severe and hence this casualty was included in the target population for Options 2 and 3.

Benefit assessment

From application of injury reduction models for FW and PDB tests described in methodology section above.

FW test – improved restraint system – no injury reduction. Restraint system already worked well, though the forward displacement of the occupant might be restrained better.

FW test – structural alignment – no injury reduction (pessimistic and optimistic) because structural alignment will not be further improved. The vehicle in this accident had its structures in alignment with the common interaction zone, which would not have further benefit in this case.

PDB test – structural interaction - decrease injury to MAIS 1 (optimistic and pessimistic) because the (M)PDB test could lead to an improvement of the compartment integrity of this car and hence forward the loadings more effectively.

Benefit

- Option 2 (FW) – no MAIS change (optimistic and pessimistic)
- Option 3 (FW & PDB) – MAIS 2 to 1 (optimistic and pessimistic)

ANNEX B: FULL-WIDTH TEST PERFORMANCE LIMITS

To start to investigate the issue of what dummy performance limits will be needed in the Full Width test to enforce the fitment of appropriate restraint systems (those capable of delivering the injury reduction assumed by the injury reduction model used in this benefit analysis) dummy injury values for full width deformable barrier (FWDB) tests in the FIMCAR test database were compared to current regulatory performance limits.

A summary of the UN-ECE Regulation 94 and US FMVSS 208 performance limits are shown in the following table for reference.

Table B1: Summary of UN ECE R94 and US FMVSS208 performance limits.

Criteria	**R94 Limit**	**FMVSS208 Limit**	
	50^{th} %tile	**50^{th} %tile**	**5^{th} %tile**
HIC_{36}	1000	1000	
HIC_{15}		700*	700
Head Resultant Acceleration (3 ms excedence)	80g		
Neck Extension Moment	57 Nm		
Neck tension +Z	Excedence corridor 3.3 kN @ 0 ms 2.9 kN @ 35 ms 1.1 kN @ ≥ 60 ms	4.17 kN	2.620 kN
Neck shear X	Excedence corridor 3.1 kN @ 0 ms 1.5 kN @ 25-35 ms 1.1 kN @ ≥ 45 ms		
Neck compression –Z		4.00 kN	2.520 kN
N_{ij}		1.0	1.0
Chest Deflection	50 mm	63mm	52 mm
Viscous Criterion	1.00		
Chest acceleration (3 ms excedence)		60g	60g
Femur Compression	9.7 kN	10.0 kN	6.805 kN
Knee Displacement	15 mm		
Tibia Compression	8 kN		
Tibia Index	1.3		

*HIC_{15} used for advanced airbags generally fitted to vehicles 2004+

Dummy injury criteria values normalised to the UNECE Regulation 94 performance limits for the FWDB tests in the FIMCAR test database are shown in Figures B.1 to B.4. All test results shown had a test speed of 56 km/h. Noting that the UN-ECE Regulation 94 limits are in general more stringent than the US FMVSS 208 ones and that some of the cars in the FIMCAR test database are quite old, (e.g. Small Family Cars 1 and 2 are model years 2004) and the majority of them still meet the performance limits with relative ease; in order for a prospective full width test to enforce the fitment of improved restraint systems that will deliver the benefit estimated in this work, it is likely that more stringent performance limits than the current R94 will be needed or indeed perhaps additional tests with different dummy sizes and/or tests at lower speeds with even more stringent performance limits.

For reference it is interesting to note:

- Chest compression 50 mm (100% of R94 performance limit) equates to a 50% risk AIS 3+ injury
- Chest compression 22 mm (44% of R94 performance limit) equates to a 5% risk AIS 3+ injury

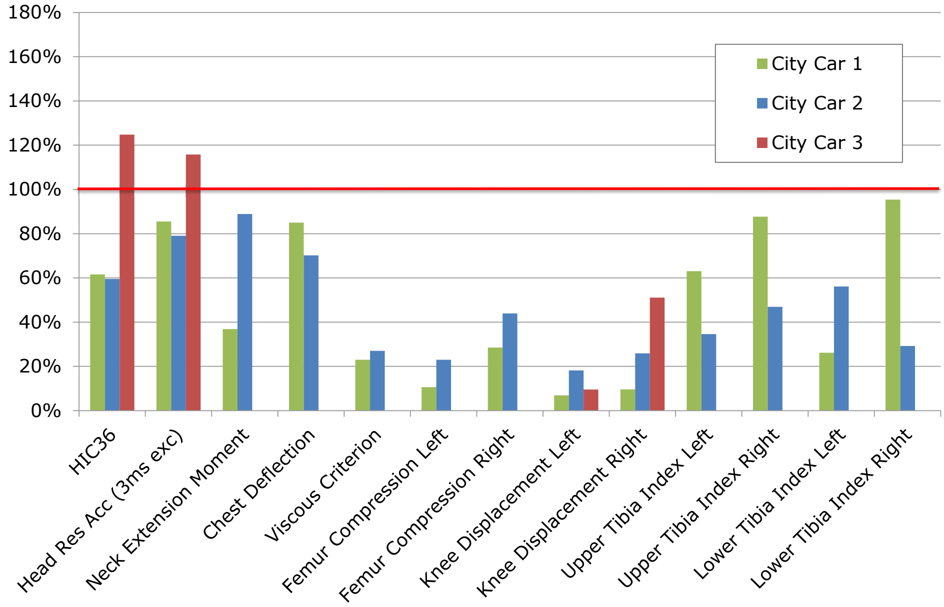


Figure B.1: Dummy injury criteria values for FWDB tests in FIMCAR test database (City Cars).

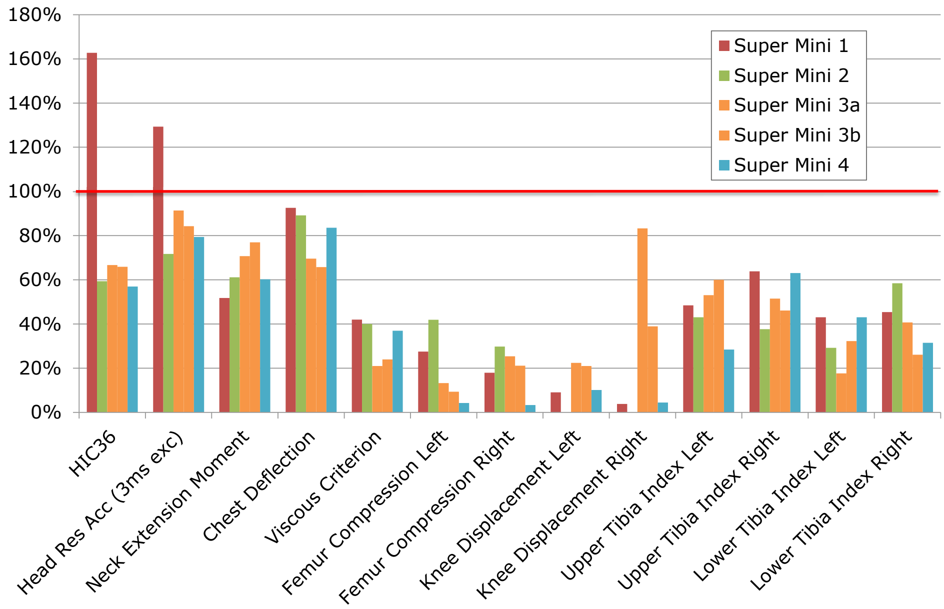


Figure B.2: Dummy injury criteria values for FWDB tests in FIMCAR test database (Super Minis).

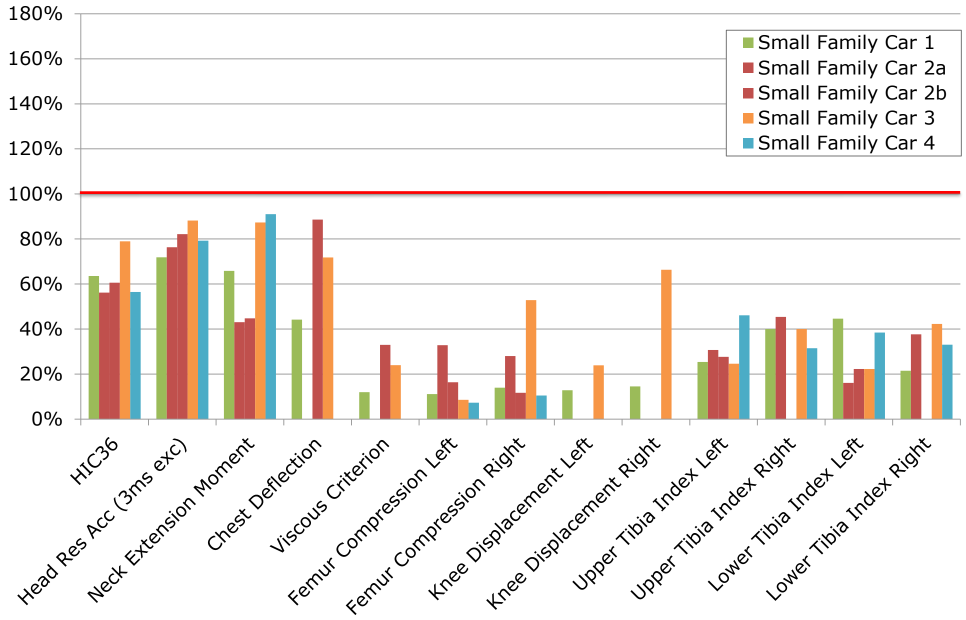


Figure B.3: Dummy injury criteria values for FWDB tests in FIMCAR test database (Small Family Cars).

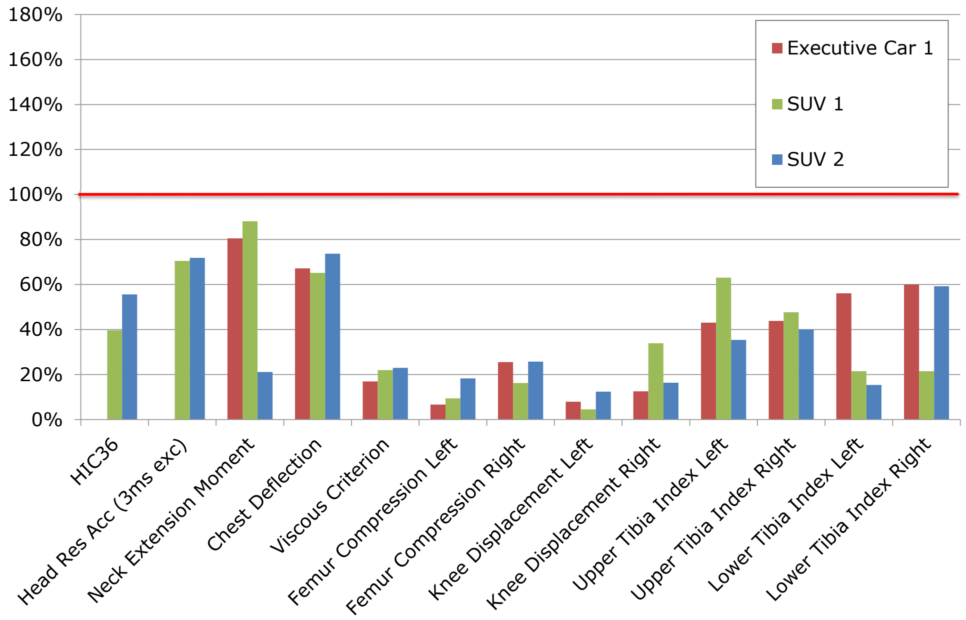


Figure B.4: Dummy injury criteria values for FWDB tests in FIMCAR test database (Executive Car and SUV).