# Estimation of the benefits for potential options to modify UNECE Regulation No. 94 to improve a car's compatibility

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**Abstract -** Although the number of road accident casualties in Europe (EU27) is falling the problem still remains substantial. In 2011 there were still over 30,000 road accident fatalities. 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. The objective of the FIMCAR FP7 EU-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 paper reports the cost benefit analyses 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 test to the current offset Deformable Barrier (ODB) test.
- Option 3 – Add a full width test and replace the current ODB test with a Progressive Deformable Barrier (PDB) test.

For the analyses national data were used from Great Britain (STATS 19) and from Germany (German Federal Statistical Office). In addition in-depth real word crash data were used from CCIS (Great Britain) and GIDAS (Germany). To estimate the benefit a generalised linear model, an injury reduction model and a matched pairs modelling approach were applied.
The benefits were estimated to be: for Option 1 'No change' about 2.0%; for Option 2 'FW test' ranging from 5 to 12% and for Option 3 ' FW and PDB tests' 9 to 14% of car occupant killed and seriously injured casualties.

## INTRODUCTION

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 [1]. 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 [2, 3]. 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 paper 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.
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- Option 3 – Add a full width test (FW) and replace the current ODB test with a Progressive Deformable Barrier (PDB) test.

## DATA SOURCES

The following databases were used for this analysis:

**Great Britain**
*STATS19*

STATS19 is a database of traffic collisions in Great Britain that result in injury to at least one person and are reported to the police. The database primarily records information on where the collision took place, when the collision occurred, the conditions at the time and location of the collision, details of the vehicles involved, and information about the casualties. When police attend a road traffic accident the officers on the scene fill out a series of standard forms. 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 within 30 days following 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.

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

*Co-operative Crash Injury Study (CCIS)*

The CCIS project 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 and questionnaires were sent to survivors. 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. It also favoured newer vehicles. More information about the study is available at www.ukccis.org.

CCIS data from phases 7 and 8, which encompasses accidents collected from 2001 to 2010, were used for this analysis.

**Germany**
*National Data*

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 (‘Länder’) 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.

*German In-Depth Accident Study (GIDAS)*

This study is devoted primarily to the task of documenting a representative sample of individual road traffic accidents involving injured people with a high level of detail. Since mid of the year 1999, the GIDAS project has investigated about 2,000 accidents per year in the regions of Hanover and Dresden and documented up to 3,000 variables per case. The project is jointly funded by the Federal Highway Research Institute (BASt) and the FAT (Automotive Research Association). GIDAS explores, corresponding to a particular statistical selection, traffic accidents with at least one person injured following the approach "on the scene" (directly at the accident site).

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

**Europe**
*CARE*
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.

## METHODOLOGY

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 [4] and APROSYS [5] for other potential regulatory changes related to car crash compatibility.

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. Both methodologies are described below.

### GB Methodology

The 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).

#### Part 1: Estimation of the benefit of Option 1 (No change)

STATS19 national data from 2008 to 2010 inclusive was used for this analysis. The benefit of this option arises from the 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 compliant.
- Since 1st October 2003: all cars are mandated to be Regulation 94 compliant.

Hence, all vehicles registered after 1st October 2003 are regulatory compliant and some vehicles registered between 1st October 1998 and 1st October 2003 are regulatory compliant.

The benefit was estimated 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 [6]. 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.

**Part 2: Estimation of the benefit and break-even cost for Option 2 and Option 3**

For this analysis, both the STATS19 national and the CCIS detailed accident databases were used because the detailed information necessary to perform the analysis was not available in the STATS19 database. It should be noted that the STATS19 ‘regulatory compliant / Euro NCAP influenced’ fleet data sample was used as the baseline for the estimation of the benefit of Options 2 and 3 to ensure that the benefits of updating the vehicle fleet (i.e. replacing non-regulatory compliant cars with compliant ones) were not double counted.

The following five-step methodology was used to estimate the benefit for each of the potential regulatory Options 2 and 3:

1. Derivation of CCIS data sample equivalent to STATS19 data sample
    - Criteria were used to select seriously injured (MAIS 2+) casualties involved in frontal impacts in ‘regulatory compliant’ cars seated on the front row of seats. Selection criteria used were:
        - Significant frontal impact defined by factors such as the deformation level.

        - Impact partner known
        - Seat-belt use known
        - Regulatory compliant
    - The injury distribution of the casualties in terms of MAIS and impact type was determined.

2. Identification of the target population in the CCIS data sample.
    - Additional criteria were used to select casualties in the target population, i.e. those likely to have a reduced risk of injury as a result of the implementation of the potential options for regulatory change as described below.
    - Full Width (FW) test
        - Compatibility performance issue
            - Structural alignment issue
                - Casualties in vehicle for which structural alignment problem identified, i.e. over/underride where there was initial misalignment of the structures
        - Restraint performance issue
            - Casualties which have deceleration restraint related injuries when there is no/little compartment intrusion
    - PDB test
        - Compatibility performance issue
            - Structural interaction issue
                - Casualties in vehicle for which structural interaction problem identified: i.e. Over/underride; fork effect; low overlap
            - Frontal force matching / compartment strength issue
                - Casualties in vehicle for which frontal force matching / compartment strength problem identified, e.g. a car-to-car impact with much more compartment intrusion in subject vehicle compared to partner.

3. Estimation of the benefit for casualties within the target population.
    - In-depth case analyses were undertaken for each casualty in the target population and their crash characteristics. For potential regulatory options 2 and 3, assessments were made of how much the casualty's injuries would have been reduced based on what safety countermeasures would need to be added to the car to enable it to comply. The following assumptions and injury reduction models were used:
    - Full Width Test
        - Assumption
            - Structural alignment (under/override)
                - Will improve and hence prevent/reduce compartment intrusion and improve deceleration pulse where an issue
            - Deceleration (restraint related)
                - Will encourage fitment of improved restraint systems and hence reduce restraint related thorax, abdomen, clavicle and leg/pelvic injuries when no/little compartment intrusion
        - Injury reduction model
            - Structural alignment (under/override)
                - Pessimistic: Reduce casualty injuries associated with contact with intrusion by up to 3 AIS levels but not less than AIS 1
                - Optimistic: In addition reduce injuries caused by deceleration and restraint system (thorax, abdomen, clavicle and leg/pelvic injuries) by 1 AIS level but not less than AIS 1
            - Deceleration (restraint related)

            - Pessimistic: Reduce restraint related injuries (thorax, abdomen, clavicle and leg/pelvic) by 1 AIS level but not less than AIS 1
            - Optimistic: Reduce restraint related injuries by 2 AIS levels but not less than AIS 1
    - PDB Test
        - Assumption
            - Structural interaction (under/override, fork effect, low overlap)
                - Will improve and hence prevent/reduce compartment intrusion and improve deceleration pulse where an issue.
            - Frontal force matching / compartment strength
                - Will improve and hence prevent/reduce compartment intrusion where an issue.
        - Injury reduction model
            - Structural interaction (under/override, fork effect, low overlap)
                - Pessimistic: Reduce casualty injuries associated with contact with intrusion by up to 3 AIS levels but not less than AIS 1
                - Optimistic: In addition reduce injuries caused by deceleration and restraint system (thorax, abdomen, clavicle and leg/pelvic injuries) by 1 AIS level but not less than AIS 1
            - Frontal force matching / compartment strength
                - Pessimistic: Reduce casualty injuries associated with contact with intrusion by up to 3 AIS levels but not less than AIS 1
                - Optimistic: In addition reduce injuries caused by deceleration and restraint system (thorax, abdomen, clavicle and leg/pelvic injuries) by 1 AIS level but not less than AIS 1

4. Scale proportions from detailed analysis to obtain overall national numbers
    - The CCIS injury reduction factors were scaled to estimate the benefit for GB.

5. Calculation of break-even costs
    - The monetary value of the benefit was calculated using casualty costs estimated by the UK DfT [7] which are fatal casualty £1.585.510 (€1,902,612 using exchange rate £1 = €1.2) and serious £178.160 (€213,792), slight £13.740 (€16,488). This value was divided by the number of new cars registered in GB per year to give a break-even cost per car which expressed another way is the cost per car for a cost / benefit ratio of one.

## German methodology

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).

### Part 1: Estimation of the benefit of Option 1 (No change)

German national accident data with personal injury from years 2005 to 2007 were used for this analysis, which were presented in Geneva in 2009 [8, 9]. 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 4). 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 being used is 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 has now been 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 has been defined as the car which received less injury to its driver. The model can be formulated like:

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

with: $P_{ij}$ : *Winning Probability car i against car j;*
$\alpha_i$ : *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 NCAP rating and the mass of the car. Secondarily, parameters as the wheelbase/total length, total width and height, the specific power and the manufacturer were considered. The crashworthiness (CW) was calculated and interpreted as a car's ability to protect its occupants in an accident.

Finally the injury risk for a car occupant has been estimated. The injury risk for the driver of one particular car has been 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 ego car

The general accident severity (1) will probably depend on accident related parameters like 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) has been 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 has to be absorbed by the cars' crashworthiness (3), as it has been estimated by the Bradley Terry Model. The injury risk of car A was then calculated using a standard logistic regression approach.

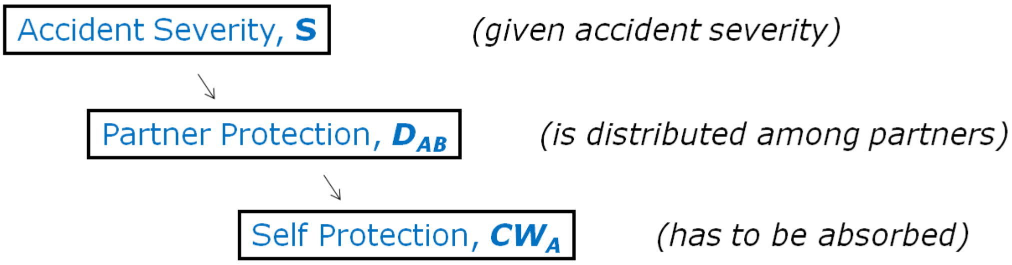


**Figure 1: Input for the estimation of injury risk of a car-to-car accident**

The final statistical model, using the inputs shown in Figure 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 is going to 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 restraints. It has been assumed that the newer cars will become more massive, simply because the older cars will leave the fleet and will be substituted by more modern cars, which have shown to be more massive (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.

**Part 2: Estimation of the benefit and break-even cost for Option 2 and Option 3**

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 (necessity of another data handling process) as for the CCIS dataset for the GB analysis. However, for the benefit analysis a different injury reduction model was used. 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, statements have finally been summarised for KSI (killed and seriously injured).

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 for Germany:

- 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.

The other difference to the GB methodology was that German calculated monetary values for saving a casualty of fatal € 1,010,907, serious € 112,296 and slight € 4,437 [10] were used instead of the GB ones. These values are considerably less than the GB ones. A probable cause of this is that the GB estimate contains a ‘willingness to pay’ element whereas the German estimate does not.

## RESULTS

### National Data

Figure 2 shows road accident casualties by user type for GB. It can be seen that approximately half of the fatally and seriously injured were car users and approximately half of these were involved in frontal impacts.

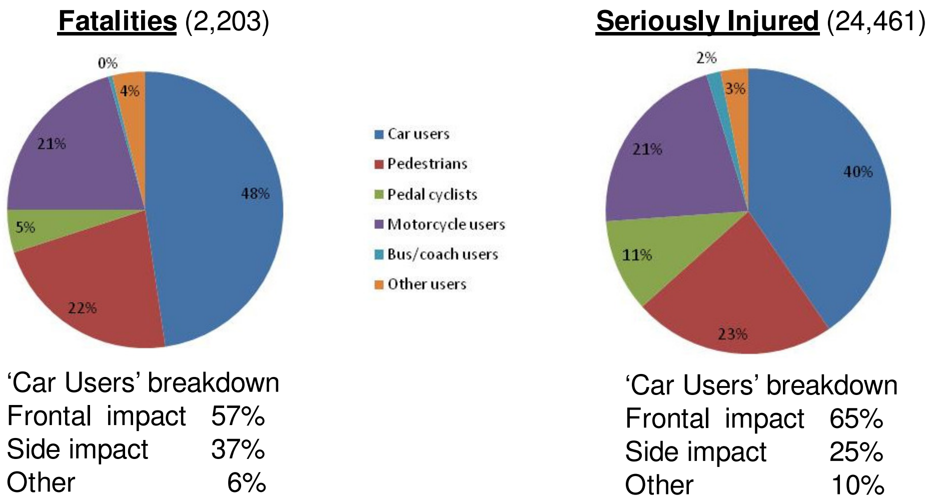


**Figure 2: Road accident casualties in GB by user type average 2008-2010.**

Figure 3 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 were car users, similar to GB. Figure 4 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.

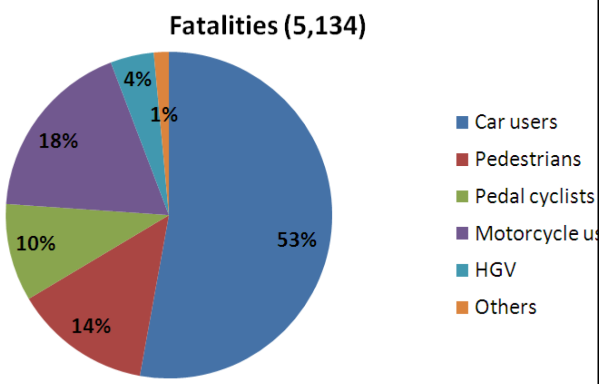


**Figure 3: Road accident fatalities in Germany by user type average 2005-2007**

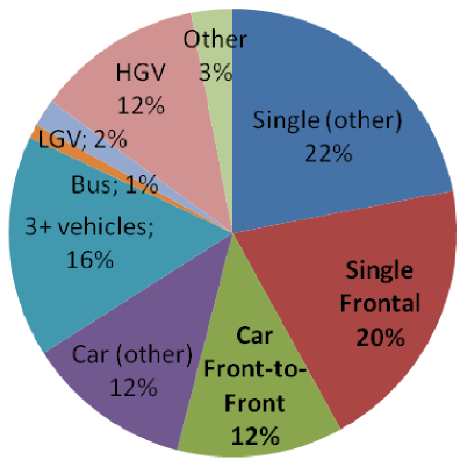


**Figure 4: Car occupant fatalities in year 2008 (German National Accident Data).**

### Part 1: Estimation of the benefit of Option 1 (No change)

### GB

British national casualty data (STATS19) from 2008 to 2010 were analysed to provide a baseline of current car occupant casualties. In this three year period, there were 40,677 injured car occupants in frontal impacts with 1,854 fatalities and 19,833 serious casualties. Table 1 shows the distribution of car occupant casualties by impact type. 'Car/LGV' refers to an impact with another car or Light

Goods Vehicle (LGV); 'HGV/PSV' refers to an impact with a heavy goods or large passenger vehicle, 'other' refers to impacts with other objects mainly single vehicle accidents and 'multiple' refers to accidents in which there were multiple impacts.

Frontal impacts were selected using the 'first point of contact' to the front of the car. 'Regulatory compliant' cars were identified using a criterion of those registered 1st Oct 2003 or later.

**Table 1. Distribution of car occupant frontal impact casualties in STATS19 (average 2008 to 2010)**

| Impact Type | All Car Occupant Injury Severity | | | Total |
|---|---|---|---|---|
| | Fatal | Serious | Slight | |
| Car/LGV-Car | 155 | 1,921 | 1,864 | 3,940 |
| | (3.93%) | (48.76%) | (47.31%) | (100%) |
| HGV/PSV-Car | 65 | 288 | 1,835 | 2,188 |
| | (2.97%) | (13.16%) | (83.87%) | (100%) |
| Object-Car | 207 | 1,855 | 11,497 | 13,559 |
| | (1.53%) | (13.68%) | (84.79%) | (100%) |
| Multiple-Car(3+ | 113 | 1,037 | 9,939 | 11,089 |
| vehicles) | (1.02%) | (9.35%) | (89.63%) | (100%) |
| Total | 600 | 6,417 | 60,836 | 67,853 |
| | (1.46%) | (9.46%) | (89.66%) | (100%) |

As described in the methodology section above, 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 frontal accidents, car-to-object frontal accidents, etc. whilst taking into account confounding factors such as occupant age and gender and vehicle type (Figure 5). It is interesting to note that while overall a benefit was predicted the number of fatal casualties in car front to car front impacts was predicted to increase with newer cars which may indicate that the increased self-protection of cars is being offset by their increased aggression. However, this was not the case for the German analysis (see below).

| **Benefit of Option 1, 'No change'** | **% (No.) of car occupant casualties** | |
|---|---|---|
| | **Killed** | **Seriously injured** |
| Casualties | 2.0% (21) | 1.7% (164) |

**Figure 5. Benefit for Option 1 'No change'.**

**Germany (D)**

The statistical model as described in the methodology part of this paper was applied to 21,764 two car front-to-front accidents. The statistical model outlined above, describing the injury severity risk for some driver is visually shown in Figure 6. 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 (sloppy 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. Seriously, 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 heavily depend on the crashworthiness of the ego car. This result goes in line with conclusions from some frontal impact research work recently done by TRL, for the European Commission [11]. In the paper (Tables 4-11, 4-12 and 4-13) 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 ego car.

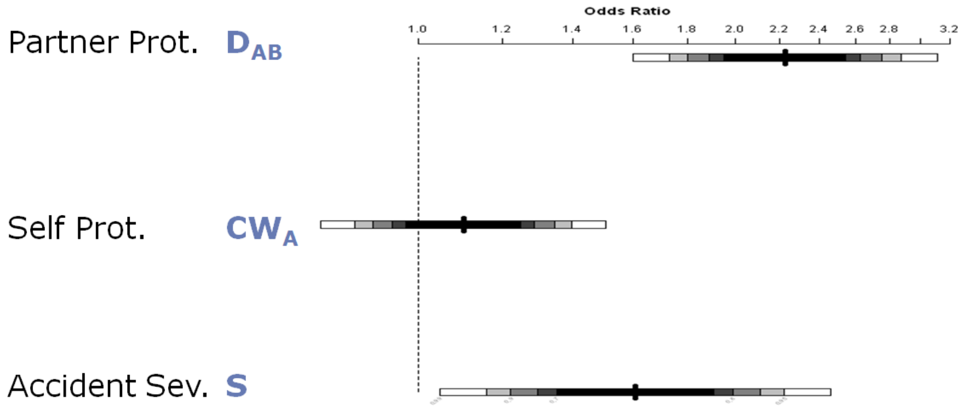


**Figure 6: Importance of factors driving injury risk for car A**

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 2 and Table 3 for option 1 'no change'.

**Table 2: 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 3: 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.

**Part 2 Estimation of the target population, benefit and break-even cost for Options 2 and 3**

The process shown in Figure 7 was used to derive a CCIS data sample equivalent to the STATS19 data sample and thereafter a sample for detailed case analysis to determine the target population and benefit.

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.

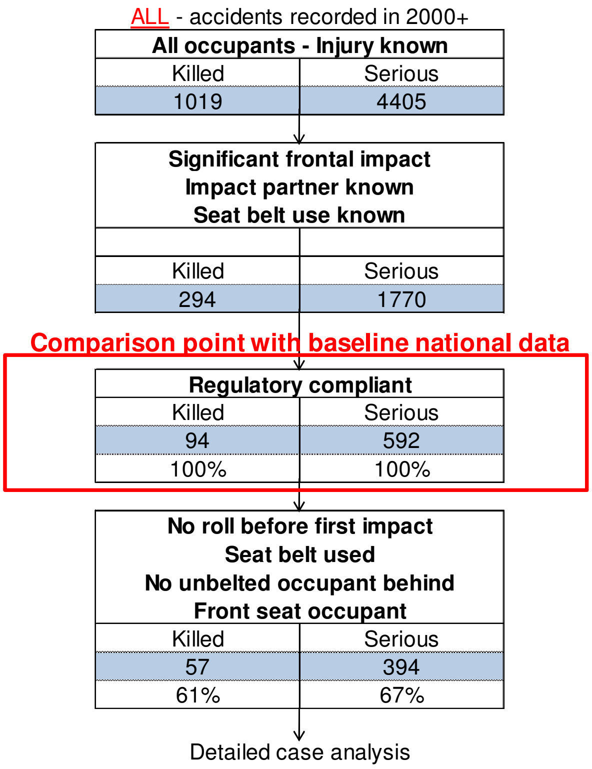


**Figure 7: Derivation of detailed accident data (CCIS) sample.**

A similar process was followed to derive a GIDAS data sample of 195 killed or seriously injured car occupant casualties for detailed case analysis.

The results of the CCIS and GIDAS detailed case analysis to determine the target populations are shown in Figure 8 and Figure 9, respectively. 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. For the CCIS analysis it should be noted that there was not sufficient information available for all cases to perform the analysis, so these cases were removed from the data set and the proportions used for scaling calculated from the remaining dataset.

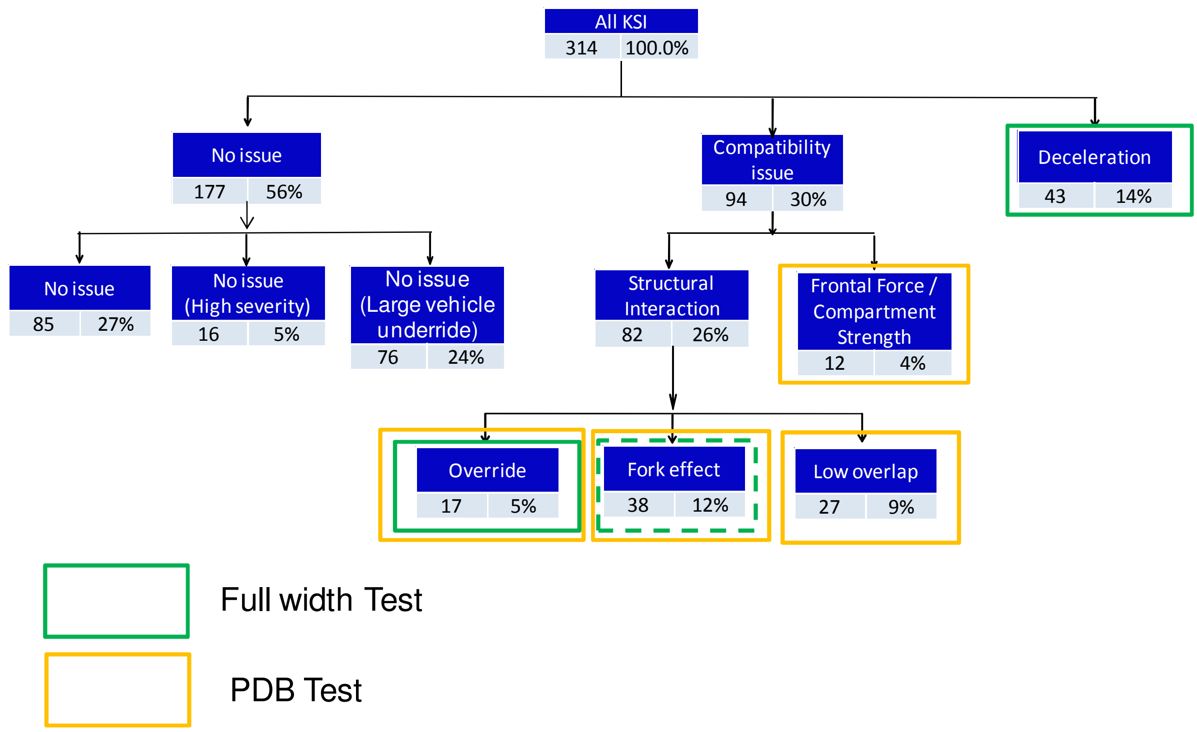


**Figure 8: GB (CCIS) detailed data sample target population breakdown KSI (MAIS2+)**

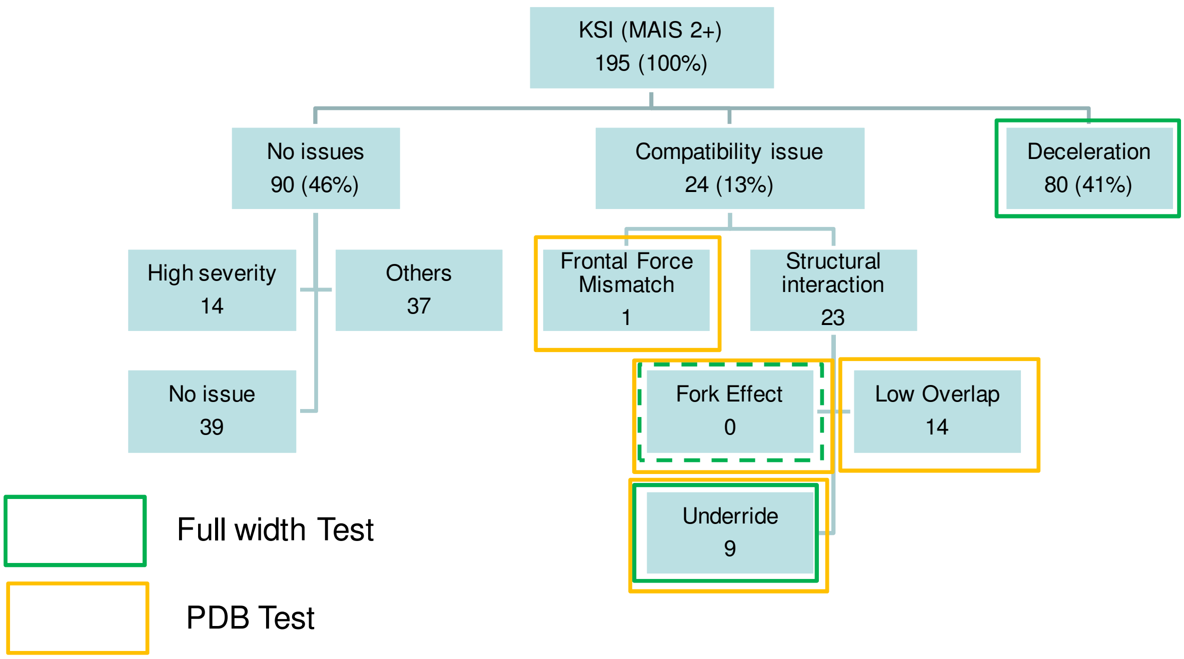


**Figure 9: German (GIDAS) detailed data sample target population breakdown KSI (MAIS 2+)**

Comparison of these Figures shows that a larger target population of casualties having injuries related to restraint performance issues in the German data and a smaller proportion having injuries related to the fork effect compared to the GB data. It is believed that this difference is in the accident data because a great deal of care was taken to perform the GB and D analyses in a similar way although a somewhat subjective approach had to be used.

*Calculation of target population and benefit*

GB

Using the methodology described above the target populations and benefits for options 2 and 3 were calculated, Table 4 and Table 5. An example of how the injury reduction model was applied is given in the Appendix. Target populations and benefits shown do not include the benefit of Option 1 'No change'.

**Table 4. Target populations and benefits for Options 2 and 3 (GB)**

| 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 tests' | **Upper** | **Lower** | **Upper** | **Lower** |
| | | 10% (105) | 9% (93) | 13% (1231) | 9% (885) |

Because it appeared to be the most likely option to be chosen, an additional analysis was performed for Option 2 to determine which proportion of the benefit was associated with improved structural alignment and which with improved restraint systems (deceleration). It is interesting to note that the majority of the benefit was predicted to be associated with improved restraint systems, although it should be remembered that the benefit predicted for improved structural alignment may be under-estimated because mis-aligned vehicles were difficult to identify in the accident data. In addition to this, aligned vehicles will have better structural interaction which allows a better restraint system triggering and therefore should help reduce injuries further.

**Table 5. Breakdown of benefit for Option 2 (GB)**

| 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) |

Germany

The target populations and benefits for Germany are shown below in a similar manner as for GB, see Table 6 and Table 7. Target populations and benefits shown do not include the benefit of Option 1 'No change'. 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.

**Table 6: 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 16% and for Option 3 to 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.

**Table 7: 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) |

Compared to the GB analysis, the German analysis 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.

Europe

Using the benefit proportions estimated for GB and Germany above, European casualty data from CARE and simple scaling, upper and lower estimates of the benefit for Europe were made (Table 8).

**Table 8. Benefits for Options 2 and 3 (Europe).**

| **Option** | **No of car occupant casualties in EU27 (excluding Bulgaria and Lithuania)** | | **% (No) of car occupant casualties** | | | |
|---|---|---|---|---|---|---|
| | **Killed** | **Seriously injured** | **Killed** | | **Seriously injured** | |
| | | | **Upper** | **Lower** | **Upper** | **Lower** |
| Option 2 'Full width test' | **18,029** | **114,581** | 6% | 5% | 12% | 6% |
| | | | 1,034 | 901 | 13,750 | 6,875 |
| Option 3 'Full width & PDB tests' | **18029** | **114581** | 10% | 9% | 14% | 7% |
| | | | 1,810 | 1,623 | 16,041 | 8,021 |

*Costs*

GB

Following the methodology described and assuming that the number of new cars registered in the UK per year for 2008 to 2010 was 2,333,792 [12] and an exchange rate of £1=€1.2, break even costs for Options 2 and 3 were calculated (Table 9).

**Table 9. Break-even costs for GB for Options 2 and 3.**

| Option | Break-even costs (€) | |
|---|---|---|
| | Upper | Lower |
| Option 2 'Full-width test' | 128 | 101 |
| Option 3 'Full-width & PDB test' | 189 | 150 |

Germany

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 [13], break-even costs for Options 2 and 3 were calculated, see Table 10.

**Table 10: 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 |

Europe

The ranges for the break-even costs for Options 2 and 3 for Europe were calculated by scaling European car occupant casualty numbers, using the highest and lowest percentage estimates for benefits from the GB and German analyses and highest and lowest monetary values for saving a casualty.

**Table 11: Break-even costs for Europe for Options 2 and 3.**

| Option | Break-even costs (€) | |
|---|---|---|
| | Upper | Lower |
| Option 2 'Full-width test' | 294 | 104 |
| Option 3 'Full-width & PDB test' | 415 | 158 |

## DISCUSSION

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 [4]
  - 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[3]
  - 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 [14]
  - Between € 297 and € 386 depending on original safety performance level of car
- NHTSA 2007: Final impact assessment to add oblique pole test [15]
  - Assume add two or four sensor curtain airbag system
  - Between $ 243 (€ 182) and $ 280 (€ 210) ($ 1 = € 0.75€)

Comparing these costs 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 are needed to deliver the injury reduction assumed for the 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.

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).

As an outcome of the 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.

## 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’ 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.

In addition 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 have not been 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.

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Further information on CCIS can be found at http://www.ukccis.org

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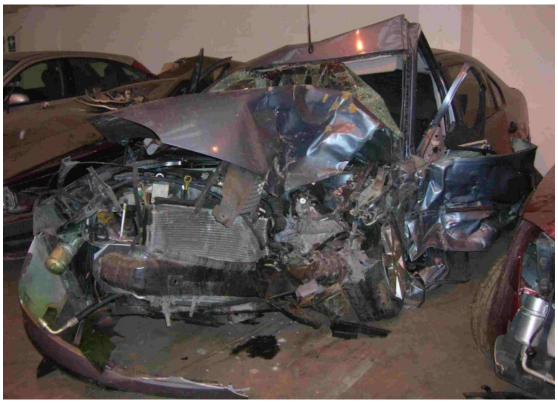
## APPENDIX A. Case examples

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

**Accident description**

Vehicle 1 (Mondeo 2002)



Vehicle 2 (Mondeo 2001)

**Figure 10: 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 12.

**Table 12: Mondeo vs Mondeo accident parameters.**

| Parameter | Vehicle 1 (Mondeo 2002) | Vehicle 2 (Mondeo 2001) |
|---|---|---|
| ETS (kph) | 26 | 46 |
| DV (kph) | 37 | 38 |
| Intrusion | o/s (driver) None | o/s (driver) steering wheel 19cm lateral, 8 cm longitudinal<br>Facia at knee contact area 18 cm<br>A-pillar / top of facia 0 cm<br>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 eachother 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**

<u>Vehicle 1 Driver MAIS 2</u>

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

*Benefit*

- Option 2 (FW) – MAIS 2 to 1 (pessimistic and optimistic)
- Option 3a (FW & PDB Full) – 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 aspsect 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 – 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).

*Benefit*

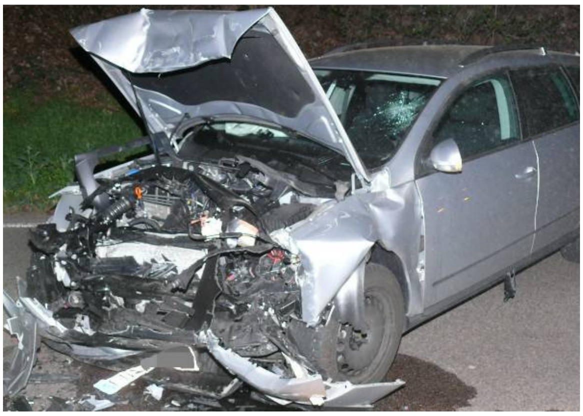
- Option 2 (FW) – no injury reduction.
- Option 3a (FW & PDB Full) – MAIS 5 to 3 (pessimistic), MAIS 5 to 2 (optimistic).

**Case Example 2 (GIDAS data set: Restraint performance issue):**

**VW Passat (2003) vs VW Passat (2006)**

**Accident description**

Vehicle 1 (Passat 2003)



Vehicle 2 (Passat 2006)

**Figure 11: 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 13.

**Table 13: Passat vs Passat accident parameters.**

| Parameter | Vehicle 1 (Passat 2003) | Vehicle 2 (Passat 2006) |
|---|---|---|
| ETS (km/h) | 42 | 43 |
| DeltaV (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**

Vehicle 1 Driver MAIS 2, male, 28 years old

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.

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)

<u>Vehicle 2 Driver MAIS 1, male, 31 years old</u>

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).