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THORAX
Thoracic injury assessment for improved vehicle safety

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Executive summary

The THORAX and THOMO projects were set-up to study thoracic injuries for a wide variety of car occupants and transfer research results into test and design tools. This task (Task 1.2) of the THORAX Project builds on the previous thorax-related accident analysis work carried out in the COVER project and on the case-by-case accident review from Task 1.1 of the THORAX Project. Taking into account this previous research regarding different occupant characteristics, accident configurations, and restraint systems, the objective for this task was to estimate the potential benefit arising from the THORAX Project. This objective was met through consideration of the thorax-related safety interventions that may be put in place as a result of the THORAX Project and the injury reductions that those measures may bring about.

Accident data from the UK (CCIS) provided information on 320 occupants who were Killed or Seriously Injured and who sustained a torso injury of at least AIS 2 (or an AIS 1 rib fracture). This information was used to estimate the potential benefit expected if outputs from the THORAX Project were used in future frontal impact testing. Occupants and their injuries were categorised by the impact conditions of their accident, their seating position, and their size, age, and sex. These categories were then used to define target groups which could be influenced by potential safety interventions. The distributions of occupants and their injuries amongst the restraint system and crash categories were compared with data from France (GIE RE PR) to establish where sample specific features were evident.

Costs were assigned to specific occupant and torso injuries using two methods, either a willingness to pay, or societal costs as reported by Miller *et al.* (2001). The benefits estimated were then associated with mitigation of torso injuries and therefore a reduction in the overall seriousness of the accident for each particular occupant influenced by the intervention.

Taking into account the THORAX Project activities and the likely use of the resulting dummy, four basic safety intervention options were considered. These were:

1. A more sensitive dummy thorax that is capable of supporting a drive towards advanced restraint systems offering improved protection for the torso
2. A new injury risk function to represent ages of the occupant population having a lower tolerance to torso loading
3. An additional size of dummy available for representing a different size of occupant as well as the mid-sized male (either smaller or larger than the mid-size)
4. Extending the scope of frontal impact testing to include another configuration:
    a. Introduction of a full-width test
    b. Introduction of a small-overlap test
    c. Introduction of another test procedure to safe-guard against injuries caused in low-speed impacts (of a speed lower than that represented by the current procedures)

It was found that a more sensitive dummy thorax that is capable of supporting a drive towards advanced restraint systems could offer protection for the torso providing a potential benefit of up to £ 33 million (€ 41 million) based on a willingness to pay. Alternatively, using the societal costs of injuries from Miller *et al.* (2001) the potential benefit was as large as £ 76 million (€ 94 million).

A new injury risk function to represent ages of the occupant population having a lower tolerance to torso loading could also be beneficial if protection is improved for older occupants. Depending on the overlap with improvements brought about through the use of a new dummy torso, this could lead to an estimated benefit of as much as £ 30 million (€ 37 million) (willingness to pay).

The influence of using a dummy that represents occupants who are either smaller or larger than the mid-sized male was difficult to determine because of small sample sizes and a lack of reporting of stature and mass information. Indications are that the use of a larger than average size dummy could lead to the greatest benefit, of up to £ 154 million (€ 190 million) (willingness to pay).

Of the three options investigated with respect to adding a new test procedure, one which helps to provide safety for accidents that occur at speeds lower than the current offset frontal impact tests appears to offer the greatest maximum estimate of benefit. This benefit could be as much as £ 247 million (€ 305 million) on a willingness to pay basis. However, the data from France suggested that low speed impacts were less important in the causation of torso injuries (of at least moderate severity) than the CCIS data from Great Britain.

A full-width test was estimated to offer benefit in the range from £ 0 to £ 105 million (€ 130 million). This could be enhanced by setting the test speed to account for accidents which occur at a lower severity than the current offset procedures, with the use of the new dummy hardware, and a torso injury criterion which protects older occupants. This could extend the benefit to beyond £ 300 million (€ 370 million), each year for the EU-27 countries, based on the CCIS data from Great Britain.

Introducing a low-speed test to protect older occupants provided a large target group of torso injuries, whether offset impacts are included or full-width impacts. On the basis of the combined intervention options considered within this report, torso protection for older occupants in impacts of severities below those of the existing frontal impact test procedures seemed to be a priority in terms of potential benefit.

Due to the small sample sizes available, once the dataset was broken down into small groups of accidents and occupants with similar impact conditions, the options investigated were extremely sensitive to small changes in numbers of injuries or occupants considered. This has led to many of the minimum benefit estimates being £ 0. This indicates that based on this sample of accident data the interventions might not produce a significant safety improvement. Such a prediction seems unavoidable within the constraints imposed by this sample selection.

In addition, differences were observed between the data from the GIE RE PR database and those from the CCIS. This means that extrapolation of findings to the European level will be sensitive to assumptions made about how well the original sample represents the accident population in Europe. On this basis care must be taken when interpreting the findings from this report.

In carrying out this investigation, it became clear that the estimates of restraint system effectiveness, related to the different safety interventions are quite subjective. As a result it was strongly recommended that these effectiveness estimates are reviewed by other partners in the THORAX Project to provide an expert opinion and consensus. Advice from those involved in Work Package 4 (Assessment of potential for restraint optimisation) should be particularly valuable as these partners have extensive experience using modern restraint systems.

Contents

1 Introduction

Around 41,600 people were killed and more than 1.7 million injured in European road accidents in 2005 (European Commission, 2006b). Although the number of road fatalities has declined by more than 17 percent since 2001, greater efforts will have to be made if the European Commission's target to halve the number of deaths on the roads by 2010 is to be met.

Motivated by findings of previous projects (including EC Framework projects) the THORAX and THOMO projects were set-up to study thoracic injuries for a wide variety of car occupants and transfer results into test and design tools. In order to maximise the safety benefits gained from new vehicle and restraint technology for various genders, ages, and sizes of occupants, these tools will have to be much more sensitive to the in-vehicle occupant environment than is the case with existing test tools.

From a review of in-depth accident data from around Europe (the UK, Germany, and France), the COVER Project Task 1.2 provided an overview of the current situation with regard to thoracic injuries resulting from frontal impact car accidents (Carroll, 2009). Of the body regions injured in the accidents analysed, the thorax was the most frequently injured body region for all killed and seriously injured occupants in frontal impact accidents. With this knowledge it is reasonable to investigate why thorax injury hasn't been reduced as much as may have been expected. Such expectations are based on improvements in protection observed for occupants generally and for other specific body regions, such as the head. Assuming thoracic safety improvements are lagging behind improvements for other body regions, then research effort is needed to understand why recent advances in crash safety have not been as effective for the thorax as for other body regions and what more needs to be done to protect the thorax during impact events.

Following the COVER accident analysis, Task 1.1 of the THORAX Project investigated the differences between accidents and crash test results. Thirty-four individual frontal impact accident cases from the CCIS and GIDAS in-depth accident studies, as used in the COVER work, were selected for further in-depth analysis. These cases were chosen such that the impact conditions were close to those used in the Euro NCAP frontal impact test and where Euro NCAP has tested the vehicle being investigated. For each case, a comparison was made between the thoracic injury outcome for the occupants predicted from the Euro NCAP crash test of that vehicle and the real-world accident.

This task (Task 1.2) of the THORAX Project builds on the understanding of thoracic injuries for different occupants, accident configurations, and restraint systems developed in the COVER work. It also includes consideration of the likely impact improved test tools and injury risk functions may have, based on the case-by-case accident review from Task 1.1. Taking into account this research, the objective for this task is to estimate the potential benefit arising from thorax-related safety interventions that may bring about injury reductions. As already understood, and shown in the previous work, it will be important to consider the effect of different interventions for different occupant groups; for instance, sizes and ages. The data generated in this task will then be used to estimate the total benefit that may be expected from the thorax hardware and injury risk function development in the THORAX Project.

2 Method

In order to estimate the potential benefit brought about by future safety-related actions and interventions, it is necessary to consider the existing scenario and how that might be caused to change in the future. In the vehicle-safety field the current situation tends to be defined through consideration of real-world accident data. Predictions of future safety benefits can then be made with respect to the current situation. It is noteworthy to acknowledge that there will always be some lag between an accident occurring and its inclusion in an accident database. Also, as a result of accident data sampling, it is necessary to consider several years worth of accident data in defining the current scenario.

2.1 Data selection

Accident data from the UK (the Cooperative Crash Injury Study [CCIS]) and France (the GIE RE PR database) were used in this analysis. Descriptions of these two databases can be found in the EC COVER Project Deliverable D5 (Carroll, 2009).

As for the COVER Project analysis, this study considers the 320 occupants from the CCIS sample who met the COVER accident analysis selection criteria, were Killed or Seriously Injured (KSI) in the accident, and had a torso injury of at least AIS 2 (Abbreviated Injury Scale: AAAM, 2005; as revised) or an AIS 1 rib fracture. A similar sample of 158 occupants was available from the GIE RE PR database for analysis.

Understanding the number of occupants with no torso injury or only a minor AIS 1 torso injury (other than a rib fracture) is important when considering risks of receiving a more severe torso injury. It is important because the uninjured occupants or those with minor injuries provide some indication of the exposure to potentially injurious crash situations for those occupants groups. The analysis within the COVER Project considered all injury severities for occupants in the French, German, and UK databases for this reason. However, in this study the objective is to focus principally on establishing those occupants whose crash outcome could be improved as a result of implementing outputs from the THORAX Project. As such, it is no longer as important to consider risks of torso injury, rather the absolute number of occupants for whom one could expect the THORAX Project to offer some injury mitigation possibilities.

The criteria used in selecting vehicles from the accident cases were as follows:

- Cars (or car-derivatives)
- Registered in 2000 or later
- Had one significant frontal impact
    - Frontal accidents being defined according to the Collision Damage Classification (CDC)
- Not rolled over at any point
- Selected occupants were wearing a seat-belt
- Known to be 12 years old or over
- Occupants had a known overall MAIS

2.2 Potential project-related interventions

It is an objective of the THORAX Project to provide an experimental tool that will enable the design and evaluation of advanced vehicle restraint systems that offer optimal protection for a wide variety of car occupants. In order to maximize the safety benefits gained from a new vehicle and restraint technology for occupants with various characteristics, any new experimental tool will have to be much more sensitive to the in-vehicle occupant environment than is the case today.

As solutions to this objective, several different technical innovations are being discussed within the THORAX Project. Each of these solutions is proposed in order to address a part of this wider goal.

- To address the sensitivity of the thorax to advanced restraint systems either a new thorax structure or new thoracic instrumentation will be developed
- To make the dummy measurements relevant to a greater part of the occupant age diversity range, a new age-specific injury risk function will be developed
- To make the dummy appropriate for different sizes of occupants, thought will be given to which sizes of dummy represent the widest part of the occupant population.

These technological advances can only deliver a benefit for society if they are incorporated in safety assessment test procedures. As such, the potential for the technology to produce a benefit is related to the scope of the testing in which it is used. As a broad example, the THORAX Project was set up to focus primarily on frontal impact accidents. This means that any safety innovations will relate to the frontal impact direction and are expected to be used in frontal impact testing. However, thoracic injuries occur in other accident configurations as well. As such, the THORAX Project is not expected to address thorax injuries resulting from side, rear, or rollover crashes, etc.

Therefore, taking into account the THORAX Project activities and the likely use of the resulting dummy, it is anticipated that the potential safety interventions made possible by the THORAX Project will be:

1. A more sensitive dummy thorax that is capable of supporting a drive towards advanced restraint systems offering protection for the torso
    - As mentioned above, this will be enabled through the provision of either a dummy torso with a revised structure or improved dummy instrumentation capability or a combination of both.
    - This assumes that the dummy will be used in regulatory and consumer information test procedures that already exist.
        i. Additional benefit should be provided through the improved dummy being available for internal development work by the restraint system and vehicle manufacturers. However, it is difficult to quantify the effect of this in relation to the formal testing and assessments.
    - It is not certain exactly what changes to the restraint system will be brought about as a result of having a frontal impact dummy with a more sensitive torso. However, it is expected that this will allow greater restraint system optimisation for safety. Work Package 4 of the THORAX Project should provide some indication as to what restraint system designers could do with the improved test tool. This should also provide a reliability check as to the expected benefit arising as a result of this intervention predicted in the next sections of the report.
2. A new injury risk function to represent ages of the occupant population having a lower tolerance to torso loading

- This would be used in conjunction with the improved dummy thorax to broaden the scope of occupants for which the maximum tolerable torso insult is appropriate.

- Again, it is expected that the dummy would be used in existing test regimes.

3. Additional size of dummy available for representing a different size of occupant as well as the mid-sized male

   - By assessing restraint systems with more than one occupant size the risk of those systems becoming optimized for one occupant class is mitigated. Therefore the benefits already realised can be transferred to another occupant size.

   - It is assumed that a female dummy would be used in some test work as an aid in representing the fact that front seat passengers tend to be female.

4. Whilst the previous four options relate to advances made with the test tool, consideration will also be given to extending the scope of frontal impact testing to include another configuration

   - By introducing a full-width test, it would be possible for the testing authority to consider car-to-car compatibility issues. Additionally, the efficacy of the restraint systems in large overlap conditions could be assessed. Therefore, the implementation of new dummy hardware could give benefits in accidents that have a more distributed frontal loading.

   - Accidents in which only a small percentage of the vehicle front is engaged are responsible for some of the serious and fatal torso injuries (TRL Appendix to COVER Deliverable D5: Carroll, 2009). The existing offset frontal test conditions offer little scope for evaluating the vehicle front structure in small overlap crashes. Adding another small overlap test could address that limitation.

   - Concerns have been raised over the efficacy of restraint systems in accidents at lower speeds than those of the routine test procedures. This may occur if the restraint systems are optimised for a particular impact severity. As a result there may be merit in requiring a further test at a lower severity to confirm that the restraint system functions correctly at speeds lower than that of the regulatory test.

Of course, these possible actions need to be considered with respect to the 'do nothing' option. For the purposes of this study, the 'do nothing' option is defined in the following way:

- Baseline level of frontal impact safety is governed by UNECE Regulation 94 (UNECE, 1995) and the EC Directive 96/79/EC (EC, 1996). The date of entry into force for all new car registrations to meet the Directive was the 1 October 2003. Therefore one can assume that all European cars registered in 2004 or later comply with this directive.

- Euro NCAP consumer information testing (Euro NCAP, 2009) has also helped to promote safer vehicles. However, the additional benefit this testing can bring to the vehicle fleet is reliant on the test tool being used. As such, substantial changes in frontal impact safety and restraint system performance are not expected until a new dummy becomes available, or there is some other revision to the test protocol.

- Therefore it is considered that the performance of vehicles registered from 2004 onwards represents a stable baseline against which potential interventions can be considered.

    i. Euro NCAP testing is one of the ways in which frontal impact performance of cars can be determined readily. The frontal impact scores from Euro NCAP car assessments over the last 15 years are shown in Figure 2-1. From this figure it can be seen that up until about 2003 or 2004 the mean frontal impact, adult occupant, score was gradually increasing. Subsequently progress (in terms of an increasing score) has been less obvious. This seems to support the assertion that the frontal impact performance of cars has been relatively stable from around this transition, around the implementation of regulatory testing of all car models.

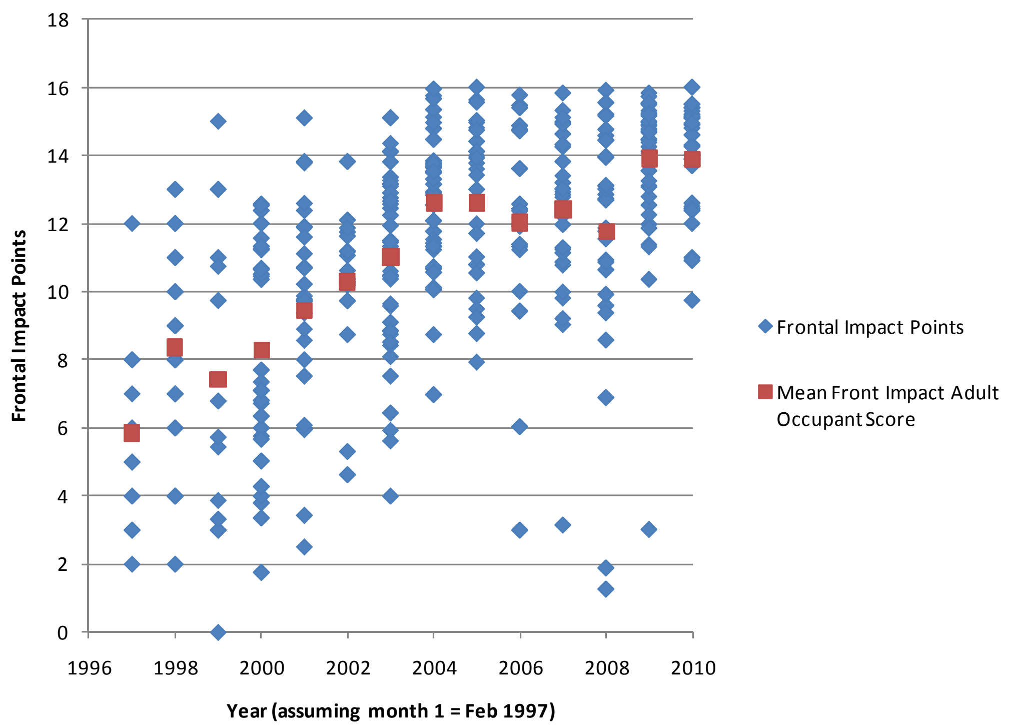

Figure 2-1 Frontal impact points obtained in Euro NCAP assessments over the last 15 years

ii. It is not possible to quantify how stable the baseline is for crash modes which are not already represented by an impact test. For full-width impacts Japan and the US already have test procedures in place which give some assurance to the level of protection available in this crash mode. Procedures for assessing the performance of cars in small overlap accidents are not included in regulatory or consumer information testing. However, some vehicle manufacturers may have internal targets for small overlap evaluations.

2.3 Benefit estimates

To calculate the benefit likely to arise from the interventions listed above, it was necessary to consider the impact each of the technological innovations may have on thoracic injury prevention. Through testing with the new dummy, it is expected that advances in restraint system technology could be brought about. These advances would find their way into vehicles and those vehicles would be driven on the roads around Europe and the World. At some point in the future an occupant would be using one of these improved restraint systems and in principle it would generate a lower risk of injury for that occupant, or a reduced severity of injury, than would have been the case without that intervention. By this process a benefit of making that change to the restraint system can be defined. The extent of the benefits each intervention can bring about will be a function of the accident exposure and system effectiveness.

The expected exposure for restraint systems will be based upon the current situation as determined on analysis of the accident databases. However, the system effectiveness also needs to be estimated. The estimates of system effectiveness are defined below. These were based on consideration of recent research into restraint system performance and engineering judgement. As such the estimates are subjective. For this reason it is strongly recommended that they are reviewed by other partners in the THORAX Project, particularly those involved in the restraint system testing within Work Package 4, once that work is underway.

2.3.1 Dummy sensitivity

Many components comprise advanced modern restraint systems. For instance, they can incorporate a seat-belt, an airbag, two or more pre-impact belt tensioning devices (pretensioners), and an element or elements that limit the maximum force transmitted through the belt (load limiters). As stated above (Section 2.2), it is not known to which component future restraint system improvements will be made. However, it is currently considered that having an appropriately set load limit that prevents gross deformation of the torso (as far as the impact conditions and occupant compartment space allow) is of benefit in providing effective thoracic protection.

Edwards *et al.* (2008) reported that, “The addition of a load limiter to the restraint technology has reduced the number of serious (‘organ’ and ‘skeletal and organ’) injuries, but proportionally there has been an increase in the number of ‘skeletal’ injuries.” The force level of the load limiter in the cases analysed by Edwards *et al.* was not known and is likely to have included several vehicles with high load limits, such as 6 to 8 kN.

The effectiveness of different load limiting levels is reported in the GIE RE PR technical annex to the earlier THORAX Project deliverable D1.1. It is expected that implementation of load limiters with a lower force limit than is generally the case with the existing fleet, would represent an improvement in protection for thoraces of occupants.

Unfortunately, as was shown by Trosseille *et al.* (2010), the Hybrid III dummy, when used in the Euro NCAP frontal impact test procedure, is not able to determine a different risk of injury with different load limiting forces. This suggests that to drive widespread adoption of load limiters with a lower force limit, the new dummy torso is required. As such, this may constitute a benefit that can be brought about if Euro NCAP were to test with the new dummy torso.

Troseille *et al.* (2010) calculated AIS ≥ 3 thoracic injury risks from Euro NCAP frontal crash tests and compared these with risks from frontal impact crash investigations. The findings from the crash investigations were derived for a 45 year old, in a collision with an EES (Energy Equivalent Speed) of 58 $km.h^{-1}$. The Euro NCAP tests predicted almost the same efficiency for both 4 kN and 6 kN load limiters. The crash investigations showed greater injury reduction efficiency for the 4 kN restraints. In these results the 4 kN thoracic risk was about nine percent, reduced from 16 percent for the 6 kN restraint systems. This indicates that advances in restraint system could prevent, approximately, a further seven out of 16 AIS ≥ 3 injuries.

It will be assumed that the AIS 3+ injuries that are mitigated through the adoption of a lower force-limit used in load limiting devices will be reduced to the AIS 2 severity level. This should provide a substantial benefit for an occupant affected in such a way, as the AIS 2 injury would be expected to have a far better prognosis than the AIS 3+ injury.

For the majority of these injuries, the change will be to mitigate a serious injury to a less severe injury, though potentially still defined as ‘serious’ in the national accident statistics. However, particular attention will be given to cases where the improvement in restraint system would have brought about a change from a fatal to a serious injury.

If a change was made to the Regulatory and Euro NCAP testing protocols, then this would be expected to bring about a change in vehicle design relative to performance under those test conditions. The extent to which any change would be of use in other impact conditions is uncertain. However, for the purposes of this analysis it has been assumed that improvements will be equivocal for impacts where one longitudinal rail and the engine are loaded in combination.

The current sternal deflection injury risk function used with the Hybrid III dummy was developed using sled tests which replicated the impact severity of real world accidents (Mertz *et al*., 1991). The ages of the injured persons in these cases is not given; however, it may be assumed that their ages reflect those of the wider population, broadly. As the body becomes increasingly frail with age, it is expected that the tolerance of older occupants to sternal deflection is lower when compared with that of the average occupant. Therefore it has been assumed that the dummy design changes used in conjunction with the existing injury risk functions will only give benefit to occupants younger than 46 years old. The categories for the age bands have been taken from those used in COVER Task 1.2.

In addition, because the dummies used in the existing test procedures are 50^{th} percentile male dummies, occupants with statures that deviate from the mid-sized male average (classed as either short, tall, slight, or obese) will be excluded from the benefits.

2.3.2 Injury risk function

Within Work Package 2 of the THORAX Project, new injury risk functions will be developed with the potential to consider how injury risk varies with occupant age. By using a different injury risk function for, as an example, sternal deflection it may be possible to extend the normal assumed level of protection to older occupants.

To calculate the benefit for this intervention, it has been assumed that the dummy sensitivity benefits will be extended to occupants of 46 years and older.

2.3.3 Dummy size

Having a dummy of different size to the mid-sized male dummy, has the potential to prevent sub-optimisation of restraint systems for another size of occupant. No decision has been taken within the project to date regarding what size this alternative should be. Therefore, the expected project benefit will be investigated for several different size options, where the target population data allow such comparisons to be made.

2.3.4 Test method

Three different potential changes to frontal impact test procedures were suggested in Section 2.2. The likely impact for each of these is reasonably clear:

- Extending the testing protocols to include a full-width test should extend the project benefit from those accidents with an offset overlap to include those accidents with a fully distributed frontal loading as well.

- Extending the testing protocols to include a small overlap test should extend the project benefit to include accidents where just a single longitudinal was engaged without direct loading to the engine.

- Extending the testing protocols to include a lower speed test should extend the project benefit to include accidents which have a lower impact severity. For instance, accidents with an ETS of up to 40 $km.h^{-1}$ will be included, as well as those from 40 to 56 $km.h^{-1}$.

2.4 Sample segregation

So that benefits could be attributed in the manners described above, it was necessary to divide the accident case sample into different groups. This process built on the case selection criteria and categorisation used previously in the COVER Deliverable D5 (Carroll, 2009).

The following flow chart (Figure 2-2) presents the process used and the groups of accidents and occupants created. At each stage it is important to know how many persons sustained a torso injury and whether the torso injury or injuries were fatal, serious, or slight.

As shown in Figure 2-2, the overlap groups used in the analysis were split into four categories: narrow, offset, wide, and other. These corresponded to the percentage overlaps: 0 to 30 %, 30 to 50 %, greater than 50 %, and level of overlap 'unknown', respectively. The unknown group included accidents with under-/over-run for which there was no discernible loading to the frontal structures as well as those for which the overlap could not be determined (for instance, if the impact was minor and didn't cause lasting, measurable, deformation of the frontal structures). Typically within the CCIS dataset, the number of accidents where under-run is recorded is very small; of the order of 2 %. This value may increase slightly in the cases reviewed here (frontal impact accidents, killed or seriously injured occupant, newer vehicles, etc.), up to about 10 % involving under-/over-run.

Whilst it was originally intended to consider collision severity on the basis of the change in velocity (Δv), because of the large number of missing values, the ETS (Equivalent Test Speed) was considered as well.

Only three occupant positions are shown in Figure 2-2: driver, front seat passenger, and rear seat passenger. The rear seat occupants were further described as being either on the near-side, on the off-side, in the centre, or in an unknown position. However, this information was not used in this analysis due to it having no direct relevance to the options being considered and there being relatively few rear seat occupants in the sample.

2.4.1 Restraint system optimisation

Before assigning benefits to all occupants in one of these sample groups, it is important to know that the injuries sustained can be affected by changes to the restraint system. To demonstrate the potential influence of restraint system modifications, injury causing contacts were reviewed for the occupants with a torso injury meeting the study criteria.

It was found that in frontal impact events the injury causing contact was often coded within the CCIS as being with the seat-belt. The distribution of injury causing contacts for the torso injuries in our sample is shown in Table 2-1. Initially, injury causing contacts were reviewed for all occupants receiving a torso injury from a frontal impact crash. However, in crashes with large intrusion into the occupant compartment it is possible that the restraint system is not as effective as in crashes without substantial occupant compartment intrusion. Even an advanced restraint system may not be able to mitigate some injuries associated with gross intrusion. Therefore cases with substantial intrusion were removed from the sample. For the resulting sub-sample selection, negligible occupant compartment intrusion was defined as being less than 100 mm. The injury causing contacts for the group without substantial compartment intrusion are shown in Table 2-2.

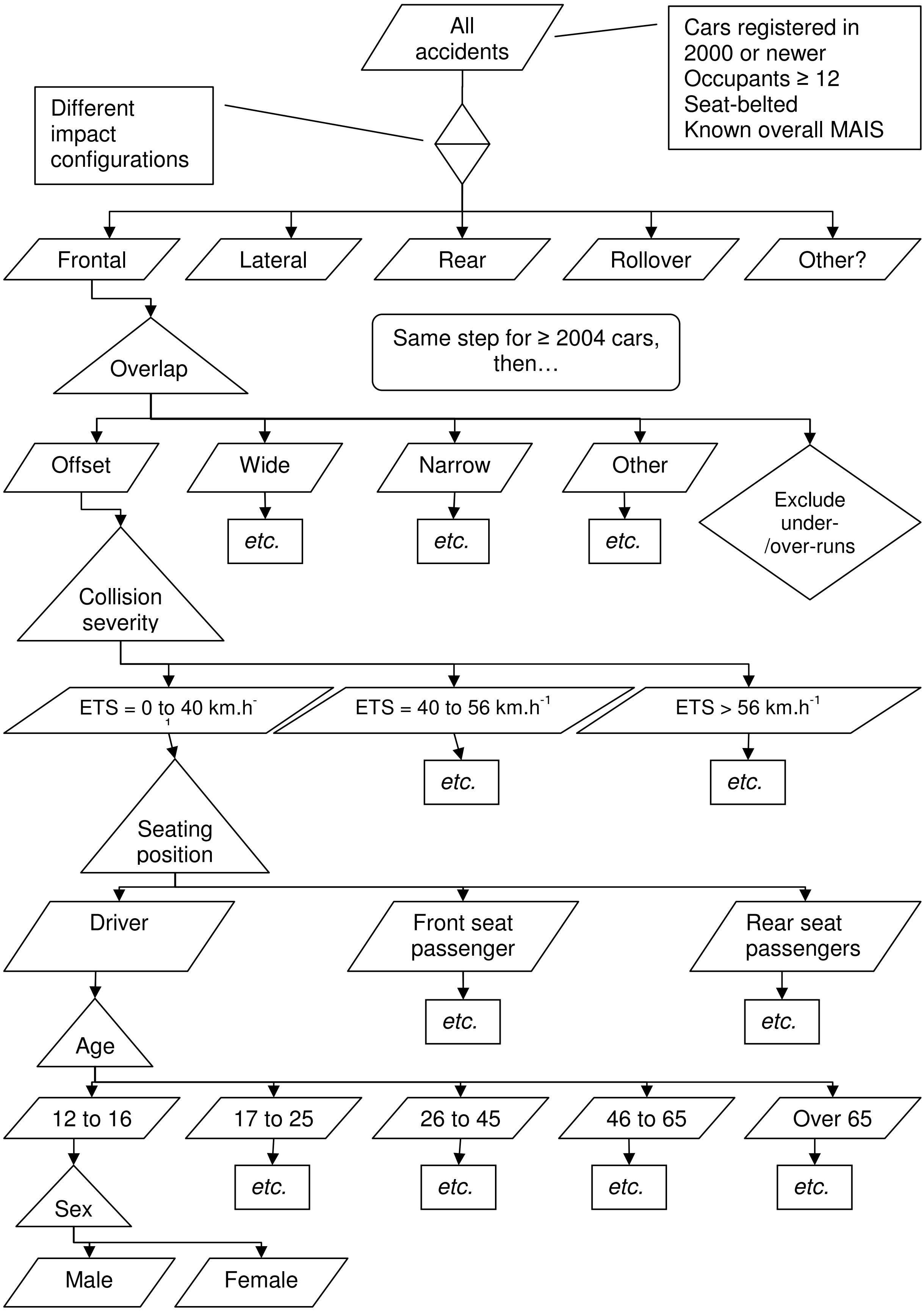

Figure 2-2 Sample segregation flow chart

Table 2-1 Injury Causation Frequency

Injury Causation Area	Frequency
Steering Wheel	152
Steering Wheel Column	4
Header Rail	3
A-Pillar	2
Facia Panel	6
Facia Top	3
Own Seat	18
Seatbelt	552
Airbag	8
Own Side, Compartment	21
Opposite Side, Compartment	1
Object in Vehicle	5
Non Contact Injury	48
External Object	15
Unknown	12
Total	**850**

Table 2-2 Injury Causation Frequency, Severe Compartment Intrusion Excluded

Injury Causation Area	Frequency
Steering Wheel	84
Header Rail	2
Facia Panel	3
Facia Top	3
Own Seat	18
Seatbelt	552
Airbag	8
Own Side, Compartment	21
Opposite Side, Compartment	1
Object in Vehicle	5
Non Contact Injury	48
External Object	15
Unknown	12
Total	**772**

2.5 Benefit calculations

Since 1993, the valuation of both fatal and non-fatal casualties has been based on a consistent willingness to pay approach (DfT, 2009). This approach encompasses all aspects of the valuation of casualties, including the human costs, which reflect pain, grief, suffering; the direct economic costs of lost output, and the medical costs associated with reported road accident injuries. The values for the prevention of fatal, serious and slight casualties include the following elements of cost:

- Loss of output due to injury. This is calculated as the present value of the expected loss of earnings plus non-wage payments made by employers.

- Ambulance costs and the costs of hospital treatment.

- The human costs of casualties. These are based on willingness to pay to avoid pain, grief and suffering to the casualty, relatives and friends, as well as intrinsic loss of enjoyment of life in the case of fatalities.

On this basis the average values of prevention per reported casualty in Great Britain for 2008 are shown in Table 2-3.

Table 2-3 Average value of prevention per reported casualty: GB 2008 (DfT, 2009)

Casualty type	Cost (£ June 2008)
Fatal	1,683,800
Serious	189,200
Slight	14,600

As noted by Assing *et al.* (2006), there is a broad range of injury cost values among European countries. Countries using willingness to pay approaches exhibit noticeably higher values than the countries calculating gross cost-of-damage losses. However, even among the countries using a willingness to pay approach smaller differences remain (up to about 20 percent). The GB values fall within this range and are available with up to date values accounting for inflation. According to Bickel *et al.* (2004) the UK costs are close to the mean values for the six European countries using a willingness to pay approach to calculate casualty costs at that time. Therefore they were considered appropriate for approximate benefit calculations representing casualty costs for Europe, for the willingness to pay approach.

A "European Standard" value of a fatality was developed by UNITE, which gave the value of a fatality as 1.5 million Euros in 1998 (Nellthorp *et al.*, 2001). Assuming inflation in the Euro area from 1998-2010 of 25.51% (calculated from the monthly rates of inflation given by the European Central Bank, 2010), and a Euro to British pounds (GBP, £) exchange rate of 0.8104[1], this European Standard value would be about £1,525,700. This is similar to the GB value of a fatality shown in Table 2-3, so the GB values are again considered appropriate for approximating the casualty costs for Europe for the willingness to pay approach.

It should be noted that slight country to country variations would change the levels of benefit predicted in this report. Therefore a small uncertainty due to the exact values for casualty costs should be assumed when viewing the results of this analysis.

In 2001, Miller *et al.* published crash costs for accidents occurring in the US, and the body regions injured by the occupants in those crashes. Social costs were provided accounting for the threat-to-life severity (AIS) of the injury and whether it involved a fracture. The comprehensive costs incorporated consideration of the following contributory expenses: medical, police and fire services, household work, wage work, insurance administration, legal/court, and property damage.

The comprehensive costs reported by Miller *et al.* were published in 1999 US dollars. Therefore to be compared with the willingness to pay values (in Table 2-3), they were

[1] The exchange rate was obtained from the EC internet site: http://ec.europa.eu/budget/inforeuro/index.cfm?fuseaction=currency_historique&currency=72&Language=en, as specified for July 2010.

converted to British pounds. This conversion assumed inflation from 1999 to 2010 of 32.69 %, and a US to GBP exchange rate of 0.6818.

For the convenience of readers in Europe, the Miller *et al.* costs are also shown in Euros, as well as pounds. For this conversion a Euro to pound exchange rate of 0.8104 has been assumed[1]. Willingness to pay prices have also been converted into Euros for the summary and conclusions; elsewhere in the report they have been kept in British pounds as this is the currency in which the costs were derived originally.

2.5.1 Calculating benefit from estimated injury reduction

The estimated injury reduction will be calculated by either removing injuries from certain body regions, or reducing the maximum injury severity in the body region. These reductions will be made by adjusting the AIS severity scores in different regions. For the willingness to pay approach, an adjusted overall occupant MAIS will then be calculated for each occupant, and these ‘new MAIS’ levels compared with previous MAIS levels to derive the benefit.

Because the costs in Miller *et al*. are based on AIS, the benefit is relatively easy to calculate. The AIS in the different body regions is known before and after the injury reduction, so the cost of the injuries for each person can be calculated before and after the injury reduction. The benefit is then the difference between the two values.

Calculating the willingness to pay costs involves an extra step, because these costs are based on the injury scale of “fatal”, “serious”, and “slight”, while the injury reduction is based on AIS. Because of this, the injury reductions need to be transformed into the equivalent reduction in the number of fatal, serious, and slightly injured casualties.

This transformation is performed using Table 2-4, which was created for this project using all the car occupants recorded in CCIS. This gives the relationship between the maximum AIS (MAIS) score and the “fatal”, “serious”, and “slight” injury categories.

This table can be used to estimate the change in the number of fatal, serious, and slightly injured casualties if the change in the MAIS distribution is known. For example, if injury reductions mean that 100 fewer people had a MAIS of 2, there would be one fewer fatality, 96 fewer serious casualties, and 3 fewer slight casualties. If the new MAIS for all the casualties was 1, there would be 10 more serious casualties, and 90 more slight casualties. This means that a reduction for 100 people of MAS 2 to MAIS 1 would have a net effect of one fewer fatality, 86 fewer serious casualties, and 87 more slight casualties.

Table 2-4 Transformation between MAIS and injury severity

MAIS	Injury severity of occupants with that MAIS (%)			
	Fatal	Serious	Slight	Non-injury
0	0	1	2	97
1	0	10	90	0
2	1	96	3	0
3	7	93	0	0
4	51	49	0	0
5	80	20	0	0
6	100	0	0	0

Once the change in the number of fatal, serious, and slight casualties is known, Table 2-3 can be used to calculate the benefit.

It should be noted that there is the potential for there to be fractional changes in the number of casualties – for example, if there are 50 fewer casualties with a MAIS of 3, this means that the reduction in the number of fatalities would be 3.5. Because in the real world a reduction of half a fatality is meaningless, the benefit will always be rounded down to the nearest whole number of casualties.

3 Target population

There are a few steps required when defining the target populations on which the THORAX project outputs will have an influence. Firstly, it is necessary to divide the sample being considered into appropriate groups for further consideration, this was done as described in Section 2.4. With these groups, consideration can be given to the number of occupants who could potentially be affected by each proposed Project action. The implications for the target occupants then need to be reviewed with particular attention to the influence of any thoracic outcome change for their overall well-being and the specific thoracic injuries being targeted. Finally, any occupants and injuries identified as targets from the sample need to be scaled up to represent the total car occupant population (within the sample countries, and within Europe).

3.1 Sample groups

In this section, the occupant population that is a target for potential benefits is derived. As a start, this analysis considers the basic sample selection of cars registered in 2000 or newer, with occupants of at least 12 years, who were wearing a seat-belt, and for whom a known overall MAIS is reported.

The following figure (Figure 3-1) shows the proportion of the total thorax injuries (of MAIS ≥ 2 severity or AIS 1 rib fractures). The numbers of occupants with a thorax injury for each impact configuration are shown in Figure 3-2.

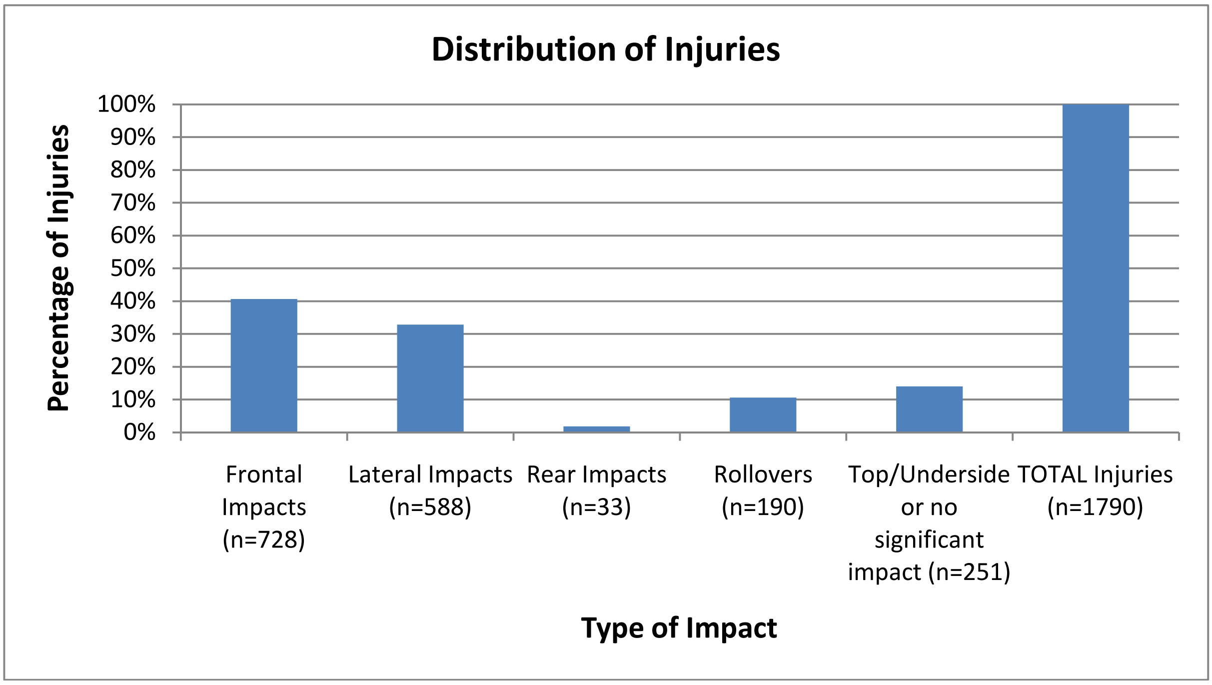

Figure 3-1 Proportions of torso injuries (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the impact configuration in which those injuries were sustained

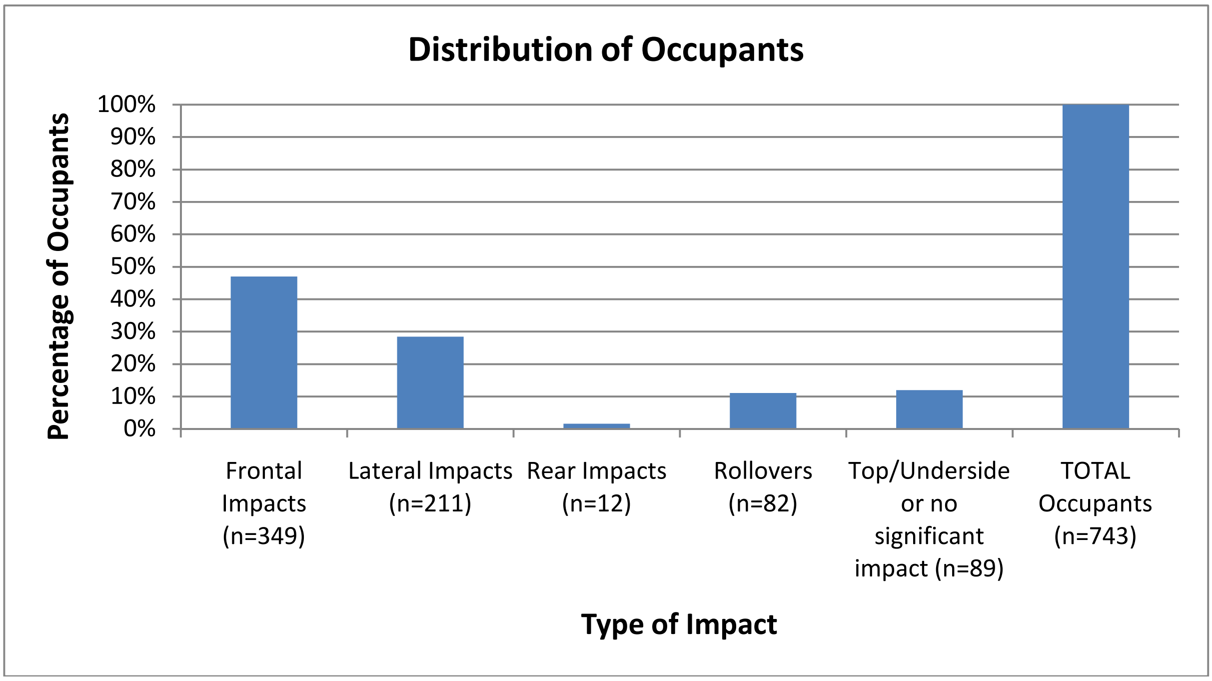

Figure 3-2 Number of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the impact configuration in which those injuries were sustained

Considering just those cars which we know to be compliant with current frontal impact regulatory requirements, that is those cars registered after 2003, then the distribution of thoracic injuries amongst the impact configurations is modified as shown in Figure 3-3. The number of persons with a thorax injury in each group is shown in Figure 3-4.

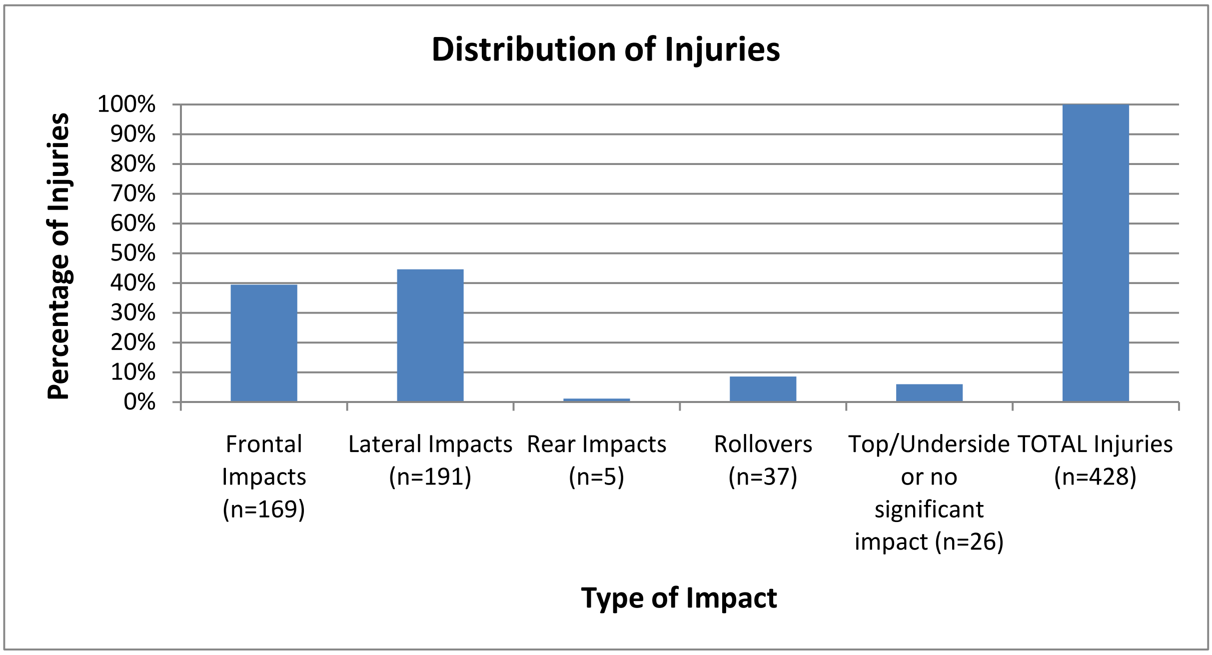

Figure 3-3 Proportions of torso injuries (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the impact configuration in which those injuries were sustained for vehicles registered in 2004 or later

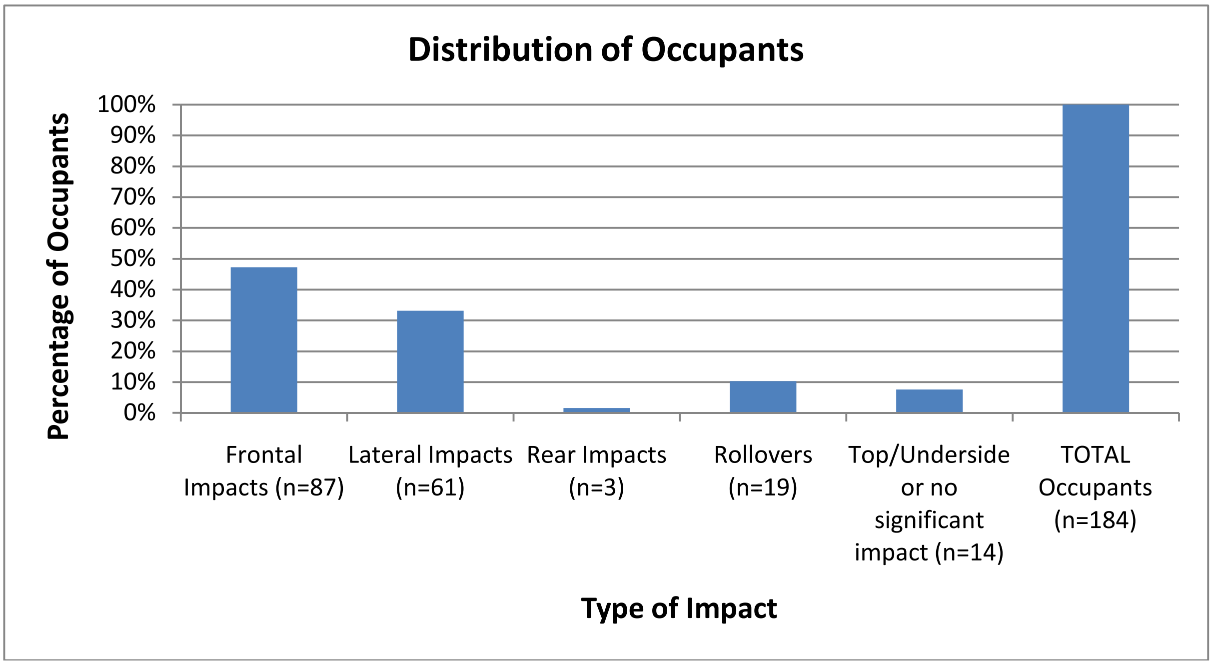

Figure 3-4 Number of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the impact configuration in which those injuries were sustained for vehicles registered in 2004 or later

As the THORAX Project only considers the frontal impact direction, it is assumed that the project has the potential for benefit to only those thoracic injuries sustained in frontal impacts.

For those vehicles having loading predominantly to the front, in which a thorax injury was sustained, then Figure 3-5 shows the distribution of the engagement of frontal structures for both the CCIS and GIE RE PR samples. The total number of occupants included in Figure 3-5 does not add up to the number of occupants having a frontal impact shown in Figure 3-3. This is because impacts where there was a substantial component of either under- or over-run have been excluded. The rationale for excluding vehicles with under- or over-run is that changes to the restraint system are unlikely to affect significantly the outcome for the injured persons. Instead the injuries to the persons involved in accidents of this type are more likely to be addressed by considering the vertical compatibility of vehicles. Furthermore, to maximise the number of cases available from the COVER accident case sample, the selection of vehicles from 2004 onwards (as applied to the whole CCIS sample) has been removed. Instead each vehicle in the sample was considered individually with respect to it being compliant with Regulation 94, or not. It was assumed that if a vehicle had a substantial model revision between 2000 and October 2003, then the updated models would be compliant, although older versions may not have been. This allowed some vehicles released between October 1998 and October 2003 to be included.

It is shown in Figure 3-5 that the proportion of occupants injured in collisions with narrow engagement of the frontal structures was greater in the GIE RE PR sample than in the CCIS. Correspondingly, the proportion of collisions with wide objects was lower in the GIE RE PR sample than in the CCIS.

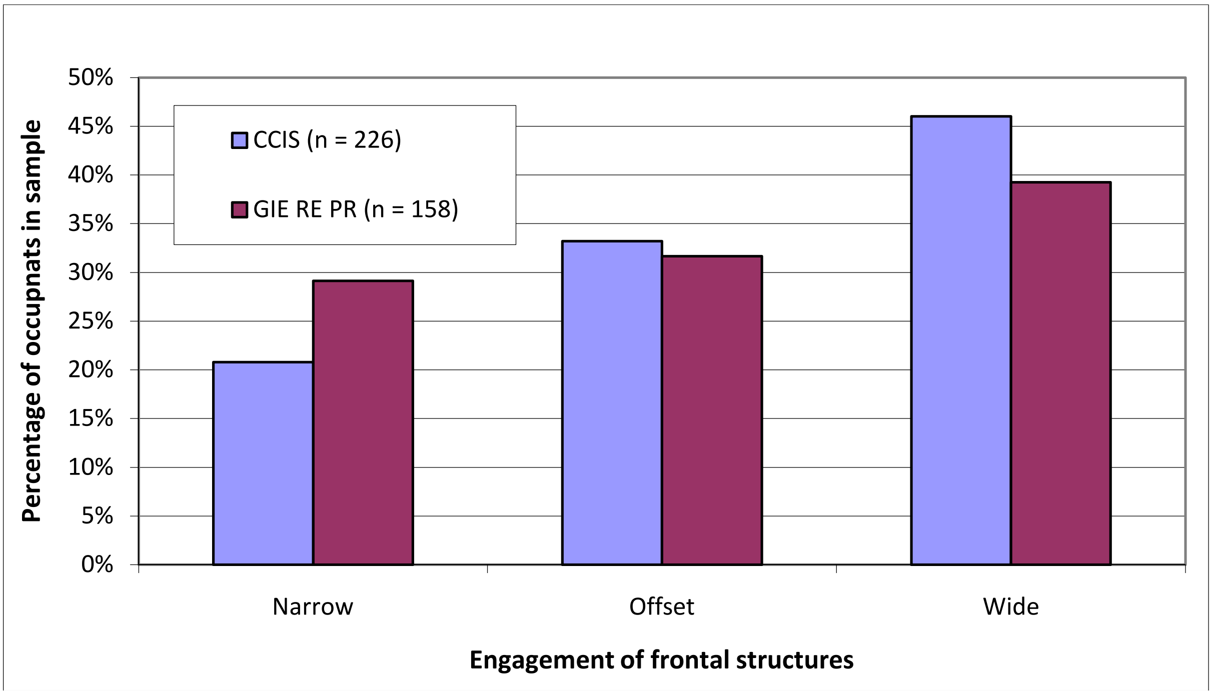

Figure 3-5 Proportion of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, for frontal impact accidents (CCIS and GIE RE PR sample data)

The distribution of impact severity amongst the groups of frontal structure loading is shown in Figure 3-6 for the CCIS sample (using Equivalent Test Speed, ETS, as the severity measure) and Figure 3-7 for the GIE RE PR sample (using Energy Equivalent Speed, EES, as the severity measure). It is clear from these two figures that in the CCIS sample there are many more low speed impacts, of all types; whereas in the GIE RE PR sample there are more high speed collisions.

Due to the assumptions in the impact severity measure, it is generally the case that EES estimates are lower than or equal to ETS estimates for an equivalent impact. This goes some way to explaining the difference observed here between the two samples. Differences in the sampling strategies and the particular accidents investigated will also affect these findings.

It should be noted that neither the CCIS or GIE RE PR samples are truly representative of the whole accident population in Europe. In the CCIS, accidents are investigated according to a stratified sampling procedure, which favours cars containing fatal or seriously injured occupants as defined by the British Government definitions of fatal, serious, and slight. The sample is therefore biased towards more severe injury accidents involving newer cars. For the GIE RE PR in-depth accident database, two methods of passive accident investigations are used: a systematic and a targeted method. All accidents in the North-western zone of Paris are systematically studied, without reference to makes and models. Additionally, in order to check the protection offered by new vehicles distributed on the market (and new safety-related technology: airbags, load limiters, child restraint systems, etc.), other car accidents (from anywhere in France) are targeted based on specific characteristics of interest. This means that the exact distributions of overlap and impact severity shown here may not accurately represent the full European accident population. However, this is the best information available to characterise severe frontal impact crashes and, making allowances for sample biases, indicates trends which we would expect to be evident in the whole population.

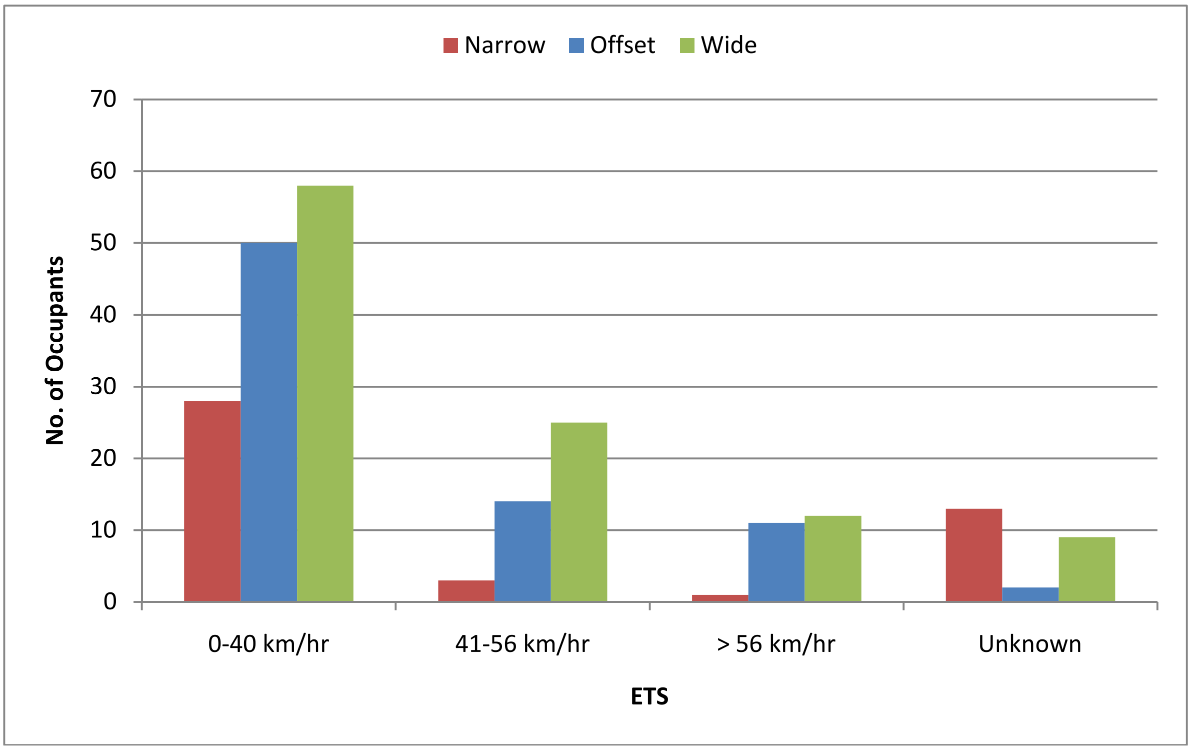

Figure 3-6 Number of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading and the impact severity, ETS (CCIS sample, n = 226)

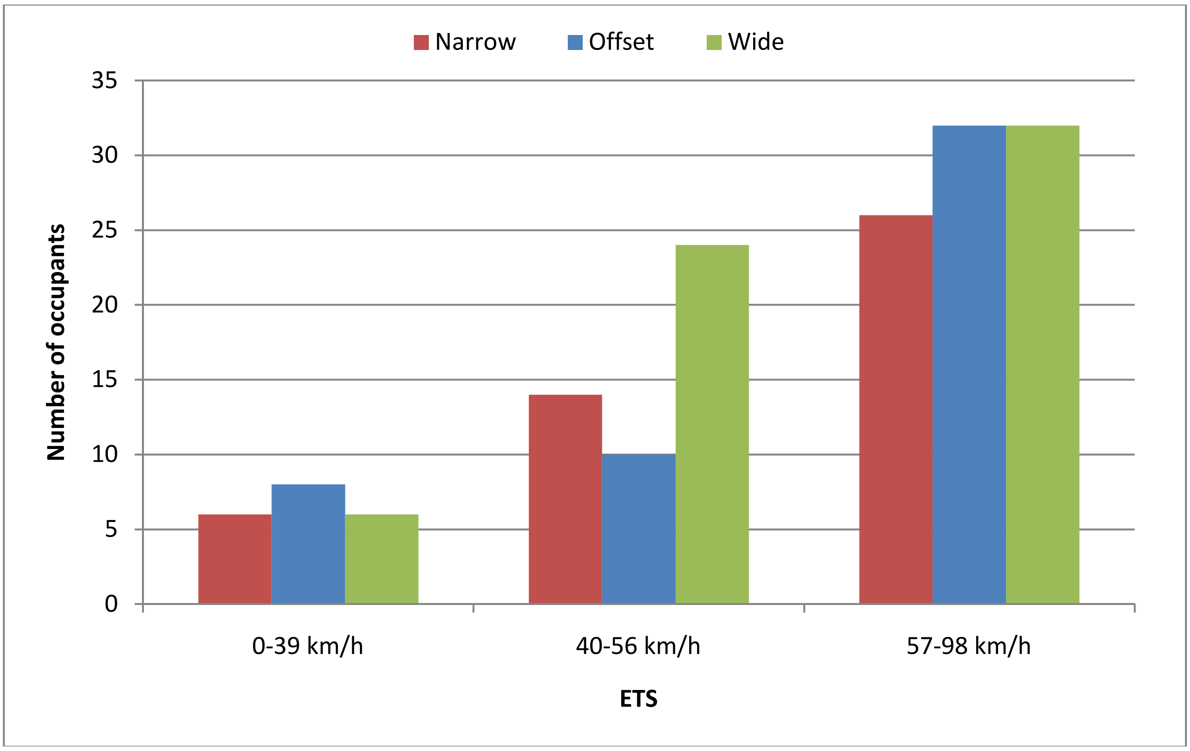

Figure 3-7 Number of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading and the impact severity, ETS (GIE RE PR sample, n = 158)

For each of the groups shown in Figure 3-6, the thoracic injuries could have occurred to occupants sitting on either the driver's, front passenger's, or rear seats. The numbers of occupants in each group of accident type and in each seating position are shown in Table 3-1. It should be noted that front structure engagement of <30% is classed as 'Narrow' overlap, 30-50% as 'Offset' and >50% as 'Wide' overlap. Loading of the longitudinal has been classified as being on the same side of the vehicle as the occupant (SS), the opposite side of the vehicle as the occupant (OS), loading to the mid-point of the vehicle, i.e. engine loading without directly loading either longitudinal (Mid), loading of both longitudinals (Both), and no loading (None). No loading in the wide overlap category relates to the situation where the frontal damage was too minor in nature to provide a reasonable estimate of the overlap. In the narrow category, the no loading (None) group can also include the scenario where the loading is narrow enough that it misses the longitudinal.

Table 3-1 Number of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, the impact severity, ETS, and seating position

Seating Position	Overlap	Loading	ETS			
			0-40km/hr	40-56km/hr	>56 km/hr	N/K
Driver	Narrow	SS	5	1		2
		OS	5			1
		Mid	5	1	1	
		None	5			4
	Offset	SS	20	10	9	
		OS	9	2		1
	Wide	SS	4	1	2	3
		OS	4	1	1	0
		Both	21	14	6	4
		None				1
Front Seat Passenger	Narrow	SS	1			1
		OS	2	1		1
		Mid	1			
		None	2			3
	Offset	SS	6			
		OS	11	2	2	1
	Wide	SS	2			
		OS	7	1		
		Mid	1			
		Both	14	4	3	1
Rear Seat Passenger	Narrow		4			1
	Offset		2			
	Wide		5	4		

The ages of the occupants in each of these accident type and seating position groups are shown in Table 3-2.

Furthermore, the sex of the occupants in the accident type, seating position, and occupant age groups is shown in Table A-1, Table A-2 and Table A-3 for the CCIS sample and Table B-1, Table B-2 and Table B-3 for the GIE RE PR sample.

Table 3-2 Number of persons with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, the impact severity, ETS, and occupant age

Age Range	Overlap	ETS			
		0-40 km/hr	40-56 km/hr	>56 km/hr	Unknown
12-16	Narrow 0-30%				
	Offset 30-50%				
	Wide >50%		2		
17-25	Narrow 0-30%	2	2	1	
	Offset 30-50%	5	5		1
	Wide >50%	8	4	4	1
26-45	Narrow 0-30%	3			5
	Offset 30-50%	11	3	3	
	Wide >50%	12	8	5	4
46-65	Narrow 0-30%	9			5
	Offset 30-50%	17	6	3	1
	Wide >50%	24	7	1	2
66+	Narrow 0-30%	14	1		3
	Offset 30-50%	17		5	
	Wide >50%	14	4	2	2

Another observation regarding the UK and French data was that the GIE RE PR sample had more occupants from the middle age groups (26 to 45) than the CCIS sample, and correspondingly, fewer from the youngest and oldest groups (17 to 25 and over 65). However, this difference was not statistically significant at the 5 percent confidence level (X^2 test).

3.2 Sample targets

Based on this division of the sample, it is possible to define target populations for the proposed project safety interventions (outputs). As noted in Section 2.2, the safety interventions were selected to represent the expected outcomes of the THORAX Project and potential implementation options. The sample targets therefore identify a particular group of occupants for whom it is considered that implementation of the project outputs will mitigate their torso injuries. These are specific groups within the frontal impact sample selected on the basis of specific occupant and crash characteristics.

3.2.1 Dummy sensitivity

This option assumes that the benefits are to arise purely through the use of an improved (mid-sized) dummy. The test conditions otherwise remain unchanged. Therefore the target sample relates to frontal impacts involving one longitudinal beam and the engine, with an ETS of 40 to 56 km.h^{-1}, occupants up to 45 years of age, who were seated on one of the front seats.

In this sample of cases there were ten front seat occupants involved in crashes of this type. Of these ten occupants, six were under the age of 46, and of these six, three had an unknown height and weight, and one was 'obese' {89 kg} (according to the CCIS coding, see Table 3-3). This means that this intervention has the potential to affect between two and five occupants in the sample selected. It should be noted that one of the drivers was seated on the opposite of the vehicle from the loading to the frontal structure of the car. Therefore, for the subsequent analysis of their injuries we have taken four of these people and assumed they would be mid-sized and hence affected by this intervention. Based on the uncertainties in occupant size and whether benefits would be seen for drivers on the non-struck side, the sensitivity of the benefits arising from this group should be considered within the range of 50 % to 125 %.

Table 3-3 CCIS coding of height and weight information

	Height			Weight		
	Lower (m)	Medium (m)	Upper (m)	Light (kg)	Well-nourished (kg)	Obese (kg)
Male	≤ 1.69	> 1.69 ≤ 1.79	> 1.79	≤ 67	> 67 ≤ 83	> 83
Female	≤ 1.57	> 1.57 ≤ 1.79	> 1.79	≤ 56	> 56 ≤ 70	> 70

It is clear from this definition of a sample target that the group size of the target groups is and will be small when based on this selection of frontal impact accidents in the CCIS dataset. Nevertheless, in this respect, the CCIS database contains the largest quantity of in-depth case files with moderate or greater severity injuries to vehicle occupants available in Europe at this time. Therefore, this is the best information source with which to carry out an analysis involving this level of detail on the occupant injuries and crash characteristics. However, the small sample size is a clear limitation of the study and will influence the confidence with which the results from the study can be used in the future. Care must be taken that the results and conclusions drawn in this report are used with due regard to the sample sizes on which they are based.

3.2.2 Injury risk function

To calculate the benefit for this intervention, it has been assumed that the dummy sensitivity benefits will be extended to occupants of 46 years and older. Inherent in this target group is the assumption that the benefit for occupants up to 45 years of age will be included. An equivalent benefit across this entire range of ages may be difficult to achieve in reality, as there may be some trade-offs between ideal protection for older and younger occupants. However, the exact balance of these considerations is beyond the scope of this benefit analysis.

By extending the target group to include the older occupants, it adds in the extra four occupants over 46 years identified in the cases above (Section 3.2.1). One of these occupants was 1.85 m tall and is therefore considered too tall to benefit from this option (without the introduction of a taller dummy). The height and weight of the other occupants was unknown. They have been included in this group as an initial approximation. However, it must be considered that the number of occupants affected by this intervention is between zero and three.

3.2.3 Dummy size

In Section 2.3.3 it was proposed that the expected project benefit will be investigated for two size options, where the target population data allow such comparisons to be made. These options have been chosen to be small or large occupants. The small occupants are defined as having a short stature with either light or medium mass, or having a light mass with short or medium height. The large occupants similarly included those who were tall with a medium or high mass, or those who were heavy with medium or tall height.

The assumption for this target group is that the addition of protection for smaller or larger occupants will be in association with increased protection for the mid-sized occupants. In practice this may require additional testing or randomised use of dummies in approval testing. The exact method of physically generating a consistent level of protection across the different occupant sizes chosen here is not considered further within this report, but would need careful thought if this option was selected. Assurance would be needed to show that introduction of a particular dummy size did not degrade the level of protection for occupants of approximately mid-size, and so forth.

There were no occupants in the sample involved in a crash with an ETS of 41 to 56 km.h^{-1} and with an overlap of 31 to 50 % who were 'small'. However, it should be noted that for six of the ten occupants injured in this type of collision their height and weight was unknown; including three of the six occupants under 46 years old. The addition of a small dummy may therefore affect between no occupants and three quarters of those listed under the dummy sensitivity option.

There was one overweight male in the sample involved in offset crashes of ETS 41 to 56 km.h^{-1}, who was under 46 years old. Assuming there were no small occupants in this subset of cases, then this intervention would account for the other occupants not included in the dummy sensitivity option.

On the basis that no occupants were expected to be either short and heavy or tall and light, then the ten occupants who had an offset crash of this type would be accounted for somewhere between the three dummy sizes being considered.

3.2.4 Test method

The additional occupants who may have injuries mitigated by the three options for test method changes are shown below:

A. Full-width:

By adding a test which affords benefit to those occupants involved in crashes with greater than 50 percent overlap, there is the potential to mitigate torso injuries for 12 drivers (no passengers) under the age of 46 years. Two of these occupants were mid-size females, and two were larger than medium height and/or weight. Therefore the benefit is expected to be seen for somewhere between ten occupants and a minimum of two occupants.

The French, GIE RE PR sample data, using EES, suggested a slightly smaller proportion of torso injury causing collisions with wide engagement of the frontal structures than the CCIS data (using ETS) at the 40 to 56 km.h^{-1} impact severity. This would indicate that, for the wider European scenario, the CCIS analysis may overestimate the potential benefit associated with the addition of a full-width test. The potential influence of an optimistic benefit estimate based on such bias should be taken into account when reviewing the estimates produced within this report.

B. Small overlap:

By adding a test which affords benefit to those occupants involved in crashes with 30 percent overlap or less, there is the potential to mitigate torso injuries for one driver and one passenger under the age of 46 years. The passenger was small and the height and weight of the driver was unknown. The benefit here could be relevant to between zero and one occupant.

However, the GIE RE PR sample suggested a greater proportion of small overlap collisions causing torso injuries at this impact severity than the CCIS sample. As such one may expect a more optimistic estimate of benefit associated with the introduction of a small overlap test when considering the wider European accident population.

C. Test speed:

By adding a test which affords benefit to those occupants involved in crashes with an ETS up to 40 $km.h^{-1}$, there is the potential to mitigate torso injuries for five drivers and four passengers under the age of 46 years. However not all of these occupants are mid-sized and not all of them were either drivers on the struck side or passengers on the non-struck side. As an initial approximation, the expected benefit is likely to extend to between one and eight occupants. It has been calculated for seven occupants, so the sensitivity range will be between 14 and 114 percent of the calculated value.

The GIE RE PR sample showed fewer torso injury causing crashes with low impact speeds than the CCIS sample. This suggests a lower estimate of benefit associated with a low-speed test may be more appropriate when representing the whole of Europe.

3.2.5 Alternative groups

The safety interventions considered above represent single changes which may be made to the existing frontal impact test protocols to include an output from the THORAX Project. However, it seems realistic that a change to the frontal impact regulatory testing would combine more than one of these aspects. For this reason some alternative options are considered in the benefit analysis. These represent combinations of options which could be introduced at the same time and are listed below:

1. Full-width test and improved dummy sensitivity
   - Making use of the new dummy thorax hardware in a new full-width test at a similar severity to the existing tests

2. Full-width test, injury risk functions for older occupants, and small passengers
   - Introduction of a full-width test where injury criteria are set to protect older occupants and the dummy in the front seat passenger position represents small female occupants

3. Offset test, injury risks for older occupants, and small passengers
   - Incorporation of injury criteria to protect older occupants and a small female front seat passenger in the existing offset test procedures

4. Offset test – low-speed, and injury risk functions for older occupants
    - Addition of a low-speed offset test making use of injury criteria designed to protect older occupants

5. Full-width test – low speed, and injury risk functions for older occupants
    - Equivalent to the previous option, but with a full-width test instead of an offset test

6. Full-width, all speeds, all occupant ages
    - Whatever steps are necessary to define protection for full-width impacts at all severities (up to existing test speeds), with injury criteria set to protect older occupants

3.3 Injury targets

For each of the sample targets mentioned in the previous subsection, the number of torso injuries has been defined. These are shown in the following series of tables.

It is important to consider exactly what those torso injuries were. It is likely that benefits from the THORAX Project will affect the incidence of different injury types in different ways. For instance, restraint system improvements may be targeted to reduce severe organ injuries but accepting that some occupants will still receive minor skeletal (rib and sternum) fractures. Therefore, the different torso injuries associated with each of the implementation options are shown in the following tables.

3.3.1 Dummy sensitivity

The number and severity of torso injuries for the occupants picked out as the target for improvements in dummy sensitivity are shown in Table 3-4. As noted in Section 3.2.1, the target sample relates to offset frontal impacts involving one longitudinal beam and the engine, with an ETS of 40 to 56 $km.h^{-1}$, occupants up to 45 years of age, who are approximately mid-sized and seated on one of the front seats.

Table 3-4 Injury target population for increasing dummy sensitivity

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		4	2		
Lower Abdomen					
Other Abdomen	1		1		
Shoulder		1			
Lung			5		
Heart					1
Rib Only	1		2		
Rib	1				
Sternum					
Other Thorax	1				1

3.3.2 Injury risk function

The number and severity of the torso injuries sustained by the older occupants picked out as the target for improvements in the thoracic injury risk functions are shown in Table 3-5. As noted in Section 3.2.2, with this intervention it has been assumed that the dummy sensitivity benefits will be extended to occupants of 46 years and older. This means the target sample includes occupants of all ages, who are approximately mid-sized and seated on one of the front seats in an offset frontal impact with an ETS of 40 to 56 km.h^{-1}.

The addition of the older occupants brings the inclusion of several minor (AIS ≤ 2) injuries, but it also yields the addition of three severe lung injuries (AIS ≥ 4).

Table 3-5 Injury target population for improving injury risk function

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		6	2		
Lower Abdomen		1			
Other Abdomen	2	2	3		
Shoulder		3			
Lung			5	2	1
Heart		1			1
Rib Only	2		2		1
Rib	2				
Sternum					
Other Thorax	2		1		1

3.3.3 Dummy size

The number and severity of the torso injuries sustained by occupants when small and light persons are included as well as mid-sized persons are shown in Table 3-6. This table is identical to Table 3-4 because it includes no additional occupants. The implication of this is that no benefit will be predicted from any measure that attempts to account for small and light occupants. Contrary to this finding, it is still expected that some small or light occupants would benefit from improved restraint systems tested with a smaller and lighter dummy. Instead it is reasoned that the lack of small/light occupants in the sample shows the limitations in the number of occupants with size and weight information that are available for inclusion in this analysis.

Table 3-6 Injury target population for including small/light occupants

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		4	2		
Lower Abdomen					
Other Abdomen	1		1		
Shoulder		1			
Lung			5		
Heart					1
Rib Only	1		2		
Rib	1				
Sternum					
Other Thorax	1				1

The number and severity of the torso injuries sustained by occupants when tall and heavy persons are included as well as mid-sized persons are shown in Table 3-7. As with the original dummy sensitivity sample, this target group considers only offset frontal impacts involving one longitudinal beam and the engine, with an ETS of 40 to 56 km.h^{-1}, and occupants up to 45 years of age, who are seated in the front.

Table 3-7 Injury target population for including tall/heavy occupants

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		4	2		
Lower Abdomen					
Other Abdomen	5		1		
Shoulder	1	1			
Lung			5	1	
Heart					1
Rib Only	1	1	2		
Rib	1				
Sternum		2			
Other Thorax	3				1

3.3.4 Test method

The number and severity of torso injuries for the occupants expected to be in the target population for the interventions considering additional test methods are shown in the following three tables (Tables 3-8 to 3-10). In each case benefits will be expected to be limited to occupants who are approximately mid-sized and seated in the front.

Table 3-8 Injury target population for full width test method

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		4	2		
Lower Abdomen	1				
Other Abdomen	5		1	1	
Shoulder	1	6			
Lung			7		
Heart					1
Rib Only	3		4		
Rib	1				
Sternum		1			
Other Thorax	4				1

Table 3-9 Injury target population for small overlap test method

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		4	2		
Lower Abdomen	0				
Other Abdomen	1		1		
Shoulder		1			
Lung			7		
Heart					1
Rib Only	1		2		
Rib	1				
Sternum					
Other Thorax	1	1			1

The target population for the introduction of a low speed test is assumed to be all impact speeds from 0 to 56 km.h^{-1}. This assumption requires that any low speed test worked harmoniously with the existing tests and filled the gap in safety assessment between impacts too slow to cause injuries and those below the regulatory test speed.

Table 3-10 Injury target population for 0-56kph test speed

Injury	AIS				
	1	2	3	4	5
Upper Abdomen		4	2		
Lower Abdomen	2	4			
Other Abdomen	5		1		
Shoulder	2	5			
Lung			7		
Heart					1
Rib Only	1		2		
Rib	1				
Sternum		3			
Other Thorax	3				1

3.4 Population targets

By comparing the number of accidents recorded in CCIS to the number which occurred in the police STATS19 dataset for Great Britain, the results from this analysis can be weighted to estimate what the national situation may be. This weighting can be extended to estimate the picture in the European Union as a whole.

3.4.1 Calculating scaling factors for weighting CCIS results to Great Britain

The first step in scaling in-depth data to national data is deciding exactly what national data should be used. Here, an estimate is made of the number of car occupant casualties which will occur nationally once the entire car fleet is compliant with current frontal impact legislation (Regulation 94). The annual number of casualties in the Regulation 94 compliant fleet is estimated by making two assumptions:

1. The overall number of casualties is equal to the number of car occupant casualties in 2008
2. The proportion of fatal, serious, and slight casualties is the same as the proportion for the Regulation 94 compliant cars in 2008

Table 3-11 gives the number of car occupant casualties in frontal impacts recorded in STATS19 in 2008. It also gives the number in Regulation 94 compliant cars – these include all cars registered after 1st October 2003 (which is when the Regulation came into force for all new cars). The number of casualties is split by injury severity and occupant age – two variables that are known to be different between CCIS and STATS19.

It is noted that the sample of cars selected, which are Regulation 94 compliant, will include some vehicles which comply with regulations from other regions that may already include some part of the proposed safety interventions. For instance, USA, Japan, Australia, China, and the Gulf States already have a full width frontal impact test and in the US tests with a fifth percentile female dummy have been added to the legislation. For this reason one might expect benefits associated with a full-width test or use of a small female dummy may be overestimated. However, it should also be considered that cars can be released with minor changes to comply with different requirements from different regions. Also, in the preceding work with the COVER Project and THORAX Task 1.1, crashes involving overlap spanning at least one longitudinal rail and the engine (offset to full-width) and occupants varying from the average male size were identified as being key characteristics in torso injury risk. This analysis uses the same sample of accident cases, as was used in the COVER report (Carroll, 2009). Assuming that the requirements specified in other regions of the world have been in place for a number of years, already; we can conclude that they have not addressed torso injuries in European road accidents satisfactorily. It seems that more can be done to mitigate torso injuries in European frontal impact accidents and this benefit analysis should identify the scope for generating safety benefit from implementing the THORAX Project outputs.

Table 3-11 Number of car occupant casualties in frontal impacts recorded in STATS19 in 2008

Age	All cars				Cars registered after 1st October 2003			
	Fatal	Serious	Slight	Total	Fatal	Serious	Slight	Total
0-11	11	150	2,484	2,645	3	48	886	937
12-25	246	2,554	23,762	26,562	93	825	8,492	9,410
26-45	197	2,115	21,325	23,637	55	630	7,336	8,021
46-65	130	1,288	10,756	12,174	40	384	3,389	3,813
66+	146	786	4,598	5,530	51	232	1,497	1,780
Total	730	6,893	62,925	70,548	242	2,119	21,600	23,961

Table 3-12 gives the estimated annual number of car occupant casualties in a Regulation 94 compliant fleet. This keeps the same total number of casualties as with all cars, but uses the distribution of fatal, serious, and slight, as was observed with only those cars registered after the 1st October 2003. These numbers, as shown in Table 3-12 are those to which the results from CCIS will be scaled.

Table 3-12. Estimated annual number of casualties in a Regulation 94 compliant fleet

Age	Fatal	Serious	Slight	Total
0-11	8	135	2,501	2,645
12-25	263	2,329	23,971	26,562
26-45	162	1,857	21,618	23,637
46-65	128	1,226	10,820	12,174
66+	158	721	4,651	5,530
Total	719	6,268	63,561	70,548

In order to scale results from CCIS to the national number of casualties, an equivalent table must be made in CCIS. This is shown in Table 3-13. This is a table of age and severity for car occupants in CCIS who were in a frontal impact in a Regulation 94 compliant car.

Table 3-13. Number of car occupant casualties in CCIS: frontal impacts, Regulation 94 compliant cars

Age	Fatal	Serious	Slight	Total
0-11	0	31	63	94
12-25	21	194	390	605
26-45	23	215	510	748
46-65	26	173	279	478
66+	30	104	99	233
Total	100	717	1,341	2,158

Table 3-12 and Table 3-13 can be directly compared, and the ratio of one to the other can be used to calculate the weighting values for scaling CCIS results to STATS19. This gives a scaling factor that scales all of the cases in the CCIS frontal impact sample used in this study to 2008 national, GB, levels. These weighting values are shown in Table 3-14. Multiplying the number of casualties from the CCIS analysis by these values will give an estimate of how many casualties there might be in Great Britain if the entire car fleet was compliant with Regulation 94. The main assumption in this scaling (given that we have calculated weighting factors by age and injury severity) is that, with the exception of age and injury severity, CCIS is representative of the accidents which occur in Great Britain.

There are no slightly injured casualties shown in Table 3-14 because the sample of frontal impact cases used in this study specifically limited the occupants to those who were killed or seriously injured.

Table 3-14 Weighting values for scaling CCIS results to STATS19 Regulation 94 compliant fleet

Age	Fatal	Serious
12-25	12.50	12.00
26-45	7.05	8.64
46-65	4.91	7.09
66+	5.28	6.93
Total	7.19	8.54

3.4.2 Calculating scaling factors for weighting Great Britain results to Europe

Once the results have been scaled to Great Britain, they can also be scaled to Europe. The only Europe-wide figures are for the number of road fatalities, which is recorded by Eurostat. In order to scale the number of fatal and serious casualties, the number of serious casualties Europe-wide needs to be estimated. It is assumed that the ratio of fatal to serious casualties is the same in Great Britain as it is in Europe. This proportion is shown in Table 3-15.

Table 3-15 Number of road casualties in Great Britain 2008

Fatal	Serious	Ratio of serious to fatal
2,358	26,034	11.04

Although the number of serious casualties Europe-wide are not available, the number of serious casualties in some individual countries are available for 2007 from CARE (Community database on Accidents on the Roads in Europe). Table 3-16 shows the number of fatalities, serious casualties, and the ratio of serious to fatal casualties for the countries where this information was available in 2007, sorted in ascending order of the serious to fatal ratio.

Table 3-16 Road casualties in individual European countries in 2007

Country	Fatalities	Serious casualties	Serious to fatal ratio
Malta	12	245	20.42
Austria	691	12,687	18.36
Germany	4,949	75,443	15.24
Netherlands	709	9,683	13.66
Northern Ireland	113	1,097	9.71
Great Britain	2,946	27,774	9.43
France	4,620	38,615	8.36
Sweden	471	3,824	8.12
Denmark	406	3,138	7.73
Hungary	1,232	8,155	6.62
Luxembourg	46	286	6.22
Belgium	1,071	6,199	5.79
Spain	3,822	19,296	5.05
Slovenia	293	1,295	4.42
Czech Republic	1,221	3,873	3.17
Portugal	974	2,996	3.08
Poland	5,583	16,053	2.88
Ireland	338	860	2.54
Romania	2,800	7,091	2.53
Latvia	419	638	1.52
Greece	1,612	1,821	1.13

This shows that there is a wide range of the ratio of serious to fatal casualties across Europe, and there are countries with higher and lower ratios than GB or France. Part of the reason for this wide variation is the definition of a "serious casualty". The CARE glossary states that the numbers of fatalities in each country are adjusted to conform to the "death within 30 days" definition (European Commission, 2006). However, the definition of serious casualties differs in different countries as follows:

France – Injured in a road accident. Hospitalised at least 6 days.
Belgium, Denmark, Spain from 1993, Greece, Luxembourg, Portugal – Hospitalised at least 24 hours.
Denmark, Netherlands – Hospitalised as in-patient.
Great Britain, Ireland, Northern Ireland – Not hospitalised, hospitalised for observation or as in-patient.
Austria, Sweden – No reference to hospitalisation.
All countries except Belgium, Spain from 1993, France, Luxembourg, Netherlands, Portugal – Opinion of the Police.
Denmark, Spain before 1993, Great Britain, Ireland, Northern Ireland – Police guidance provided.
All countries except France, Luxembourg, Portugal – Persons died 30 days after accident included.

Because of these different definitions, it is very difficult to determine a consistent measure of the number of seriously injured casualties in Europe. For the estimation of benefit in this report, the number of serious casualties in Europe will be based on the number of fatalities in Europe and the proportion of fatal to serious casualties in Great Britain. This is because the estimate of casualties prevented is based on in-depth accident data where the GB definition of a serious casualty has been used.

The number of road fatalities in Europe in 2007 (from Eurostat) is given in Table 3-17 for the countries in the EU 27, EU 25, and EU 15. This also gives the estimated number of serious road casualties, calculated using the ratio of fatal to serious casualties in Table 3-15.

Table 3-17 Number of road casualties in Europe in 2007

Area	Fatalities	Estimated number of serious (based on proportion in GB)
EU 27	42,854	410,074
EU 25	39,054	373,711
EU 15	28,644	274,097

Comparing the number of road casualties in Great Britain (Table 3-15) to the number of road casualties in Europe (Table 3-17) enables the weighting values to be calculated, which are shown in Table 3-18. There are a number of assumptions in this calculation, including the assumption that the proportion of road casualties which are car occupants is the same in Europe and Great Britain.

Table 3-18 Weighting values for scaling results for Great Britain to Europe

Area	Fatal	Serious
EU 27	18.17	15.75
EU 25	16.56	14.35
EU 15	12.15	10.53

By applying the scaling factors defined in the previous tables, it is possible to define the numbers of thorax injuries in target samples at the national and European level. These target samples for each of the previously mentioned project interventions are shown in the series of tables in Appendix B. It should be observed that the injuries appear in specific groups. This feature represents the small number of injuries in the CCIS data for each group. It serves to highlight the problems when handling small quantities of data and the need to apply care when interpreting such findings.

4 Benefit

The following section presents the benefit, or cost saving, that would be expected if the project interventions were adopted and mitigated the injuries picked out in the target groups.

For each option four different concepts are presented in terms of the benefit efficacy. Firstly, the cost associated with all of the injuries, as identified in each target group, are shown. This level of cost saving could only be achieved if the intervention was perfectly effective and let none of those injuries occur. Such a level of injury mitigation is thought to be unrealistic. Therefore, additional, more reasonable, options are shown. These are:

- Reduction of AIS ≥ 4 injuries to the AIS 3 level
- Reduction of AIS ≥ 3 injuries to the AIS 2 level
- Reduction of the AIS level by one for all injuries

It should be noted that the first two of these reasonable options may not produce much impact on a willingness to pay model, unless some fatal injuries can be prevented. This is because, reducing an AIS 3+ or 4+ injury to the AIS 2 or 3 level will have only a small chance of changing the overall occupant severity from serious to slight. An AIS 2 or 3 injury is still likely to be considered as serious rather than slight. Instead these effectiveness options are more likely to show a benefit if a fatal injury can be reduced to a serious outcome for that occupant. As there are only a few fatally injured occupants in the sample of CCIS cases selected here, these first two 'reasonable' options are likely to be quite conservative on the willingness to pay basis.

Each of these injury reductions are applied to all of the torso injuries excluding the lower abdomen contents. This is because the dummy developments being undertaken within the THORAX Project are not dealing with protection of the abdomen. Therefore, the project outputs will not be expected to lead to safety improvements in this area. It may be that improvements in restraint system technology brought about by the THORAX Project could indeed improve seat-belt lie and reduce abdominal injuries, but this is not certain enough to be included in these benefit estimates.

By offering this suite of potential effectiveness options, it is hoped that the likely range of intervention effectiveness is covered. It is expected that the true effectiveness will fall somewhere in the range of benefit shown for each option.

As mentioned in Section 3.2, each of the tables of expected benefits will be sensitive to the exact number of occupants affected by that intervention. With the uncertainties associated with the estimated number of occupants, as mentioned earlier, one should expect variation in benefits due to errors in the estimation. The likely sensitivity of the results to the known uncertainties is discussed around each set of results. However, it should be borne in mind that variations due to the influence of the number of occupants affected will be large when that number of occupants is so small. This is a limitation of the analysis, which strongly inhibits the confidence with which conclusions can be drawn from this work.

4.1 Willingness to pay

4.1.1 Dummy sensitivity

The following table (Table 4-1) shows the benefits related to the torso injury target group and dummy sensitivity intervention in terms of the UK willingness to pay values. The results are shown based on the number of occupants affected in the sample, and the equivalent casualty numbers when multiplied up to either the national (GB) level or European (EU27) populations.

Table 4-1 Benefit (willingness to pay) of reducing injuries in dummy sensitivity group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-3	0	4	£ 2,251,400
	GB	-7	-32	0	41	£ 17,841,000
	EU27	-141	-517	11	651	£ 335,071,600
Remove all torso injuries	Sample	0	0	0	0	£ -
	GB	-1	-6	8	0	£ 2,702,200
	EU27	-26	-100	128	0	£ 60,830,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400
Reduce AIS of torso injuries by 1	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400

It can be seen that the injuries that form the target for the introduction of a new, more sensitive, dummy thorax cost £ 335 million for the countries in the full EU (i.e. EU-27). In the UK they account for seven fatalities and 32 seriously injured casualties each year; with a cost of almost an estimated £ 18 million.

Despite the value of these injuries, introducing a more sensitive dummy thorax is not expected to bring about any benefit in Great Britain, based on the willingness to pay system of cost estimation for fatal, seriously injured, or slightly injured casualties. This is because, based on the available population and the probability of certain injuries giving a slight, serious, or fatal outcome, the intervention would not be expected to change the overall occupant severity outcome. Where a probability has produced a non-integer value, the benefit has been rounded down to count only integer numbers of occupants.

On the European scale (EU-27) introducing a new dummy thorax would be expected to prevent between zero and 17 fatal injuries to the thorax. With the serious injuries as well, this equates to between £ 0 and £ 26.6 million.

Due to the uncertainties in the number of occupants and their sizes and whether benefits would be seen for drivers on the non-struck side, it was recommended in Section 3.2.1 that the benefits arising from this group should be considered within the range of 50 % to 125 %. This would alter the range of benefit for the EU-27 to be between £ 0 and £ 33.3 million.

4.1.2 Injury risk function

Extending the safety intervention to include older occupants has the result on the estimated benefit as shown in Table D-2. These benefit estimates relate to offset impact accidents, with an estimated impact speed of between 40 and 56 km.h^{-1}, for front seat occupants of approximately mid-size. It assumes no transfer of benefits to other occupant sizes or impact configurations. The total cost, on a willingness to pay basis, for these injuries is £ 750 million. However, the addition of injury risk functions to protect the older occupants doesn't result in any additional reductions in fatal injuries over that estimated for the first intervention (for the improved dummy sensitivity alone). Again, the reduction in fatalities is predicted to be between zero and 17 at the EU-27 level. The range of benefit is expected to be between £ 0 and £ 30.4 million. It should be noted that this benefit includes the affect of improved dummy sensitivity, it is not additive.

It is interesting to note that removing all injuries from the sample results in the prevention of the injuries to two fatal and six seriously injured occupants in this CCIS sample. This is a substantial improvement over the previous (dummy sensitivity) group. It also matches the injury target group (Table 3-5) which showed several severe lung injuries being sustained by older occupants. It is unfortunate then, that this potential group is unlikely to be addressed by moderation of their injuries as estimated for the other mitigation categories below. This may suggest that minor improvements in restraint system designs are unlikely to show a benefit using the willingness to pay model for these particular older occupants. Instead the introduction of advanced restraint system technology would be required to show substantial improvements based on a willingness to pay model.

Table 4-2 Benefit (willingness to pay) of reducing injuries in injury risk function group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-2	-6	0	9	£ 4,502,800
	GB	-19	-53	-6	82	£ 42,107,400
	EU27	-351	-836	-105	1303	£ 750,718,000
Remove all torso injuries	Sample	0	0	0	0	£ -
	GB	-1	-7	0	8	£ 3,008,200
	EU27	-26	-112	9	130	£ 64,837,800
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400
Reduce AIS of torso injuries by 1	Sample	0	0	0	0	£ -
	GB	0	0	-7	8	£ 102,200
	EU27	-17	-1	-110	130	£ 30,419,800

4.1.3 Dummy size

The benefit brought about by the mitigation of the torso injuries sustained by occupants including those who are small and light, is shown in Table 4-3. As predicted earlier in the report, this table is identical to Table 4-1 because no small or light front seat occupants were identified as sustaining their injuries in an offset crash at an ETS of between 40 and 56 km.h^{-1}. However, as noted in Section 3.2.3, there are several occupants in the sample for whom their size and weight is not known. Therefore it could be that this intervention is needed to make some of the improvements already listed in the upper estimate of benefit from the dummy sensitivity target group. On this basis the benefit estimated to be provided through the introduction of testing with a small and light dummy will be between £ 0 and £ 20 million at the EU-27 level.

Table 4-3 Benefit (willingness to pay) of reducing injuries in dummy size (light and small) group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-3	0	4	£ 2,251,400
	GB	-7	-32	0	41	£ 17,841,000
	EU27	-141	-517	11	651	£ 335,071,600
Remove all torso injuries	Sample	0	0	0	0	£ -
	GB	-1	-6	8	0	£ 2,702,200
	EU27	-26	-100	128	0	£ 60,830,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400
Reduce AIS of torso injuries by 1	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400

The benefit expected through the introduction of a tall and large dummy is shown in Table 4-4 as derived using the willingness to pay model. Based on the sample used, three seriously injured occupants could be helped through this intervention. This leads to a range of benefit from £ 83.3 million to £ 153.6 million. However, to deduce the benefit from this measure alone, one must subtract those occupants already included in the dummy sensitivity option. This leads to an increased range from £ 50 million to £ 153.6 million.

Table 4-4 Benefit (willingness to pay) of reducing injuries in dummy size (heavy and large) group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-6	0	7	£ 2,819,000
	GB	-11	-53	0	66	£ 28,549,400
	EU27	-209	-837	10	1042	£ 510,128,600
Remove all torso injuries	Sample	0	-2	2	0	£ 349,200
	GB	-4	-17	22	0	£ 9,630,400
	EU27	-84	-275	362	0	£ 188,184,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	-3	3	0	0	£ 4,483,800
	EU27	-56	58	0	0	£ 83,319,200
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	-4	4	0	0	£ 5,978,400
	EU27	-73	68	7	0	£ 109,949,600
Reduce AIS of torso injuries by 1	Sample	0	-1	1	0	£ 174,600
	GB	-4	-10	15	0	£ 8,408,200
	EU27	-75	-163	241	0	£ 153,606,000

4.1.4 Test method

The benefits expected to arise as a result of modifications to the current frontal impact test procedures are shown in the next three tables.

The specific option of adding a full-width test is represented by the benefits shown in Table 4-5. The total cost of the torso injuries sustained in this group of accidents is over £ 700 million when calculated for the EU-27 level of accident occurrence. When the range of expected benefit is considered, it is hoped that the full-width test could prevent one fatal injury in GB each year. A range of £ 0 to £ 104.9 million is predicted for EU-27 accidents. Taking into account the differences between the CCIS and GIE RE PR sample data, the top of this range may be optimistic for the whole of Europe; wide overlap impacts with an ETS of around 40 to 56 $km.h^{-1}$ may occur less frequently in some European countries when compared with Great Britain. It should be noted that the exact distribution of impact configurations occurring in Europe is difficult to determine when one considers differences in sampling strategies for the in-depth accident data collection and the low number of accident cases investigated with respect to the total number of accidents in Europe.

Table 4-5 Benefit (willingness to pay) of reducing injuries in test method (full width) group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-11	0	13	£ 3,765,000
	GB	-13	-100	1	115	£ 40,794,800
	EU27	-248	-1585	16	1825	£ 717,230,800
Remove all torso injuries	Sample	0	-3	1	2	£ 553,000
	GB	-5	-33	15	24	£ 14,443,600
	EU27	-103	-532	248	391	£ 270,465,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	-1	0	0	0	£ 1,683,800
	EU27	-26	15	11	0	£ 40,780,200
Reduce AIS of torso injuries by 1	Sample	0	-2	2	0	£ 349,200
	GB	-1	-21	22	0	£ 5,335,800
	EU27	-28	-333	361	0	£ 104,879,400

The value of torso injuries resulting from small overlap collisions is shown in Table 4-6. The willingness to pay values derived for this option are lower than for the full-width test option. The range of benefit for the EU-27 level of collisions is therefore predicted to be in the range from £ 0 to £ 40.8 million.

The French data from GIE RE PR showed a greater importance of small overlap loading to the frontal structures in crashes causing torso injuries than indicated by the CCIS data. From this it can be inferred that in the European accident population the maximum potential benefit associated with the addition of a small overlap test may be closer to the potential associated with adding a full-width test, than is presented based on data from Great Britain alone. However, it is still assumed that wide overlap accidents cause torso injuries to more occupants than small overlap accidents at the 40 to 56 km^{-1} impact severity. Therefore, the assertion that the benefit associated with mitigating torso injuries in wide overlap crashes is likely to be greater than the benefit associated with injuries in small overlap crashes should still be appropriate for Europe, though it is expected that both crash configurations are important in the causation of torso injuries in frontal impact accidents. The exact balance of importance between wide and small overlap configurations cannot be determined conclusively based on the two data samples considered here because of differences in the sampling strategies and lack of information to determine how these accident samples relate to the full accident scenario throughout Europe.

Table 4-6 Benefit (willingness to pay) of reducing injuries in test method (small overlap) group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-4	0	5	£ 2,440,600
	GB	-8	-40	0	49	£ 21,038,400
	EU27	-151	-639	13	782	£ 374,962,800
Remove all torso injuries	Sample	0	-1	1	0	£ 174,600
	GB	-1	-13	15	0	£ 3,924,400
	EU27	-36	-211	248	0	£ 96,917,200
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	-1	0	0	0	£ 1,683,800
	EU27	-26	15	11	0	£ 40,780,200
Reduce AIS of torso injuries by 1	Sample	0	0	0	0	£ -
	GB	-1	0	0	0	£ 1,683,800
	EU27	-26	15	11	0	£ 40,780,200

Finally, the benefit expected with extension of the frontal impact tests to account for lower speed collisions is shown in Table 4-7. This accounts for the largest group of seriously injured occupants in the estimates presented in this section. As a result the upper boundary of the predicted benefit is the largest of any of these individual options. The range suggests benefits between £ 0 and £ 247.4 million for the crashes in the EU-27.

Again it should be noted that due to differences in the sample composition, the GIE RE PR data showed fewer torso injury causing crashes with low impact speeds than the CCIS sample. As a result it must be noted that, the finding that this option gives the greatest maximum potential benefit of any of the individual options, based on data from Great Britain, may not hold true for Europe as a whole. However, it has been shown (for instance; Carroll, 2009) that torso injuries can be sustained at severities lower than those of the current regulatory impact test, particularly when considering older occupants who have a greater risk of torso injuries in frontal impacts than younger occupants. Therefore, it is still expected that accidents with an impact severity below that of the current regulatory test are a priority for torso injury mitigation.

Table 4-7 Benefit (willingness to pay) of reducing injuries in test speed group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-16	0	17	£ 4,711,000
	GB	-9	-137	0	148	£ 41,074,600
	EU27	-178	-2165	2	2346	£ 709,305,200
Remove all torso injuries	Sample	0	-8	6	2	£ 1,426,000
	GB	-2	-74	52	24	£ 16,609,200
	EU27	-50	-1171	832	391	£ 293,596,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -
Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	-1	1	0	0	£ 1,494,600
	EU27	-34	20	15	0	£ 53,246,200
Reduce AIS of torso injuries by 1	Sample	0	-7	7	0	£ 1,222,200
	GB	-2	-65	67	0	£ 14,687,400
	EU27	-41	-1025	1067	0	£ 247,387,600

4.1.5 Alternative groups

It is acknowledged that if any of the options presented above were to be implemented by regulators, it may make more sense to consider adopting more than one option at a time. This may reduce the number of regulatory changes required to implement the options, and offer a chance to maximise the effectiveness of the options. To demonstrate such potential for the options to work in harmony or in a complementary way, some combined options, or alternative groupings were developed. Six of these were considered based on the different options already described. These were:

1. Full width and dummy sensitivity
   a. This option describes the benefit expected if a new full-width test was introduced which made use of the improved dummy sensitivity offered by the THORAX Project hardware. It therefore represents a different way of considering two of the options described already. When reporting the dummy sensitivity option only offset crashes were considered. Then in the original full-width option, use of the new dummy thorax was assumed for both offset and full-width tests. This new alterative considers use of the new hardware in the full-width test only, with the offset tests staying as they are.
   b. The willingness to pay benefit for this alternative option is presented in Table 4-8. Based on the maximum estimate of the potential benefit associated with this option, then it exceeds that of the original dummy sensitivity target group. This supports the notion that full-width accidents account for more torso injuries than offset accidents. This was identified in the COVER accident analysis (Carroll, 2009) and is also supported by the French data from the GIE RE PR database.

Table 4-8 Benefit (willingness to pay) of reducing injuries in full width and dummy sensitivity group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	0	-7	0	8	£ 1,324,400
	GB	-5	-67	0	74	£ 21,095,400
	EU27	-107	-1068	5	1173	£ 382,159,200
Remove all torso injuries	Sample	0	-3	0	2	£ 567,600
	GB	-4	-27	7	24	£ 11,741,400
	EU27	-77	-431	119	391	£ 209,460,400
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -

Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-8	5	3	0	£ 12,480,600
Reduce AIS of torso injuries by 1	Sample	0	-2	2	0	£ 349,200
	GB	0	-21	22	0	£ 3,652,000
	EU27	-10	-343	354	0	£ 76,565,200

2. Full-width, injury risks, and small passengers
    a. The second alternative combination of options again relates to making changes to the current situation through the introduction of a full-width test. However, in the new test this option would also include the use of new injury risk functions set to protect older occupants. Also the passenger used in the test would be a small female.
    b. The benefits associated with this alternative are shown in Table 4-9. Of the total injury target of almost £ 500 million, the estimated effectiveness would account for a benefit range from £ 0 to £ 135 million. This maximum value is larger than the first alternative option, which indicates the worth of considering older occupants, and smaller passengers if a full-width test procedure was to be introduced.

Table 4-9 Benefit (willingness to pay) of reducing injuries in full width and dummy sensitivity and light and small and older group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	0	-11	0	12	£ 2,081,200
	GB	-6	-99	0	107	£ 28,833,600
	EU27	-119	-1575	2	1694	£ 498,333,000
Remove all torso injuries	Sample	0	-5	2	3	£ 916,800
	GB	-4	-49	22	33	£ 15,684,800
	EU27	-88	-787	356	521	£ 291,877,200
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -

Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400
Reduce AIS of torso injuries by 1	Sample	0	-4	4	0	£ 698,400
	GB	-1	-36	37	0	£ 7,954,800
	EU27	-21	-570	592	0	£ 134,560,600

3. Offset, injury risks, small passenger
    a. The third of the alternative options relates to the offset tests rather than a full-width test procedure. This is intended to show the value of implementing similar changes in the offset test as have been described for the full-width test. It is an accompaniment to the previous option where injury risks relating to the tolerance of older occupants are used as well as the incorporation of a small dummy in the front passenger seat position.
    b. The benefits associated with this option are shown in Table 4-10. From the value put on all the torso injuries in the target group, it can be seen that this option should address more torso injuries than the full-width equivalent. However, when considering the benefit estimates, there is not expected to be any significant difference between the occupants moved to a lower overall injury severity with either this option or the previous option.

Table 4-10 Benefit (willingness to pay) of reducing injuries in offset and dummy sensitivity and light and small and older group

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-2	-6	0	8	£ 4,502,800
	GB	-19	-52	0	74	£ 41,830,600
	EU27	-351	-824	12	1173	£ 746,739,400
Remove all torso injuries	Sample	0	0	0	0	£ -
	GB	-1	-6	8	0	£ 2,702,200
	EU27	-26	-100	128	0	£ 60,830,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	0	0	0	0	£ -

Reduce AIS 3+ torso injuries to AIS 2	Sample	0	0	0	0	£ -
	GB	0	0	0	0	£ -
	EU27	-17	10	7	0	£ 26,630,400
Reduce AIS of torso injuries by 1	Sample	0	-4	4	0	£ 698,400
	GB	-1	-36	37	0	£ 7,954,800
	EU27	-21	-570	592	0	£ 134,560,600

4. Offset, low-speed and injury risks
    a. This option describes the benefit expected from a conventional offset test but at a lower speed. In addition it includes the assumption that injury risk functions are chosen to protect older occupants.
    b. The willingness to pay benefit for this alternative option is presented in Table 4-11. Based on the total value of the torso injuries associated with this option, then it is clear that this target group is the largest considered so far. The torso injuries account for over 80 percent of the total injury value, which is a larger proportion than observed with other options shown above. This supports some of the trends reported by Carroll (2009) that torso injuries tend to be prevalent for older occupants and occur frequently in impacts with a severity lower than that of existing test procedures. Therefore to gain the most from the introduction of a low-speed offset test, it would seem important to set injury criteria at levels appropriate for the protection of older occupants.
    c. Whilst low-speed collisions were responsible for a smaller proportion of the occupants sustaining torso injuries in the GIE RE PR sample data than in the CCIS sample, the combination of offset configuration, lower impact severity than currently tested, and protection of older occupants in this configuration would still be expected to produce a substantial target group for injury mitigation. However, it is less clear whether (if the French data could be scaled to represent the national scenario) this option would yield greater expected maximum benefit than other options, as was the case with the data scaled from Great Britain.

Table 4-11 Benefit (willingness to pay) of reducing injuries for older occupants in low speed offset impacts

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-1	-13	0	14	£ 4,143,400
	GB	-10	-111	0	124	£ 37,839,200
	EU27	-189	-1749	-11	1955	£ 649,309,600

Remove all torso injuries	Sample	-1	-9	6	3	£ 3,299,000
	GB	-10	-80	59	33	£ 31,112,600
	EU27	-186	-1271	940	522	£ 539,936,000
Reduce AIS 4+ torso injuries to AIS 3	Sample	-1	1	0	0	£ 1,494,600
	GB	-8	9	0	0	£ 11,767,600
	EU27	-151	155	0	0	£ 224,927,800
Reduce AIS 3+ torso injuries to AIS 2	Sample	-1	1	0	0	£ 1,494,600
	GB	-9	10	0	0	£ 13,262,200
	EU27	-177	170	11	0	£ 265,708,000
Reduce AIS of torso injuries by 1	Sample	0	-8	9	0	£ 1,382,200
	GB	-6	-74	81	0	£ 22,921,000
	EU27	-111	-1176	1289	0	£ 390,581,600

5. Full-width, low-speed and injury risks
    a. This option is the same as the previous alternative option, except for the fact that it considers the benefit expected from a full-width test at a lower speed, instead of an offset test.
    b. The willingness to pay benefit for this alternative option is presented in Table 4-12. Based on the total value of the torso injuries associated with this option, then it is even larger than the previous offset option. Again, the torso injuries account for a large proportion of the total injury value. This reinforces the early suggestion that accidents with large levels of overlap are important in the incidence of torso injuries.
    c. The fact that this option presents a larger target group than the previous option encourages the observation that a low-speed full-width test may be more important in the mitigation of torso injuries than a low-speed offset test, when protection is specifically targeting the older occupants.
    d. Based on differences between the French accident data from GIE RE PR and the GB data from the CCIS, it is not clear exactly how this ranking of full-width and offset tests would be continued for the whole of Europe. Therefore, care needs to be taken when extrapolating the results to the European region. However, the results shown here are still useful in identifying wider trends such as the need to consider lower severity impacts than the current regulatory test and to protect the older occupants.

Table 4-12 Benefit (willingness to pay) of reducing injuries for older occupants in low speed full width impacts

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-2	-19	0	21	£ 6,962,400
	GB	-16	-162	0	182	£ 57,591,200
	EU27	-294	-2561	-3	2867	£ 979,622,200
Remove all torso injuries	Sample	-1	-12	5	8	£ 3,881,200
	GB	-13	-102	44	74	£ 40,545,400
	EU27	-253	-1615	703	1173	£ 721,295,600
Reduce AIS 4+ torso injuries to AIS 3	Sample	-1	1	0	0	£ 1,494,600
	GB	-8	9	0	0	£ 11,767,600
	EU27	-151	155	0	0	£ 224,927,800
Reduce AIS 3+ torso injuries to AIS 2	Sample	-1	1	0	0	£ 1,494,600
	GB	-9	10	0	0	£ 13,262,200
	EU27	-177	170	11	0	£ 265,708,000
Reduce AIS of torso injuries by 1	Sample	0	-10	11	0	£ 1,731,400
	GB	-6	-89	96	0	£ 25,540,000
	EU27	-121	-1403	1527	0	£ 446,893,200

6. Full-width, all speeds and injury risks (all occupants)
    a. This option represents the total target group for the introduction of a full-width test with mid-sized dummies. It considers all ages of occupants and all accident speeds.
    b. The willingness to pay benefit for this alternative option is presented in Table 4-13. The total benefit associated with the removal of these torso injuries is almost £ 1.3 billion per annum, for the countries in the EU-27. More realistically, it is expected that the availability of injury risk functions which can protect the older occupants as well as younger ones, applied in a full-width test could bring a benefit for the EU-27 of between £ 300 million and £ 800 million.
    c. Again care must be taken using these results for the EU-27 when differences in the importance of wide overlap crash configurations have been shown between the GIE RE PR and CCIS data. However, regardless of the dataset

used, it is expected that this combination of options would produce a large target group and hence a large expected maximum benefit estimate.

Table 4-13 Benefit (willingness to pay) of reducing injuries for occupants of all ages in full width impacts from 0-56 $km.h^{-1}$

Reduction model	Population	Change in number of casualties				Benefit
		Fatal	Serious	Slight	Non-injury	
Remove all injuries	Sample	-4	-41	0	45	£ 14,492,400
	GB	-31	-351	0	388	£ 118,607,000
	EU27	-571	-5536	-3	6126	£ 2,008,904,800
Remove all torso injuries	Sample	-3	-23	11	15	£ 9,242,400
	GB	-23	-202	97	132	£ 75,529,600
	EU27	-421	-3182	1529	2086	£ 1,288,590,800
Reduce AIS 4+ torso injuries to AIS 3	Sample	-1	1	0	0	£ 1,494,600
	GB	-11	13	0	0	£ 16,062,200
	EU27	-207	213	0	0	£ 308,247,000
Reduce AIS 3+ torso injuries to AIS 2	Sample	-2	1	0	0	£ 3,178,400
	GB	-14	15	1	0	£ 20,720,600
	EU27	-268	249	26	0	£ 403,768,000
Reduce AIS of torso injuries by 1	Sample	-1	-18	20	0	£ 4,797,400
	GB	-11	-158	171	0	£ 45,918,800
	EU27	-211	-2491	2707	1	£ 787,056,800

4.2 Societal costs

The following table shows the benefits related to the torso injury target group and dummy sensitivity intervention in terms of the societal costs, as estimated by Miller *et al.* (2001). These costs have been converted from 1999 US dollars to 2010 British pounds, using the US inflation rate from January 1999 – April 2010 (InflationData.com, 2010), and the currency exchange rate for 2nd June 2010 (International Monetary Fund, 2010). It must be noted that this conversion is subject to several limitations, for example: medical costs are generally more expensive in the US than in GB (and Europe) because private healthcare costs are higher in the US. Also, in the Miller *et al.* paper the costs are broken down by medical costs, wages, insurance costs, etc. Each of these aspects may be more or less costly in GB, but by varying amounts. It was not possible to account for these variations in this analysis because costs showing individual items (at this level) are not available publicly for European countries.

Again, the same four options are shown in terms of the injury reduction effectiveness for each intervention. These start with the total value assigned to the torso injuries in that target group. This gives a value for the complete removal of all torso injuries. Then, either the reduction of AIS ≥ 4 injuries to AIS 3, or AIS ≥ 3 to AIS 2, and lastly, the reduction of an AIS level for all torso injuries.

4.2.1 Dummy sensitivity

The benefits for the dummy sensitivity target group are shown in Table 4-14 using the Miller *et al.* (2001) crash costs. This method of injury calculation suggests that the total cost of these injuries is almost £ 15 million (€ 18.5 million) for GB each year and over £ 250 million (€ 308.5 million) for the EU-27. These are smaller values than derived from the willingness to pay estimates, which reflects the differences in the methods used to derive the costs. Again it should be noted that the cost of healthcare, and other constituent costs, might differ significantly between the US and European countries. Therefore the Miller *et al.* costs can only be used as indicative of the European societal costs.

Another difference between the two cost methods is shown when considering the effects of reducing the AIS ≥ 4 injuries to be AIS 3 injuries. With the willingness to pay approach it was not possible to demonstrate any benefit of such effectiveness, whereas the Miller *et al.* costs show a non-zero benefit of over £ 2 million (€ 2.5 million) at the national, GB, level of accidents.

Factoring in the uncertainties with the occupant sizes and weights, the range of benefits associated with the improvement in dummy sensitivity is between £ 21.4 million (€ 26 million) and £ 151.6 million (€ 187 million) for the EU-27.

Table 4-14 Benefit (Miller *et al.*, 2001) of reducing injuries in dummy sensitivity group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£14,847,461 €18,321,151	£250,846,968 €309,534,758
Reduce AIS 4+ torso injuries to AIS 3	£2,354,388 €2,905,217	£42,788,357 €52,799,058
Reduce AIS 3+ torso injuries to AIS 2	£4,378,552 €5,402,952	£76,295,405 €94,145,366
Reduce AIS of torso injuries by 1	£7,236,560 €8,929,615	£121,305,150 €149,685,526

4.2.2 Injury risk function

The total cost of the injuries in the target group, when extended to include older occupants is shown in Table 4-15. The total cost of this group of torso injuries is £ 586 million (€ 723 million) for the EU-27, if the Miller *et al.* (2001) costs are used. The benefit estimates using the Miller *et al.* costs for the different levels of effectiveness are much larger than was calculated using the willingness to pay values. This reflects the numerous injuries picked out with this target group. However, the difference between the two methods raises the concern that mitigation of the torso injuries alone may not be sufficient to substantially improve the overall injury outcome for the older occupants.

Table 4-15 Benefit of reducing injuries in injury risk function group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£34,501,081 €42,572,904	£585,924,652 €723,006,728
Reduce AIS 4+ torso injuries to AIS 3	£6,010,507 €7,416,716	£102,000,966 €125,864,963
Reduce AIS 3+ torso injuries to AIS 2	£15,090,441 €18,620,979	£262,567,015 €323,996,810
Reduce AIS of torso injuries by 1	£21,723,259 €26,805,601	£368,497,287 €454,710,374

4.2.3 Dummy size

The benefit brought about by the mitigation of the torso injuries sustained by occupants including those who are small and light, is shown in Table 4-16. No small or light front seat occupants were identified as sustaining their injuries in an offset crash at an ETS of between 40 and 56 km.h^{-1}. However, due to the uncertainties in height and weight for occupants where their information wasn't available, the benefit estimated to be provided through the introduction of testing with a small and light dummy will be between £ 0 and £ 91 million (€ 112 million) at the EU-27 level.

Table 4-16 Benefit of reducing injuries in dummy size – light and small group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£14,847,461 €18,321,151	£250,846,968 €309,534,758
Reduce AIS 4+ torso injuries to AIS 3	£2,354,388 €2,905,217	£42,788,357 €52,799,058
Reduce AIS 3+ torso injuries to AIS 2	£4,378,552 €5,402,952	£76,295,405 €94,145,366
Reduce AIS of torso injuries by 1	£7,236,560 €8,929,615	£121,305,150 €149,685,526

The benefit expected through the introduction of a tall and large dummy is shown in

Table 4-17 as derived using the Miller *et al.* (2001) costs. Accounting for the fact that some of these occupants may already have been counted in the dummy sensitivity target group, then the range of benefits for the EU-27 is from £ 0 to £ 149.1 million (€ 184 million).

Table 4-17 Benefit of reducing injuries in dummy size – heavy and large group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£17,963,798 €22,166,582	£299,933,820 €370,105,898
Reduce AIS 4+ torso injuries to AIS 3	£3,150,037 €3,887,015	£55,320,983 €68,263,799
Reduce AIS 3+ torso injuries to AIS 2	£5,453,330 €6,729,183	£93,224,721 €115,035,441
Reduce AIS of torso injuries by 1	£9,002,335 €11,108,508	£149,118,684 €184,006,273

4.2.4 Test Procedure

The Miller *et al.* (2001) benefits for the test procedure options are shown in the following three tables. As with the willingness to pay estimates, the largest benefit is expected with an intervention which could protect against torso injuries in low speed accidents (Table 4-20). The smallest benefit, of these test procedure options is associated with those injuries sustained in small overlap accidents (Table 4-19). Although again, there is a substantial value which can be attributed to the injuries brought about by small overlap crashes.

It is worth noting that the minimum estimate, which comes from reducing only the AIS ≥ 4 torso injuries to the AIS 3 level, is equivalent for each of these procedural interventions. It matched that of the dummy sensitivity target group. This suggests that the actual benefit of making changes to the test procedure could be zero depending on whether it is also associated with the implementation of a dummy with improved sensitivity. In which case, the addition of another test type could be ineffective.

Table 4-18 Benefit of reducing injuries in test method – full width group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£24,189,241 €29,848,520	£397,993,630 €491,107,638
Reduce AIS 4+ torso injuries to AIS 3	£2,354,388 €2,905,217	£42,788,357 €52,799,058
Reduce AIS 3+ torso injuries to AIS 2	£5,066,799 €6,252,220	£87,136,305 €107,522,588
Reduce AIS of torso injuries by 1	£12,190,940 €15,043,115	£199,343,858 €245,982,056

Table 4-19 Benefit of reducing injuries in test method – small overlap group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£17,749,158 €21,901,725	£296,552,921 €365,934,009
Reduce AIS 4+ torso injuries to AIS 3	£2,354,388 €2,905,217	£42,788,357 €52,799,058
Reduce AIS 3+ torso injuries to AIS 2	£4,657,681 €5,747,385	£80,692,094 €99,570,698
Reduce AIS of torso injuries by 1	£9,367,930 €11,559,637	£154,877,345 €191,112,222

Table 4-20 Benefit of reducing injuries in test method – test speed

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£30,079,594 €37,116,972	£490,775,295 €605,596,366
Reduce AIS 4+ torso injuries to AIS 3	£2,354,388 €2,905,217	£42,788,357 €52,799,058
Reduce AIS 3+ torso injuries to AIS 2	£4,936,810 €6,091,819	£85,088,783 €104,996,030
Reduce AIS of torso injuries by 1	£20,344,267 €25,103,982	£327,770,672 €404,455,420

4.2.5 Alternative groups

As presented in Section 4.1.5, the same six alternative implementation options were considered here again using the Miller *et al.* (2001) costs structure. The following six tables show the benefits for the six alternative options on this basis.

With the Miller *et al.* costs it becomes apparent that the changes to use injury risk functions representing older occupants and a smaller front seat passenger are more influential for the offset test than the full-width at current test severities. This difference was not discernible on the basis of the willingness to pay benefit estimates. Here it seems that changes to the offset test could be more important than the full-width test. This effect is not seen with the low-speed, older occupant groups, where the full-width option has a slightly larger overall benefit than the offset test. However, care should be taken with this interpretation because these target groups assume no interaction between the different test and accident classifications. In reality it is expected that safety advances brought about in offset tests would give some benefit in full-width crashes and *vice versa*. The extent of those cross-group benefits may alter the balance of importance put on either a change to the offset procedure or the introduction of a full-width test.

Table 4-21 Benefit of reducing injuries in full width and dummy sensitivity group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£9,341,779 €11,527,368	£147,146,661 €181,572,879
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£688,247 €849,268	£10,840,900 €13,377,221
Reduce AIS of torso injuries by 1	£4,954,379 €6,113,498	£78,038,709 €96,296,531

Table 4-22 Benefit of reducing injuries in full width and dummy sensitivity and light and small and older group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£21,284,341 €26,263,994	£335,259,446 €413,696,256
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£8,177,793 €10,091,058	£128,812,176 €158,948,885
Reduce AIS of torso injuries by 1	£14,828,090 €18,297,248	£233,564,060 €288,208,366

Table 4-23 Benefit of reducing injuries in offset and dummy sensitivity and light and small and older group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£34,350,528 €42,387,127	£583,553,216 €720,080,474
Reduce AIS 4+ torso injuries to AIS 3	£6,010,507 €7,416,716	£102,000,966 €125,864,963
Reduce AIS 3+ torso injuries to AIS 2	£15,090,441 €18,620,979	£262,567,015 €323,996,810
Reduce AIS of torso injuries by 1	£21,572,706 €26,619,825	£366,125,852 €451,784,121

Table 4-24 Benefit of reducing injuries of older people in low speed offset impacts

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£16,490,139 €20,348,148	£274,311,907 €338,489,520
Reduce AIS 4+ torso injuries to AIS 3	£3,745,817 €4,622,183	£66,148,621 €81,624,656
Reduce AIS 3+ torso injuries to AIS 2	£4,636,905 €5,721,749	£81,171,456 €100,162,211
Reduce AIS of torso injuries by 1	£11,326,525 €13,976,462	£187,728,923 €231,649,708

Table 4-25 Benefit of reducing injuries of older people in low speed full width impacts

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£31,985,876 €39,469,245	£512,851,994 €632,838,097
Reduce AIS 4+ torso injuries to AIS 3	£3,465,418 €4,276,182	£56,208,799 €69,359,327
Reduce AIS 3+ torso injuries to AIS 2	£5,193,894 €6,409,050	£84,421,701 €104,172,879
Reduce AIS of torso injuries by 1	£19,740,027 €24,358,375	£316,754,226 €390,861,582

Table 4-26 Benefit of reducing injuries of all ages in full width impacts from 0-56 kph

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£69,604,707 €85,889,323	£1,105,403,483 €1,364,022,067
Reduce AIS 4+ torso injuries to AIS 3	£4,261,067 €5,257,980	£68,741,426 €84,824,070
Reduce AIS 3+ torso injuries to AIS 2	£15,209,281 €18,767,622	£242,178,677 €298,838,446
Reduce AIS of torso injuries by 1	£47,338,131 €58,413,291	£751,464,658 €927,276,231

4.3 Relative injury severity

For some occupants, the torso injury or injuries they sustain may not be the most critical in terms of their accident outcome. In these cases, improvements to the thoracic protection may offer no significant advantage in terms of mitigating the accident severity for that occupant. However, it is expected that in the majority of cases improvements to the thoracic protection would offer an improvement in the general accident severity for that occupant and the ensuing sequelae. To separate these two classes of occupants, those with an injury to another body region of dominating importance and those where the thoracic injury mitigation would be important, the torso and overall body MAIS were compared. Occupants for whom the torso injury was the most severe (on the basis of the body region MAIS) are segregated to show their key importance, in terms of torso injury mitigation. Equivalent tables to those shown in sections 4.1 and 4.2 were complied for those occupants whose torso injuries were the most severe.

It was found that considering only the occupants whose torso injuries were the most severe (or were equally severe as any other injury) made no difference to the costs estimated using the willingness to pay structure. However, when the costs were entered based on those provided by Miller *et al.* (2001), there was a reduction in the total benefit estimates when considering occupants with the torso injuries being the most severe. The tables demonstrating this are provided in Appendix D. The headline values from those tables are reproduced in the following summary.

5 Discussion and summary

Many tables were presented in the previous section to describe the range of benefits expected with each suggested safety intervention that may come as a result of the THORAX project outputs. These are summarised in the following table (Table 5-1) for the individual interventions.

It is interesting to observe that each of the potential safety improvements, except accounting for tall or heavy occupants, has a range of benefits which includes £ 0, when considering the willingness to pay cost estimate. This suggests that the interventions, based on the assumed effectiveness estimates, may not be dramatic enough to move people from one overall severity level to the next severity level down (from fatal to serious, serious to slight, or from slight to uninjured). In contrast, when the Miller *et al.* costs are apportioned to the injuries, then only the dummy size options have an estimated benefit range which includes zero (for all occupants). However, when the occupants considered are reduced to only those where the torso injuries they sustained were more severe, or at least as severe, as any other injury, then even the Miller *et al.* benefit estimates include £ 0 as the minimum.

From the sample analysed for this study and the benefit estimates made above, it has been shown that the work of the THORAX Project in developing a dummy torso will give a benefit somewhere between £ 0 and £ 33 million (€ 41 million) on a willingness to pay basis, related to the frequency of accidents observed in the EU-27 countries. This assumes that the new test tool has demonstrably better sensitivity to modern restraint systems and is able to discern differences between adequate and improved restraints. It also assumes that the dummy is adopted for use in the current frontal impact test procedures to replace the Hybrid III.

Through the adoption of injury risk functions targeted to match the tolerance of older occupants it may be possible to protect a broader target group than is currently the case. Up to a further £ 30 million (€ 37 million) of benefit could be obtained through the injury risk function work expected to be carried out within the THORAX Project. However, this is dependent on the injury criterion selected for use with the dummy in the test procedures, and the balance of improvements that may already be obtained simply through the use of the new hardware. These two points blur the division between the first two intervention options that have been considered, so that absolute values for each are very difficult to define.

When considering occupant size for the CCIS sample that was used in this analysis, the low reporting rate of stature and mass created large uncertainties in the benefit that may be associated with protection for smaller or larger occupants. However, it is expected that extending protection for different occupant sizes, and preventing optimisation for a mid-sized occupant will give some benefit. In the COVER analysis of frontal impact accidents (Carroll, 2009), it was suggested that small female occupants, particularly in the front seat passenger position were at an increased risk of sustaining a torso injury. This was largely based on the analysis of the BASt sample of GIDAS cases, which contained a larger proportion of minor injuries than the CCIS sample. However, the trend was also present in the CCIS sample, though again the low level of reporting of stature and mass in the CCIS precluded any statistical significance from being shown with that trend.

On the balance of benefits shown in the report above, it is expected that providing additional protection for larger occupants will generate greater benefit than for smaller occupants. This finding reflects both the exposure and risk of torso injury for these groups of occupants. Small occupants may be at a greater risk of sustaining a torso injury, but larger occupants are involved in frontal impact accidents more frequently. Assuming this to be the case, then this latter point seems to dominate the results observed here. Again it must be noted that the sample sizes considered in this study were small, particularly when considering the occupants with a defined stature and mass. Therefore care should be taken when using these results to define future research directions and test specifications. Some corroboration of the results is needed to increase confidence in the findings.

Table 5-1 Summary of benefit estimates for individual interventions (EU-27 frequency of accident occurrence)

Intervention option	Estimate basis	Thorax severity	Minimum (million)	Maximum (million)
Dummy sensitivity	Willingness to pay	All occupants	£ 0	£ 33 (€ 41)
	Miller *et al.* (2001)	All occupants	£ 21 (€ 26)	£ 152 (€188)
		Torso most severely injured	£ 0	£ 76 (€ 94
Injury risk functions (+ dummy sensitivity)	Willingness to pay	All occupants	£ 0	£ 30 (€ 37)
	Miller *et al.* (2001)	All occupants	£ 102 (€ 126)	£ 368 (€ 454)
		Torso most severely injured	£ 0	£ 63 (€ 78)
Dummy size – small/light (+ dummy sensitivity)	Willingness to pay	All occupants	£ 0	£ 20 (€ 25)
	Miller *et al.* (2001)	All occupants	£ 0	£ 91 (€ 113)
		Torso most severely injured	£ 0	£ 46 (€ 57)
Dummy size – tall/heavy (+ dummy sensitivity)	Willingness to pay	All occupants	£ 50 (€ 62)	£ 154 (€ 190)
	Miller *et al.* (2001)	All occupants	£ 0	£ 149 (€ 184)
		Torso most severely injured	£ 0	£ 89 (€ 110)
Test procedure – full-width	Willingness to pay	All occupants	£ 0	£ 105 (€ 130)
	Miller *et al.* (2001)	All occupants	£ 43 (€ 53)	£ 199 (€ 246)
		Torso most severely injured	£ 0	£ 95 (€ 117)
Test procedure – small overlap	Willingness to pay	All occupants	£ 0	£ 41 (€ 51)
	Miller *et al.* (2001)	All occupants	£ 43 (€ 53)	£ 155 (€ 191)
		Torso most severely injured	£ 0	£ 94 (€ 116)
Test procedure – test speed	Willingness to pay	All occupants	£ 0	£ 247 (€ 305)
	Miller *et al.* (2001)	All occupants	£ 43 (€ 53)	£ 328 (€ 405)
		Torso most severely injured	£ 0	£ 242 (€ 299)

Looking at the different options for incorporating a new test procedure, it becomes apparent that each of the three options has a minimum estimated benefit that is £ 0. However, when considering the potential maximum benefit estimated on the basis of the cases reviewed here, then accounting for accidents which occur at test speeds lower than the current frontal impact tests seems to give the largest potential based on the ETS data from the CCIS. The French EES data from GIE RE PR puts a greater importance on crash configurations with an impact severity around that of the current regulatory test than the data from the CCIS. It may be that inventive definition of a complimentary test procedure allows inclusion of improved full-width or small overlap protection as well. Clearly this would enhance the benefit offered by the option of adding another test procedure to those which are already established.

Options for implementing a full-width test procedure alongside the existing offset tests were considered in addition to the specific intervention options presented above. These demonstrated that a new full-width test which made use of the THORAX project outputs could be beneficial up to the value of about £ 77 million (€ 95 million) extrapolating the CCIS data to accident figures for the EU-27. Tailoring the injury risk functions and criteria used in conjunction with the dummies to increase the level of protection offered to older occupants would add value to such an implementation option; as would setting the test speed to account for accidents which occur at lower severities than the existing offset test procedures. The value of reducing torso injuries for occupants of all ages in full width impacts from 0 to 56 $km.h^{-1}$ was estimated to be up to £ 1.3 billion (€ 1,604 million), for the EU-27 countries annually, again based on the CCIS data. There was some indication that incorporating a smaller dummy on the passenger seat for any change in test procedures would also be beneficial, though this was difficult to confirm based on the sample of accident cases analysed.

Options were also considered for the use of either the offset test or full-width tests, at a reduced impact speed, to protect older occupants. Both of these scenarios provided substantial target groups; larger than the options considered previously and consisting of a higher proportion (as many as 80 %) of torso injuries in the overall composition of body regions injured. Targeting protection for older occupants in accidents at lower impact severities than current test speeds seems to be a priority on the basis of this analysis, particularly so on the basis of the CCIS data from Great Britain. However, on the basis of these data, it was not clear whether a low speed offset or low speed full-width test, or even perhaps a small overlap test, would provide the most benefit.

It should be remembered that the casualty cost values used in this benefit analysis were not derived for the European population specifically. Therefore, the exact values produced in the analysis may not be perfectly representative of the costs for Europe. This is a limitation of the study and hence further care should be taken when interpreting the precise values presented in this report.

In the original selection criteria for the sample used in this THORAX Project work and the previous COVER Project analysis, several requirements were implemented to pick out occupants for which THORAX Project interventions could help to mitigate torso injuries. For instance, the car had only one significant frontal impact, without rolling over; the occupant was wearing a seat belt, was 12 years old or over, and had a known injury severity. Through adopting these criteria we have potentially ruled out other occupants for whom some benefit may be transferable. An example would be occupants with an unknown age. Based on uncertainties over the likelihood of benefit being passed to the excluded cases, no effort has been made to reintroduce these occupants. In this way the estimations and assumptions used in the analysis have been kept to a minimal level. However, it can be noted that there is potential for the benefit presented here to be an underestimate of the total benefit if other, less stringent, selection criteria were used.

6 Risk Register

Risk No.	What is the risk	Level of risk[2]	Solutions to overcome the risk
1	As noted in the benefit estimate section, the estimated benefit is subjective to a certain extent. As such it may be open to criticism	2	Involve other THORAX Project partners to reach an expert consensus. Review this estimate following test work with the THORAX dummy in Work Package 4 of the Project.
2	The benefit for each intervention is based on the injury mitigation possible for a small number of occupants in the CCIS sample then multiplied to national and international levels. The small number of original cases makes the results very susceptible to case-to-case variations and gives a wide range in the levels of benefit being predicted.	1	Care must be taken when interpreting and using the results derived in this work task.

[2] Risk level: 1 = high risk, 2 = medium risk, 3 = Low risk

7 Conclusions

Accident data from the UK (CCIS) provided information on 320 occupants who were Killed or Seriously Injured and who sustained a torso injury of at least AIS 2 (or an AIS 1 rib fracture). This information was used to estimate the potential benefit expected if outputs from the THORAX Project were used in future frontal impact testing. Supporting data for 158 similar occupants from the French GIE RE PR database were used to assess the validity of extrapolating the CCIS data to the European level. The benefit is associated with mitigation of torso injuries and therefore a reduction in the overall seriousness of the accident for each particular occupant influenced by the intervention.

A more sensitive dummy thorax that is capable of supporting a drive towards advanced restraint systems offering protection for the torso was estimated as offering the potential benefit of up to £ 33 million (€ 41 million) based on a willingness to pay. Alternatively, using the societal costs of injuries from Miller *et al.* (2001) the potential benefit was as large as £ 76 million (€ 94 million) (for the EU-27 countries).

A new injury risk function to represent ages of the occupant population having a lower tolerance to torso loading could also be beneficial if protection is improved for older occupants. Depending on the overlap with improvements brought about through the use of a new dummy torso, this could lead to an estimated benefit of as much as £ 30 million (€ 37 million) (willingness to pay, for the EU-27 countries).

The influence of using a dummy that represents occupants who are either smaller or larger than the mid-sized male was difficult to determine because of small sample sizes and a lack of reporting of stature and mass information. Indications are that the use of a larger than average size dummy could lead to the greatest benefit, of up to £ 154 million (€ 190 million) (willingness to pay). The benefits for small occupants were not as large, which may reflect the comparative exposure of larger and smaller occupants in frontal impact accidents.

Of the three options investigated with respect to adding a new test procedure, one which helps to provide safety for accidents that occur at speeds lower than the current offset frontal impact tests appears to offer the greatest maximum estimate of benefit. This benefit could be as much as £ 247 million (€ 305 million) on a willingness to pay basis. However, the French data suggested low speed impacts were less important in the causation of torso injuries (of at least moderate severity) than the CCIS data from Great Britain.

A full-width test was estimated to offer benefit in the range from £ 0 to £ 105 million (€ 130 million). This could be enhanced by setting the test speed to account for accidents which occur at a lower severity than the current offset procedures, with the use of the new dummy hardware, and a torso injury criterion which protects older occupants. This could extend the benefit to beyond £ 300 million (€ 370 million), each year for the EU-27 countries, based on the CCIS data.

Introducing a low-speed test to protect older occupants provided a large target group of torso injuries, whether offset impacts are included or full-width impacts. On the basis of the combined intervention options considered within this report, torso protection for older occupants in impacts of severities below those of the existing frontal impact test procedures seemed to be a priority in terms of potential benefit.

Due to the small sample sizes available, once the dataset was broken down into small groups of accidents and occupants with similar impact conditions, the options investigated were extremely sensitive to small changes in numbers of injuries or occupants considered. This has led to many of the minimum benefit estimates being £ 0. This indicates that based on this sample of accident data the interventions might not produce a significant safety improvement. Such a prediction seems unavoidable within the constraints imposed by this sample selection.

In addition, differences were observed between the data from the GIE RE PR database and those from the CCIS. This means that extrapolation of findings to the European level will be sensitive to assumptions made about how well the original sample represents the accident population in Europe. On this basis care must be taken when interpreting the findings from this report.

8 Recommendations

Based on the similarities between the test procedure changes suggested and the target group associated with introduction of a dummy with improved sensitivity, it was suggested that changing the test procedure with use of the existing dummy could be ineffective. It is therefore recommended that changes to the existing test procedures strongly consider the implementation of a new, more sensitive, dummy thorax as well.

The estimates of restraint system effectiveness, related to the different safety interventions made possible by the THORAX Project, are subjective in part. It is strongly recommended that these effectiveness estimates are reviewed by other partners in the THORAX Project to provide an expert opinion and consensus. In particular, input should be sought from those partners involved in the Work Package 4 restraint system testing, once that work is underway.

Conclusions regarding the value of testing with dummies set to represent either smaller or larger than average occupants were difficult to draw from the sample of accident cases reviewed for this report. This is because of the small number of cases in each category of accident defined and the absence of stature and mass information for all occupants. To increase the confidence of the findings suggested by this work, it is recommended that other similar analyses are considered. No such studies were available for review within this task; however, they may be in the future. As there is no alternative THOR-based dummy size ready for use alongside the mid-sized male dummy, then this may not be a pressing issue. Regardless of this unavailability of a suitable test tool it is recommended that this occupant diversity issue is monitored closely. It may be that joined up consideration of the accident analysis results reported within the COVER and THORAX projects, together with other supporting evidence, can lead to a definition of the next dummy size required. This may also provide the justification necessary to stimulate further research and dummy development in that topic area.

The alternative options involving protection of older occupants in impacts at severities below those of the existing frontal impact tests provided the largest target groups of torso injuries and benefit estimates within this analysis. On this basis, it is recommended that older occupants in low-speed collisions are considered within future revisions to frontal impact testing requirements.

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Appendix A. Full breakdown of occupants with a torso injury (CCIS sample)

Table A-1 Number of drivers with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, ETS and occupant age and sex

	Age Range	*Overlap*	*Loading*	ETS 0-40km/hr	40-56km/hr	>56 km/hr	N/K
Male	17-25	Narrow	Mid	1	1	1	
		Offset	SS		2		
			OS	1		1	
		Wide	SS	1	1		
			OS			1	1
			Both		2		
	26-45	Narrow	OS	1			
			None				2
		Offset	SS	3	1	2	
		Wide	SS	1		1	1
			OS	1			
			Both	4	2	2	1
			None				1
	46-65	Narrow	SS	3			1
			OS	1			
			Mid	2			
			None				1
		Offset	SS	4	2	1	
			OS	2	1		
		Wide	SS				1
			Both	7	4	1	1
	66+	Narrow	SS	1			
			OS	3			1
			Mid	1			
			None	3			1
		Offset	SS	6		2	
			None	3			
		Wide	SS	1			
			OS	1			
			Both	1	1	1	1
Female	17-25	Offset	SS	1	2		
			OS	1			
		Wide	Both				1
	26-45	Narrow	SS				1
		Offset	SS	2	1	1	
			OS		1		
		Wide	SS		1		1
			OS		1		
			Both	2	4	2	

	Age Range	*Overlap*	*Loading*	ETS 0-40km/hr	40-56km/hr	>56 km/hr	N/K
	46-65	Narrow	None	2			
		Offset	SS	4	2	1	
			OS	1			
		Wide	SS	1			
			OS	2			
			Both	6			
	66+	Narrow	SS	1	1		
			Mid	1			
		Offset				2	
		Wide	SS			1	
			Both	1	1		

Table A-2 Number of front seat passengers with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, ETS and occupant age and sex

	Age Range	Overlap	Loading	ETS >40km/hr	40-56km/hr	>56 km/hr	N/K
Male	12-16	Wide	Both		1		
	17-25	Narrow			1		
		Offset	OS	1			
		Wide	Both	1		2	
	26-45	Narrow	Mid	1			
		Offset	OS	1			
		Wide	OS	1			
	46-65	Offset	OS			1	
	66+	Offset	OS	1			
			Both	2			
Female	17-25	Narrow	OS		1		
		Offset	SS	1			
			OS	1			
		Wide	SS	2			
			Both	2		1	
	26-45	Narrow	OS				1
			None				1
		Offset	SS	1			
			OS	1			
		Wide	SS	1			
			Mid	1			
	46-65	Narrow	OS	1			
			None				2
		Offset	SS	3			
			OS	2	1		1
		Wide	OS	1	1		
			Both	6	2		

	Age Range	Overlap	Loading	ETS >40km/hr	40-56km/hr	>56 km/hr	N/K
	66+	Narrow	SS	1			1
			OS	1			
			None	1			
		Offset	SS	1			
			OS	5			
		Wide	SS	1			
			OS	3			
			Both	3	1		1

Table A-3 Number of rear seat passengers with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, ETS and occupant age and sex

Gender	Age Range	Overlap	ETS 0-40km/hr	40-56km/hr	>56 km/hr	Unknown
Male	12-16	Wide >50%		1		
	17-25	Wide >50%		1		
	26-45	Offset 30-50%	2			
	66+	Wide >50%	1			
Female	17-25	Wide >50%	2	1		
	26-45	Narrow 0-30%	1			
		Wide >50%	1			
	46-65	Narrow 0-30%				1
		Offset	1			
		Wide >50%	1			
	66+	Narrow 0-30%	1			
		Offset	1			
		Wide >50%		1		

Appendix B. Full breakdown of occupants with a torso injury (GIE RE PR sample)

Table B-1 Number of drivers with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, EES and occupant age and sex

	Age Range	*Overlap*	EES 0-40km/hr	EES 40-56km/hr	EES >56 km/hr
Male	17-25	Narrow	0	0	1
		Offset	0	0	0
		Wide	0	0	0
	26-45	Narrow	1	1	9
		Offset	1	1	3
		Wide	0	2	6
	46-65	Narrow	2	3	0
		Offset	1	2	7
		Wide	4	2	7
	66+	Narrow	0	2	2
		Offset	1	3	1
		Wide	1	3	1
Female	17-25	Narrow	0	0	0
		Offset	1	0	3
		Wide	0	1	0
	26-45	Narrow	0	1	3
		Offset	1	1	3
		Wide	0	2	2
	46-65	Narrow	0	0	1
		Offset	0	1	2
		Wide	1	6	1
	66+	Narrow	0	1	0
		Offset	0	0	0
		Wide	0	0	0

Table B-2 Number of front seat passengers with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, EES and occupant age and sex

	Age Range	*Overlap*	EES 0-40km/hr	EES 40-56km/hr	EES >56 km/hr
Male	17-25	Narrow	0	0	0
		Offset	0	0	0
		Wide	0	0	0
	26-45	Narrow	0	0	1
		Offset	0	0	0
		Wide	0	0	0
	46-65	Narrow	0	0	0
		Offset	0	0	1
		Wide	0	0	1

	Age Range	*Overlap*	EES 0-40km/hr	40-56km/hr	>56 km/hr
	66+	Narrow	0	1	0
		Offset	0	0	1
		Wide	0	2	3
Female	17-25	Narrow	0	0	2
		Offset	0	0	0
		Wide	0	0	0
	26-45	Narrow	0	2	2
		Offset	0	0	1
		Wide	0	2	2
	46-65	Narrow	3	1	3
		Offset	1	2	3
		Wide	0	1	6
	66+	Narrow	0	1	1
		Offset	2	0	2
		Wide	0	0	1

Table B-3 Number of rear seat passengers with a torso injury (MAIS ≥ 2, including AIS 1 rib fractures) grouped by the extent of the vehicle front structures engaged in the loading, EES and occupant age and sex

	Age Range	*Overlap*	EES 0-40km/hr	40-56km/hr	>56 km/hr
Male	17-25	Narrow	0	0	1
		Offset	0	0	0
		Wide	0	0	0
	26-45	Narrow	0	0	0
		Offset	0	0	0
		Wide	0	0	0
	46-65	Narrow	0	0	0
		Offset	0	0	1
		Wide	0	0	0
	66+	Narrow	0	0	0
		Offset	0	0	0
		Wide	0	0	0
Female	12-16	Wide	0	0	1
	17-25	Narrow	0	1	0
		Offset	0	0	1
		Wide	0	0	0
	26-45	Narrow	0	0	0
		Offset	0	0	1
		Wide	0	0	0
	46-65	Narrow	0	0	0
		Offset	0	0	1
		Wide	0	1	0
	66+	Narrow	0	0	0
		Offset	0	0	1
		Wide	0	2	1

Appendix C. National number of injuries for fatal or seriously injured occupants

Table C-1 Number of injuries for fatal occupants at a National level, for dummy sensitivity target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		7	7		
Lower Abdomen					
Other Abdomen			7		
Shoulder					
Lung			7		
Heart					7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7				7

Table C-2 Number of injuries for seriously injured occupants at a National level, for dummy sensitivity target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		26	9		
Lower Abdomen					
Other Abdomen	9				
Shoulder		9			
Lung			34		
Heart					
Rib Only	9		9		
Rib	9				
Sternum					
Other Thorax					

Table C-3 Number of injuries for fatal occupants at a National level, for injury risk function target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		14	7		
Lower Abdomen					
Other Abdomen		14	22		
Shoulder					
Lung			7	7	
Heart		7			7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7		7		7

Table C-4 Number of injuries for serious occupants at a National level, for injury risk function target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		34	9		
Lower Abdomen		9			
Other Abdomen	17				
Shoulder		26			
Lung			34	9	9
Heart					
Rib Only	17		9		9
Rib	17				
Sternum					
Other Thorax	9				

Table C-5 Number of injuries for fatal occupants at a National level, for dummy size (small and light) target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		7	7		
Lower Abdomen					
Other Abdomen			7		
Shoulder					
Lung			7		
Heart					7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7				7

Table C-6 Number of injuries for serious occupants at a National level, for dummy size (small and light) target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		26	9		
Lower Abdomen					
Other Abdomen	9				
Shoulder		9			
Lung			34		
Heart					
Rib Only	9		9		
Rib	9				
Sternum					
Other Thorax					

Table C-7 Number of injuries for fatal occupants at a National level, for dummy size (large and heavy) target sample

Injury	AIS 1	2	3	4	5
Upper Abdomen		7	7		
Lower Abdomen					
Other Abdomen			7		
Shoulder					
Lung			7		
Heart					7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7				7

Table C-8 Number of injuries for serious occupants at a National level, for dummy size (large and heavy) target sample

Injury	AIS 1	2	3	4	5
Upper Abdomen		26	9		
Lower Abdomen					
Other Abdomen	43				
Shoulder	9	9			
Lung			34	9	
Heart					
Rib Only	9	9	9		
Rib	9				
Sternum		17			
Other Thorax	17				

Table C-9 Number of injuries for fatal occupants at a National level, for test method – full width, target sample

Injury	AIS 1	2	3	4	5
Upper Abdomen		7	7		
Lower Abdomen					
Other Abdomen			7		
Shoulder					
Lung			7		
Heart					7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7				7

Table C-10 Number of injuries for serious occupants at a National level, for test method – full width, target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		26	9		
Lower Abdomen	9				
Other Abdomen	43			9	
Shoulder	9	51			
Lung			51		
Heart					
Rib Only	26		26		
Rib	9				
Sternum		9			
Other Thorax	26				

Table C-11 Number of injuries for fatal occupants at a National level, for test method – small overlap, target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		7	7		
Lower Abdomen					
Other Abdomen			7		
Shoulder					
Lung			7		
Heart					7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7				7

Table C-12 Number of injuries for serious occupants at a National level, for test method – small overlap, target sample

	AIS				
Injury	1	2	3	4	5
Upper Abdomen		26	9		
Lower Abdomen					
Other Abdomen	9				
Shoulder		9			
Lung			51		
Heart					
Rib Only	9		9		
Rib	9				
Sternum					
Other Thorax		9			

Table C-13 Number of injuries for fatal occupants at a National level, for test method – test speed, target sample

Injury	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Upper Abdomen		7	7		
Lower Abdomen					
Other Abdomen			7		
Shoulder					
Lung			7		
Heart					7
Rib Only			7		
Rib					
Sternum					
Other Thorax	7				7

Table C-14 Number of injuries for serious occupants at a National level, for test method – test speed, target sample

Injury	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Upper Abdomen		26	9		
Lower Abdomen	17	34			
Other Abdomen	43				
Shoulder	17	43			
Lung			51		
Heart					
Rib Only	9		9		
Rib	9				
Sternum		26			
Other Thorax	17				

Appendix D. Benefit values for cases where torso injury is most severe

Dummy Sensitivity

Table D-1 Benefit of reducing injuries in dummy sensitivity group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£8,041,820 €9,923,272	£129,886,648 €160,274,738
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,074,832 €1,326,298	£16,930,168 €20,891,125
Reduce AIS of torso injuries by 1	£3,860,892 €4,764,181	£60,814,682 €75,042,796

Injury Risk Function

Table D-2 Benefit of reducing injuries in injury risk function group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£8,192,374 €10,109,050	£132,258,084 €163,200,992
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,074,832 €1,326,298	£16,930,168 €20,891,125
Reduce AIS of torso injuries by 1	£4,011,445 €4,949,957	£63,186,117 €77,969,049

Dummy Size

Light and small

Table D-3 Benefit of reducing injuries in dummy size – light and small group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£8,041,820 €9,923,272	£129,886,648 €160,274,738
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,074,832 €1,326,298	£16,930,168 €20,891,125
Reduce AIS of torso injuries by 1	£3,860,892 €4,764,181	£60,814,682 €75,042,796

Heavy and large

Table D-4 Benefit of reducing injuries in dummy size – heavy and large group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£11,158,157 €13,768,703	£178,973,500 €220,845,879
Reduce AIS 4+ torso injuries to AIS 3	£795,649 €981,798	£12,532,627 €15,464,742
Reduce AIS 3+ torso injuries to AIS 2	£2,149,609 €2,652,528	£33,859,484 €41,781,199
Reduce AIS of torso injuries by 1	£5,626,667 €6,943,074	£88,628,216 €109,363,544

Test Method

Full width

Table D-5 Benefit of reducing injuries in test method – full width group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£13,297,322 €16,408,344	£212,668,471 €262,424,076
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,279,391 €1,578,715	£20,152,273 €24,867,069
Reduce AIS of torso injuries by 1	£6,022,027 €7,430,932	£94,855,713 €117,048,017

Small Overlap

Table D-6 Benefit of reducing injuries in test method – small overlap group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£10,943,517 €13,503,846	£175,592,601 €216,673,989
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,353,961 €1,670,732	£21,326,857 €26,316,457
Reduce AIS of torso injuries by 1	£5,992,262 €7,394,203	£94,386,877 €116,469,493

Test Speed

Table D-7 Benefit of reducing injuries in test method – test speed

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£21,462,662 €26,484,035	£341,284,498 €421,130,921
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,633,090 €2,015,165	£25,723,546 €31,741,789
Reduce AIS of torso injuries by 1	£15,373,918 €18,970,777	£242,161,654 €298,817,441

Alternative groups

Full width and dummy sensitivity

Table D-8 Benefit of reducing injuries in full width and dummy sensitivity group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£5,255,502 € 6,485,072	£82,781,823 € 102,149,337
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£204,559 € 252,417	£3,222,105 € 3,975,944
Reduce AIS of torso injuries by 1	£2,161,135 € 2,666,751	£34,041,031 € 42,005,221

Full width and dummy sensitivity and light and small and older

Table D-9 Benefit of reducing injuries in full width and dummy sensitivity and light and small and older group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£16,478,399 € 20,333,661	£259,558,833 € 320,284,838
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£7,694,105 € 9,494,207	£121,193,382 € 149,547,609
Reduce AIS of torso injuries by 1	£11,315,180 € 13,962,463	£178,230,608 € 219,929,181

Offset and dummy sensitivity and light and small and older

Table D-10 Benefit of reducing injuries in offset and dummy sensitivity and light and small and older group

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£8,041,820 €9,923,272	£129,886,648 €160,274,738
Reduce AIS 4+ torso injuries to AIS 3	£ - € -	£ - € -
Reduce AIS 3+ torso injuries to AIS 2	£1,074,832 €1,326,298	£16,930,168 €20,891,125
Reduce AIS of torso injuries by 1	£3,860,892 €4,764,181	£60,814,682 €75,042,796

Older people, low speed, offset

Table D-11 Benefit of reducing injuries of older people in low speed offset impacts

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£15,967,432 €19,703,149	£266,078,503 €328,329,841
Reduce AIS 4+ torso injuries to AIS 3	£3,745,817 €4,622,183	£66,148,621 €81,624,656
Reduce AIS 3+ torso injuries to AIS 2	£4,636,905 €5,721,749	£81,171,456 €100,162,211
Reduce AIS of torso injuries by 1	£10,954,371 €13,517,240	£181,866,954 €224,416,281

Older people, low speed, full width

Table D-12 Benefit of reducing injuries of older people in low speed full width impacts

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£28,816,237 €35,558,042	£462,925,546 €571,230,930
Reduce AIS 4+ torso injuries to AIS 3	£3,465,418 €4,276,182	£56,208,799 €69,359,327
Reduce AIS 3+ torso injuries to AIS 2	£4,710,206 €5,812,199	£76,802,907 €94,771,603
Reduce AIS of torso injuries by 1	£18,013,974 €22,228,497	£289,566,374 €357,312,900

All ages, 0-56 kph, full width

Table D-13 Benefit of reducing injuries of all ages in full width impacts from 0-56 kph

Injury reduction	Benefit (GB)	Benefit (EU27)
Remove all injuries	£55,750,080 €68,793,287	£887,172,896 €1,094,734,571
Reduce AIS 4+ torso injuries to AIS 3	£4,261,067 €5,257,980	£68,741,426 €84,824,070
Reduce AIS 3+ torso injuries to AIS 2	£13,962,776 €17,229,487	£222,544,399 €274,610,561
Reduce AIS of torso injuries by 1	£37,141,004 €45,830,459	£590,845,021 €729,078,259