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A review of secondary safety priorities

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A Review of Secondary Safety Priorities

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Undertaken on behalf of

Department for Transport

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Executive Summary

This report identifies passenger car occupant safety issues that can be considered priorities for injury mitigation through secondary safety interventions. The results are relevant to a newer car fleet designed to meet the current regulatory and consumer test requirements.

The project was conducted in a number of stages. Issues have been identified through analysis of national and in-depth accident data sets, through workshops held with experts in the field of vehicle safety (Project Consultative Group), and through a review of the literature. Throughout the project consultations have been held with the Department for Transport.

National accident data highlighted the continued importance of car occupant injury mitigation within the accident constellation. Further priority areas for passenger car occupants were then defined primarily according to the frequency of the injury, the cost to society of the injury, and through the existing knowledge base across members of the Project Consultative Group (PCG).

A total of 18 priority areas have emerged relating to injury mitigation in frontal, side, rear, rollover and multiple impact configurations. Additionally, 6 areas were identified concerned with associated issues such as vulnerable road users. For each of these an indication of the extent of current research activity is given and recommendations made for further actions that could be undertaken to advance the current knowledge.

Consensus was sought among the PCG members for 5 leading priority areas and the potential for injury mitigation through secondary safety intervention by means of vehicle design or regulatory compliance was explored by means of a workshop. These 5 areas were femur fractures in frontal impact, foot/ankle injuries in frontal impacts, chest injuries in struck side impacts, whiplash in frontal impacts and rear occupant protection in frontal impacts.

Some suggestions were made for secondary safety interventions but the general conclusion for all areas was that more understanding of the injury mechanisms, further enhanced biomechanical data, and improved dummy bio-fidelity were required before the most effective countermeasures (including both changes in regulation and vehicle design) could be determined and their respective benefits quantified.

The main conclusion from this study is that whilst various priority areas have been identified and some secondary safety interventions suggested, the benefit that these would have in mitigating injury is unclear since some injury mechanisms are still largely undefined. It would be inadvisable to simply implement design solutions/develop new regulation without due consideration to the shortfall in current biomechanical knowledge and the limitations of the current test procedures/tools in predicting injury outcome under real world crash conditions.

In addition to the main study, a pilot driver survey was carried out to gain knowledge of public opinion and perception of car safety as an influencing factor in vehicle purchase. This survey demonstrated a potential methodology but the results are limited due to the small sample size.

This report is intended as a summary of the extensive work that has been undertaken for the project. There are a number of substantial appendices which document the in-depth research undertaken on which this summary report is based.

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1 Introduction

In order to support the Department for Transport's (DfT's) aims to ensure the UK has a modern integrated transport system that is safe, sustainable and minimises the impact on society, the Transport Technology and Standards Division (TTS) has a broad based research programme directed towards decreasing the number of road accidents and resulting casualties as well as towards reducing the impact of vehicles on the environment.

In 2004, 65% of the 280,840 road accident casualties were occupants of cars. In addition, car occupants made up 51% of fatally injured road accident casualties and 47% of seriously injured road accident casualties. According to the UK Governments calculated cost of casualties, in 2004 the total cost of car occupant casualties amounted to approximately £6.5 billion.

The DfT has a priority to reduce road casualties in the United Kingdom. By the year 2010, the Department wants to achieve, compared with the average for 1994-98:

- A 40% reduction in the number of people killed or seriously injured in road accidents;
- A 50% reduction in the number of children killed or seriously injured; and
- A 10% reduction in the Slight casualty rate expressed as the number of people slightly injured per 100 million vehicle kilometres.

It has been suggested that improvements in car design from a safety viewpoint represent the single most effective way of reducing road accident casualties in the UK and therefore offer the best means of helping the UK to meet the casualty reduction targets. A study by Broughton et al (2000) looked at assumed effects of various new road safety policies. Improved secondary safety in cars was predicted to lead to a 10% reduction in the numbers of Killed/Seriously Injured (KSI) car occupants and a 15% reduction in the numbers of KSI pedestrians. These predictions were based on the assumption that there would be an increase in the vehicle fleet of cars equipped with existing technologies. Further improvements in car secondary safety would give additional benefits. Another study by Lowne

(2000), using estimates of casualty reductions and not based on systematic data analysis, predicted that the introduction of various secondary safety features on vehicles would provide potential benefits for several road user groups. For car occupants, the greatest potential reduction in KSI rates were to be found following the introduction of EU Directives on Frontal and Side Impact protection, the introduction of the EuroNCAP test programme and the introduction of energy-absorbing front under-run guards for HGVs. For pedestrians, potential casualty savings were predicted following the introduction of the EU Directive on pedestrian protection. For motorcyclists, potential reductions were predicted in the event that leg protectors were fitted. Large potential reductions were predicted for HGV occupants through improved cab-strength and the use of 3-point belts. It should be noted that many of the directives listed above were already in force at the time that Lowne's study was undertaken, however it is felt unlikely that fleet penetration would have been sufficient to show any discernable benefits.

Following on from these two studies, the DfT now wishes to identify more completely where future casualty savings can best be made. In order to achieve this, it is necessary to undertake a review of existing UK and international accident research to help identify the highest priority injuries (in terms of threat-to-life, impairment, etc.) their associated costs and how they should be addressed by vehicle design.

The main focus of this study will be secondary safety in passenger cars as this is the largest casualty group but it will also address briefly the passive safety opportunities for other road-user types.

In order to determine the road user groups and accident types deemed to be a priority for the future, consideration will be paid to the following structured and ordered criteria:

- Casualty frequency – the primary consideration will be the frequency with which a casualty type occurs within the most recent accident data.

- Cost of injury in conjunction with frequency – having established the most frequent casualty types, further consideration will be given to injuries incurred and the associated financial burden.
- Ability to reduce frequency and severity – the next consideration will be whether or not a potential solution can be identified; this will help concentrate the research effort into areas where benefits are most likely to be seen.
- Child casualty type and frequency – if further prioritisation is required then an emphasis will be placed on the reduction of child casualty frequency and severity.

It should be noted that much national and international effort is currently being devoted to research in a number of key areas of road injury prevention involving a number of road-user groups.

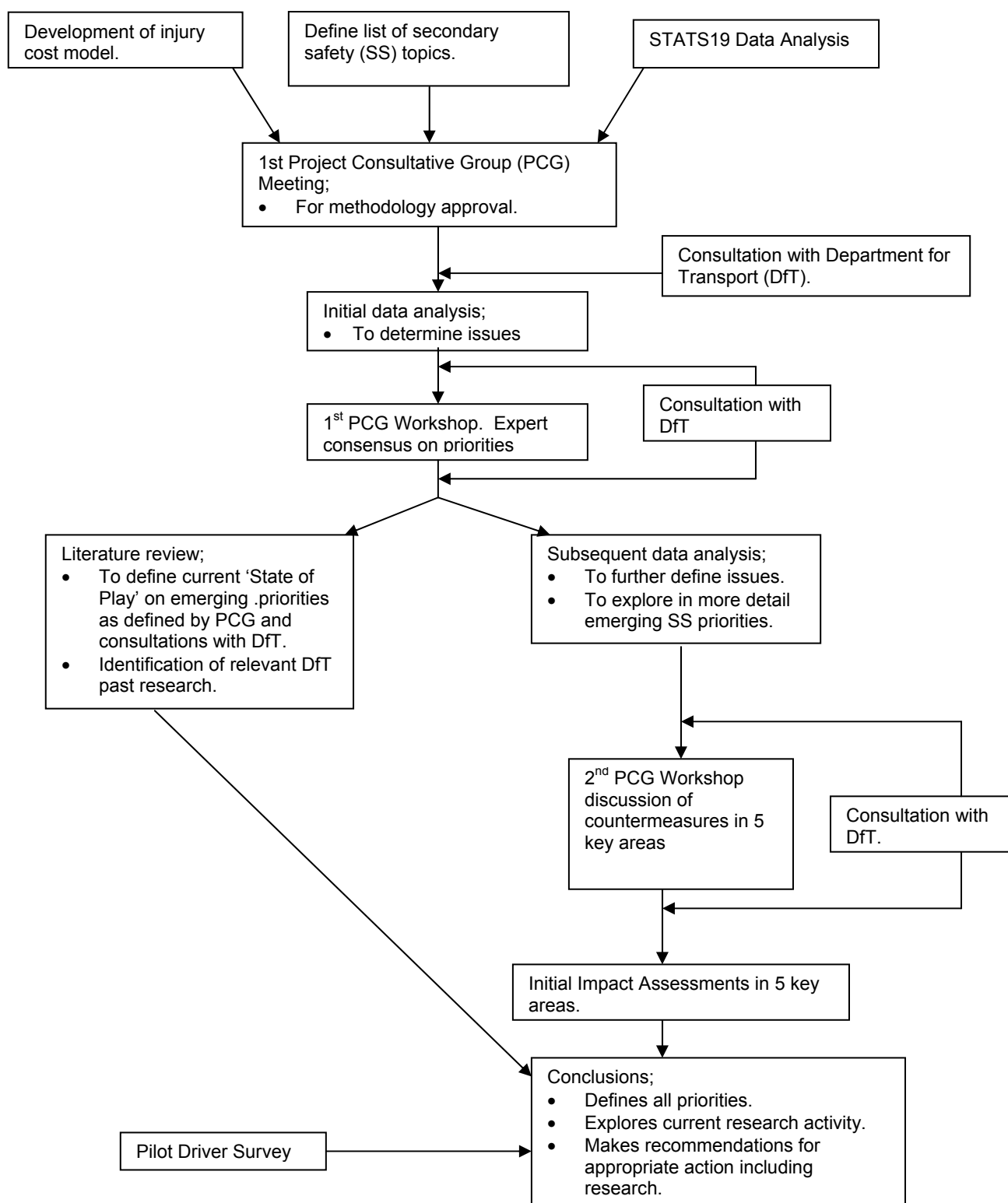
In addition, a pilot driver survey has been carried out. The aim of the pilot was to develop and apply, to a localised sample, a number of questions relating to car safety. A large scale survey based on the pilot questionnaire would provide data relating to the public's general awareness and understanding of safety issues and, in conjunction with accident data, would assist in identifying gaps in actual and perceived safety-related issues which the Department may choose to address through education campaigns or by other means as appropriate.

2 Methodology

In order to carry out this study a combination of data analysis, literature review and peer group review has been used. Previous analytical studies were reviewed and new analysis carried out utilising both the national accident data (STATS19) and the UK in-depth accident data (CCIS). A review of relevant research activity published in conference proceedings was undertaken and a compilation made of previous research projects carried out by the DfT. A peer review group, known as the Project Consultative Group (PCG) was established and used to approve methodology and to provide technical assistance where required.

2.1 Overall Project Methodology

The project progressed through a number of stages. These are illustrated in the following flow diagram:



The overall project methodology and the injury costing approach were presented at an initial PCG meeting for approval. Each of the stages is now discussed in more detail.

2.2 Initial Analysis Topics

Topics to be considered in the initial data analysis were decided upon based on the expertise within the Centre, where current knowledge suggested the areas that would be most appropriate starting points.

These were as follows:

- An overview of the UK accident statistics including the cost to the government of various road user casualty types.
- A more detailed overview of the nature of car accidents within the UK.
- Further specific analysis relating to the injury outcome for passenger car occupants for the following situations;
 - Frontal Impacts.
 - Side Impacts.
 - Non struck side occupants.
 - Rear Impacts.
 - Rollovers.
 - Multiple Impacts.
- Airbag effectiveness in European passenger cars.
- Injury outcomes in newer model cars.
- Vehicle size as a factor in injury outcome.
- Occupant stature as a factor in injury outcome.
- Considerations for older vehicle occupants.
- Pedestrian casualties.
- Motorcyclist injuries and injury causation including helmet effectiveness.

2.3 STATS19 Analysis

An analysis of the STATS19 data was made using data from the years 1997-2004. Trends in Fatal, Serious and Slight injury outcome among all road users were considered and the associated costs for each casualty type derived.

Crash circumstances were then considered by casualty severity (Slight or KSI) for car occupants, pedestrians and motorcyclists. A subsequent analysis specifically

considered the crash circumstances for Fatal car occupants, pedestrians and motorcyclists.

2.4 Injury Costing

Within much of the analysis carried out as part of this project consideration has been given to the costs of casualties. The UK government's calculated cost of road accidents and road casualties by accident/casualty severity, whilst providing a good overall cost to society, does not allow enough distinction for the purposes of this project. An alternative method was needed that associated a cost to specific injury outcomes.

Upon consultation with DfT, it was decided to adopt a willingness to pay approach that assigns a cost, as a proportion of the cost of a fatality, to an injury state. A method for studying the cost of injury *states* is described in Hopkin and Simpson (1994). In their study, a number of Injury State Descriptors were determined to cover a range of serious injuries from a fractured finger to those involving permanent disability or death more than 30 days after the accident. The descriptors covered different aspects of the consequences of injuries including extent and duration of pain, period of treatment (in hospital or as an out-patient), recovery period and social and professional consequences. These injury state descriptors are shown in Table 1. A survey was carried out (Hopkin 1994) and respondents were asked to provide an estimate of the value of the different injury states as a percentage of the injury state of fatality and the results from this survey were used to apply a value for each injury relative to the value of death. These figures are also shown in Table 1.

Medical researchers within the VSRC then assigned one of these states to each injury appearing within the CCIS database in order for cost analyses to be carried out as part of the prioritisation process.

Additionally, slight injury (superficial cuts and bruises) and whiplash injury are treated separately from the injury states in table 1. Whiplash is a diverse injury, the consequences of which can fall into any number of injury states depending on the

severity of the whiplash. The figure of £42,574 assigned to whiplash injury is derived by assuming that a proportion of whiplash falls within state W and the remaining within state X (Hopkin, 1995). All slight injuries are assigned an average cost of £8,693.

Table 1: Injury costs – willingness to pay approach

Injury State	% value of death	Value (2003 prices)
Recover 3-4 months (Out-patient): F	2.0	£24,328
Recover 3-4 months (In patient): W	2.0	£24,328
Recover 1-3 years (in-patient): X	5.5	£66,902
Mild permanent disability (Out patient): V	5.5	£66,902
Mild permanent disability (In patient): S	15.1	£183,675
Some permanent disability with scarring: R	23.3	£283,420
Paraplegia/quadriplegia: L and N	100	£1,216,394
Severe head injuries L and N	100	£1,216,394

2.5 First Project Consultative Group (PCG) meeting

A project consultative group was formed at the outset of the project. The role of the PCG was to serve as an advisory group to help guide the project to a successful outcome through the valuable contribution of a wide range of experts within the vehicle safety community. The PCG Members and respective affiliations are shown in Appendix 1.

The first PCG meeting gave the opportunity for the overall project methodology to be presented and approved together with the intended approach to injury costing.

2.6 Initial Data Analysis

Each of the topics above (2.2) was reviewed using a combination of existing published material and new data analysis. Where necessary the following data

sources were employed, Table 2. Where CCIS data analysis was carried out the data were selected to contain belted occupants.

Table 2: Data sources used for accident analysis

Data Source	Data Type	Year/Period
Co-operative Crash Injury Study	In-depth	1992-present
Jaguar Cars Pedestrian Injury Study	Published pilot study	1999
On-the-Spot	In-depth	2001 to present
MAIDS	In-depth	1999 to present
GIDAS	In-depth	1992-2001

2.7 Second PCG meeting and first workshop

The results of the initial data analysis were circulated to members of the PCG and a subsequent workshop held. The aims and objectives of the workshop were as follows:

- to help the DfT and the VSRC prioritise the most promising areas of research for injury prevention and casualty reduction based on the data analysis.
- to identify areas where engineering solutions are foreseeable.
- to obtain expert opinion concerning the potential benefits of future systems.

A modified Delphi approach was used for the purposes of the workshop. A number of steps were used in the process;

- Initially PCG members received an Executive Summary of the initial data analysis.
- Each PCG member was requested to read through the Executive Summary and begin to formulate their own opinion about priority areas and potential injury mitigation measures by way of a questionnaire prior to the workshop.
- The areas considered as priorities were then consolidated into 9 distinct secondary safety areas and these were then ranked in importance by members of the PCG.

- The responses were then further analysed and consolidated so that factors within each issue could be identified in terms of both commonality and perceived importance.

A round table discussion then resulted in 4 priority areas being established:

- Frontal Impacts (including Compatibility).
- Side Impacts.
- Population variance.
- Rear Impacts.

PCG members were then divided into groups, each group being responsible for holding a discussion for one of the priority areas. The discussions focussed upon injury mitigation potential and effectiveness for the given area.

At the end of this process, a number of areas evolved as worthy of further analytical consideration due to (all or some of) the injury frequency, the associated cost and the opinion of the expert PCG members.

2.8 Literature Review

Complementary to the data analysis, a literature review had been undertaken. This took the form of a review of the technical literature pertaining to occupant protection over the period 1990 to 2005. Due to the wealth of information available, some pre-selection of topic areas was made based upon the results of the initial data analysis and the first PCG workshop.

These topics are:

- Protection of car occupants seated on the non-struck side in lateral impacts.
- Effectiveness of airbags in protecting occupants in frontal impacts.
- Protection of elderly car occupants.
- Protection of pedestrians and other vulnerable road users.
- Protection of car occupants in multiple collision sequences.
- Protection from neck injuries in low-speed rear impacts (“whiplash” injuries).

- Protection of car front seat occupants from lower leg injuries in frontal impacts.
- Protection from chest injuries.
- Protection of car occupants in lateral impacts.

For each of these topics, a search was made of the abstracts of the principal vehicle safety and occupant crash protection conferences over the 15 year period. This was done using keywords relevant to each topic. Relevant papers were then listed and a brief review compiled for each. On the basis of these reviews, a technical review for each of the topics was compiled. This sought to answer the key questions that could be used by the department to guide its research policy, namely:

- What is the problem?
- What is being done?
- How is it being done?
- What is not being done?

The last section is the most important, insofar as it identifies important topics that are either not currently being investigated, or where little work is taking place.

The key findings from the literature review have been used in the conclusion section of this report. The review in its entirety can be found in Appendix 6.

In order to establish where resources have been deployed in the past, a comprehensive list of previous research projects concerned with secondary safety in passenger cars commissioned by the DfT has been compiled. This was achieved by examining the department's research compendium for the years 1997-2003. These were classified according to the area of the research activity as follows:

- Frontal Impacts:
 - Dummy Development (includes biomechanical models).
 - Barrier Development.
 - Adult Occupant Protection (includes seatbelts, airbags, padding, anti-intrusion systems).

- Compatibility (includes car to car, car to other object).
 - Test Procedures / Evaluation.
- Side Impacts:
 - Dummy Development (includes biomechanical models).
 - Barrier Development.
 - Adult Occupant Protection (side airbags, seats, padding, anti-intrusion systems).
 - Barrier Development.
 - Compatibility (includes car to car, car to other object).
 - Test Procedures / Evaluation.
- Rear Impacts.
- Vulnerable Occupants:
 - Children (includes restraint systems).
 - Women and Small Adults.
- Pedestrian Protection.
- Real World Accident Studies.
- EuroNCAP
- Other Vehicles:
 - Two-wheeled vehicles.
 - Non-car 4+ wheeled vehicles.
- General / Other.

Relevant past research projects are listed within the conclusions section of this report. The full list can be found in Appendix 7.

2.9 Subsequent Data Analysis

In parallel to the literature review, further in-depth data analysis was carried out in a number of areas defined by the results of the first PCG workshop and based upon subsequent discussions with DfT. These comprised:

- Injury costing
- Leg injuries in front and side impact
- Side impacts in relation to the regulatory test procedure
- Whiplash

- Rear occupants in all impact types
- Chest injuries in front and side impacts
- Child injury data
- Cycle helmet use

2.10 Third PCG Meeting and Second Workshop

Upon completion of the subsequent data analysis a further presentation of results was made to the PCG members. Following the presentation a second workshop was held.

The aims and objectives of the workshop were as follows:

- To examine topic areas defined as priority areas through the previous analysis process.
- To establish whether sufficient knowledge exists to define countermeasures for injury mitigation.
- Where sufficient knowledge exists, to identify possible countermeasures and their likely impact.
- Where sufficient knowledge does not exist, to make suggestions for further research in order to better understand the problem area.

The focus was upon injury type rather than impact type and the following topics were discussed:

- Femur injuries in frontal impacts.
- Foot and ankle injuries in frontal impacts.
- Chest Injuries in side impacts.
- Whiplash in frontal impacts.
- Rear Seat Occupant injuries.

2.11 Pilot Driver Survey

A pilot study was carried out to determine the extent of public perception and awareness with regard to car safety issues. A questionnaire was developed that was based upon a review of similar studies but that also incorporated the objectives of this study. The questionnaire required answers of both a categorical and

subjective nature. On street interviews were conducted with 100 respondents and the resulting information compiled and analysed.

3 Results

Throughout this section the key results and findings from the project activities are presented. Full details of each of the initial analyses, the workshops, the literature review and the driver surveys can be found in the relevant appendices which are clearly referenced throughout this section.

3.1 STATS19 and Initial CCIS Data Analysis

The following table (Table 3) summarises the main findings from the comprehensive STATS19 and initial data analyses. The supporting evidence for each conclusion can be found in the relevant section of Appendix 2. These are clearly referenced within the table.

Table 3: Conclusions from STATS19 and Initial CCIS Data Analyses

No.	Appendix reference	Conclusion Relating to	Conclusion
1	Table 1.4	STATS19	In terms of casualty frequency and cost using the Government's derived costs, amelioration of car occupants, pedestrian and motorcyclist casualties are priorities.
2	Table 1.5	STATS19	Costs of seriously injured road casualties outweigh those of fatally injured road casualties.
3	Table 1.6	STATS19	An overall reduction in car occupant casualties is observed for all severities during the period 1997 to 2001 but fatalities increased by 5% from 2000 to 2001 (NB exposure data available up to 2001)
4	Table 1.7	STATS19	An overall reduction in pedestrian casualties is observed for all severities during the period 1997 to 2001. (NB exposure data available up to 2001)
5	Table 1.8	STATS19	During the period 1998-2001, increases in Serious and Slight motorcycle casualties were observed. (NB exposure data available up to 2001)
6	Figures 1.8 & 1.9	STATS19	Younger car passengers are a problem group. However, it is not clear whether this is a secondary safety or other road safety issue.
7	Figures 1.4 to 1.9	STATS19	The data have shown that there are differences in gender and age distributions of car occupant casualties implying that population characteristics should be considered.
8	Figure 1.35	STATS19	Car-v-car accidents account for only 35% of fatalities whilst car-v-other objects account for 65% of fatalities.
9	Figures 1.35 & 1.38	STATS19	20% of total fatalities involve car-to-pole/tree impacts.
10	Figures 1.16 to 1.18	STATS19	Multiple impacts appear to be a common problem in KSI crashes and account for over 30% of KSI outcomes.

11	Figure 2.3	CCIS overview	Risk of fatality is 1.5 times greater in side impacts and rollovers compared to front impacts. Belt use is a factor in injury outcome.
12	Figure 2.6	CCIS overview	MAIS 3+ injuries are 1.5 times as prevalent (in terms of rate) in side impacts compared to front impacts. The rate in rollovers is slightly higher than in frontal crashes. Belt use is a major factor in injury outcome.
13	Figs 2.7, 2.8 and 2.13	CCIS overview	AIS 3+ injuries most frequently occur to the head, chest and lower extremity. AIS 3+ chest and leg injuries are most common in front and side impacts. AIS 3+ head injuries are most common in side impacts and rollovers.
14	Figure 3.4	CCIS Frontal impacts	75% of fatally injured belted drivers in Frontal impacts sustained an AIS 3+ chest injury. 60% sustained an AIS 3+ head injury.
15	Figure 3.5 & 3.6	CCIS Frontal impacts	MAIS 3+ injuries to surviving drivers were relatively rare. AIS 2+ injuries (fractures) to the arms and legs were common.
16	Figure 3.10	CCIS Frontal impacts	Around 50% of fatally injured Front Seat Passengers sustained an AIS 3+ injury to the chest. Approximately 50% of fatally injured Front Seat Passengers sustained AIS 3+ injuries to the head.
17	Figure 4.1	CCIS Side impacts	21% of struck-side Front Seat occupants sustained MAIS 3+ injury – significantly more than in Frontal impacts.
18	Figure 4.3	CCIS Side impacts	28% of non-fatally injured struck-side Front Seat occupants sustained AIS 2+ injuries.
19	Figure 4.4	CCIS Side impacts	90% of fatally injured struck-side Front Seat occupants sustained AIS 3+ Chest injury and 70% sustained AIS 3+ head injury.
20	Figure 4.6	CCIS Side impacts	MAIS 3+ injury to non-fatally injured struck-side Front Seat occupants was relatively rare.
21	Table 4.1	CCIS Side impacts	Approximately 60% of chest injuries and 66% of head injuries occur in crashes where the impact is with something other than a passenger car.
22	Figure 5.4	CCIS Non-struck Side impacts	Priorities for the prevention of fatalities in Non-struck Side (NSS) impacts include prevention of head and chest injuries.
23	Figure 5.8	CCIS Non-struck Side impacts	Median crash severity that resulted in injury was not high – for MAIS 3+, the median crash severity was 33km/h.
24	Figure 5.5	CCIS Non-struck Side impacts	Non-fatally injured occupants sustain AIS 2+ injury to the chest, head and arms (in that order).
25	Figure 5.9	CCIS Non-struck Side impacts	The presence of another adjacent occupant reduces the overall injury severity to all body regions except for the chest.
26	Figures 6.4 , 6.5 & 6.6	Rear impacts	8 Front Seat occupants were fatally injured in Rear impacts. Such occupants sustained AIS 3+ head (63%) and AIS 3+ chest (75%) injuries. However, AIS 3+ injuries to survivors were very rare.
27	Figure 6.5	Rear impacts	50% of survivors sustained neck injury (predominantly 'Whiplash').
28	Table 7.1	Rollovers	Ejection is a main factor governing injury severity. An ejected driver is 6 times more likely to sustain AIS 4+ head injury and 12 times more likely to sustain AIS 4+ chest injury than a non-ejected driver. Prevention of ejection through side windows is a priority. Belt use is an important factor

29	Table 8.2	Multiple impacts	Multiple impact crashes make up a substantial proportion (~30%) of the accident constellation.
30	Tables 8.11 & 8.12	Multiple impacts	Compared to a single impact, there is a comparable or higher risk of being seriously injured in a multiple impact, although in many cases, these involve one major impact followed by a more minor impact.
31	Section 8	Multiple impacts	Increasing the duration of time over which deployable airbag/restraint systems maintain their activated state could further extend protection possibilities
32	Figure 9.1	Airbag effectiveness	MAIS 2+ injuries have reduced from 32% to 24% in airbag equipped vehicles in Frontal impacts. Particular reductions have been found in head injury.
33	Figure 9.3	Airbag effectiveness	Airbags are not particularly effective in reducing chest injury.
34	Figure 10.3	Newer model vehicles	More occupants in 'newer' vehicles die in Side impacts compared to Front impacts – 27% of these are on the Non-struck side.
35	Figure 10.4	Newer model vehicles	The collision severities of Fatal Side impacts remain substantially above Regulatory Compliance and Consumer Test speeds.
36	Table 11.3 Figures 11.1, 11.2 & 11.3	Vehicle size	Vehicle design should not be over-optimised and should take into account variation in crashes in terms of collision partners and occupant characteristics.
37	Figures 12.1 & 12.2	Occupant height	Drivers below 160cm in height have the highest rate of AIS 2+ injuries particularly to the head.
38	Section 12	Occupant height	Smaller drivers adopt a more forward seat position and therefore are closer to the front vehicle structures exacerbating the risk of head injury.
39	Figure 12.2	Occupant height	Taller drivers also show an increased risk of AIS 2+ head injury.
40	Figures 13.3 & 13.4	Older vehicle occupants	Older drivers are 5 times more likely to be fatally injured in a Frontal impact crash and twice as likely to be fatally injured in a Side impact.
41	Figures 13.7, 13.8 & 13.9	Older vehicle occupants	Older driver head injury rates (at all injury severities) compared to other age groups do not differ but MAIS 3+ chest injury rates are much higher (3 times) amongst older drivers. The same is true for Side impacts. The seat belt is the cause of most AIS2+ chest injuries among older drivers in Frontal impacts.
42	Figures 13.15 & 13.19	Older vehicle occupants	Older front seat passengers (FSP's) are 2 times more likely to be fatally injured in a Frontal impact crash. When compared to younger occupants, older FSP's are 5 times more likely to receive MAIS 3+ chest injury in Frontal impacts.
43	Table 13.6	Older vehicle occupants	The data suggest that older male and female passengers sustain serious chest injuries from the seat belt in frontal impacts.
44	Section 14	Pedestrians	There are not much data on pedestrian injury outcomes although data are being collected elsewhere (within the OTS study). Consequently it is difficult to define research priorities.
45	Table 14.5	Pedestrians	Initial indications are that in terms of MAIS 3+ injuries, the head, chest and lower extremity are the most common body regions injured.
46	Table 14.6	Pedestrians	Initial indications highlight the importance of the scuttle and A-pillar as injury contact sources for future consideration.

47	Section 15	Motorcyclists	In the MAIDS study the lower extremity was the most frequently injured body region followed by the upper extremity then the head and neck.
48	Section 15	Motorcyclists	Fatally injured motorcyclists sustain injury most commonly to the head, face and thoracic chamber.
49	Section 15	Motorcyclists	In 9.1% of cases within the MAIDS study the helmet came off the riders head during the accident.

3.2 First PCG Workshop

The overall aim of the first PCG workshop was to derive a consensus among leading experts in the field of vehicle safety concerning prioritisation of the most promising areas of secondary safety research that would lead to injury prevention and hence casualty reduction on UK roads.

However, it was not the intention that the workshop alone would identify all the necessary priority areas since a number of other approaches have been considered. Of particular importance in this respect has been the contribution of the data analysis undertaken to date. Data analysis has also highlighted a number of research priority areas, see section 3.1. This has taken one of two forms:

- Analysis of frequency of injury by crash type.
- An initial cost of injury according to the DfT's preferred cost model (DfT, Nov 2003).

NB. An updated cost analysis using weighted CCIS data is presented in section 3.3.1 of this report.

The results of the initial data analysis (table 3) were presented to the PCG group for consideration along with their own views. The main conclusion, in the form of priority areas identified from the workshop, is presented here but the full comments made throughout the workshop are available in Appendix 3.

Table 4 shows a number of priority research topics that arose through the workshop discussion/individuals views and illustrates how each priority has been additionally identified (i.e. by data analysis and or injury cost analysis).

Table 4: Conclusion from first PCG workshop

Secondary Safety Priority	Data Analysis	Injury Cost Analysis (un-weighted data)	PCG Workshop
Non-struck side occupants	✓	?	✓
Multiple impacts	✓	?	✓
Compatibility (front and side)	✓?	?	✓
Side impacts	✓	✓	✓
Chest injuries	✓	✓	✓
Rollover and ejection	✓	?	✓
Pole impacts	✓	?	✓
Ageing occupants	✓	?	✓
Population variance	✓	?	✓
Foot/ankle injury	✓	✓	✓
Whiplash	✓	✓	✓
Active safety	x	x	✓
EuroNCAP validation	x	?	✓
Rescue implications	x	x	✓
Impairment and disability	x	✓	✓
Pedestrian head injuries	✓	?	✓
Motorcyclist injuries	✓	?	✓

As can be seen from the table, at this stage of the project, a number of key priority subject areas emerged. These have been identified as follows:

Identified by all 3 Approaches:

- Side impacts.
- Chest injuries.
- Foot/ankle injuries.
- Whiplash.

Identified by 2 Approaches:

- Non-struck side occupants.
- Multiple impacts.
- Compatibility (frontal and side impacts).
- Rollover and ejection.
- Pole impacts.
- Ageing occupants.
- Population variance.
- Impairment and Disability.

- Pedestrian head injuries.
- Motorcyclist injuries.

Following the outcome from the workshop and subsequent consultations with DfT it was acknowledged that the data analysis undertaken to date needed to be broadened to take into account additional issues that have not yet been considered. Therefore the conclusions that have been reached at this stage should be considered somewhat provisional and the final conclusions will also be supported by a review of the existing literature. When all approaches have been completed, the resulting evidence will be considered as more conclusive.

The further analysis carried out covered the following topics:

- Injury costing using weighted CCIS data.
- Leg injuries in front and side impacts.
- Side impacts in relation to the current test procedure.
- Whiplash.
- Rear occupant protection.
- Chest injuries in front and side impacts.
- Child injury data.
- Cycle helmet use.

3.3 Further data analysis

In this section, the analysis that was carried out according to the recommendations of the PCG is presented. This complements the substantial analysis that was carried out previously, which can be found in Appendix 2.

3.3.1 Injury costing

An analysis has been made of the CCIS data for the phases 5, 6 and 7 in order to examine the costs associated with injuries to different body regions sustained by car occupants of newer model cars (manufactured 1998 onwards). An injury cost analysis forms a fundamental part of the prioritisation process. When all injury severities are considered (Figure 1), a weighted data set has been used in order to address the bias towards Serious injury outcome in the CCIS data so that the data

represent the true proportions of Slight/Serious/Fatal accidents occurring within a given time frame. Weighting factors are calculated as:

‘The number of accidents of a given severity in a sample region during a quarter of a year notified to the CCIS investigating teams divided by the number of these accidents sampled within the CCIS database’.

Records of the number of notifications are only available for the Leicestershire and Nottinghamshire regions and so the weighting factors have only been calculated for these regions. Hence this analysis uses a reduced sample of the CCIS data (Leicestershire and Nottinghamshire only) but reflects the true accident severity ratio within these regions. Under the assumption that the accident situation within these two counties is indicative of the national accident population, then these results could be seen as nationally representative.

When AIS 2+ injuries only are considered (Figures 2, 3 and 4), un-weighted data is used in order to retain the diversity of injury types within the data. An analysis of serious injuries does not suffer from the same sampling bias issues as an analysis of all injury severities.

The data are presented so as to illustrate both the frequency (as a proportion of all injuries) and the cost (as a proportion of the total cost) of injuries to each body region.

Figure 1 shows the results when all crash modes and all injury severities are considered. As can be seen from the figure, ‘whiplash’ is by far the most costly injury involving 31% of the total cost though accounting for only a little over 15% of all injuries. It should be noted that the underlying assumptions associated with the derivation of the cost for an individual whiplash injury (discussed in section 2.4) may have resulted in an over-inflated cost for this injury type. Injuries to the upper and lower extremities together account for 26% of the total cost but 43% of the injuries sustained.

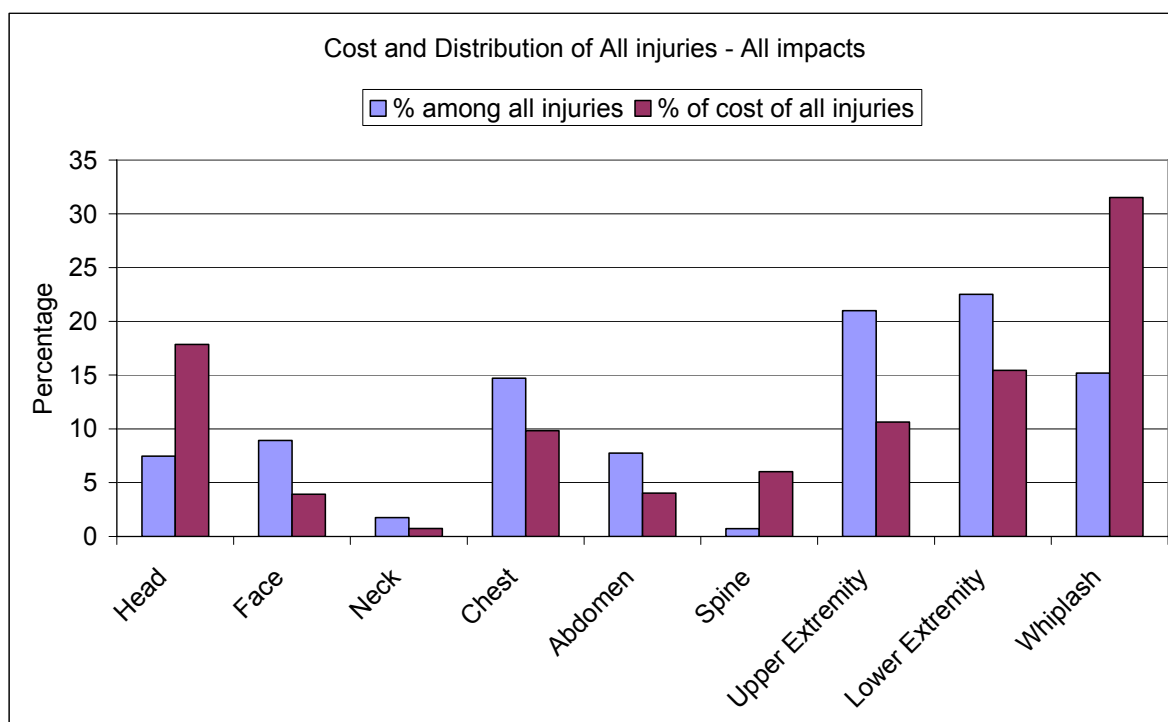


Figure 1

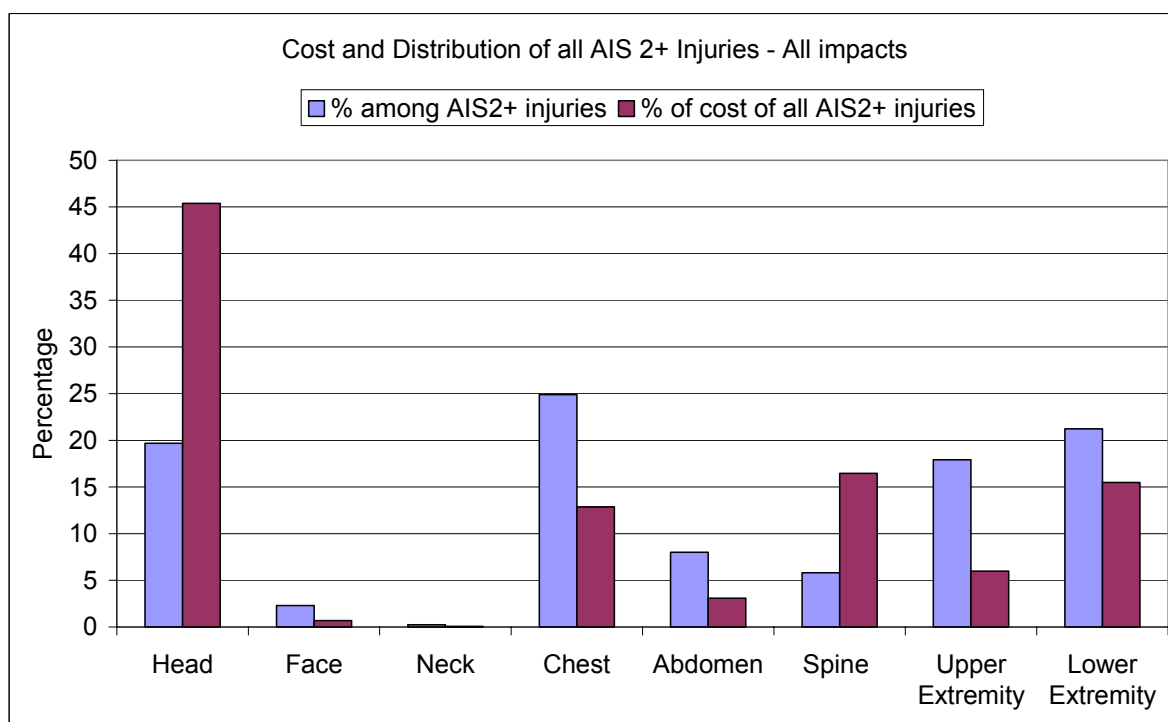


Figure 2

Figure 2 shows a revised analysis of costs where Slight injuries and whiplash have been discounted. Thus only more serious injuries (AIS2+) are considered. Injuries to the extremities are the most common, followed by those to the chest, then those to the head. However, when costs are considered, it is clear that head injuries are

by far the most costly. This is because many of the more severe head injuries result in long term permanent disability and expensive palliative care and are therefore costed equivalent to fatality (Table 1). The same applies for severe injuries to the spine, especially where partial or full transection of the cord occurs. Lower extremity injuries are the third most costly of all AIS 2+ injuries. Whilst severe head and spine injuries are associated with a high mortality rate this is not the case for lower extremity injuries. Road trauma survivors who suffer a serious leg injury are likely to have long term consequences and a loss of quality of life.

Figure 3 shows the analysis for AIS 2+ injuries to front occupants in frontal impacts. Again, whiplash and Slight injuries are excluded from the analysis so that the proportional representation of Serious injuries to the various body regions among the total cost of Serious injuries can be determined. In the case of frontal impacts, it can be seen that lower extremity injuries followed by chest injuries form the largest proportions of AIS 2+ injuries. However injuries to the head are the most costly because of the risk of death and extreme disability (e.g. severe brain injury) associated with higher severity injuries. Lower extremity injuries are also costly as serious injury can result in long term impairment and loss of mobility, however, on a willingness to pay approach, this is more favourable than injuries resulting in brain damage and associated neurological deficit.

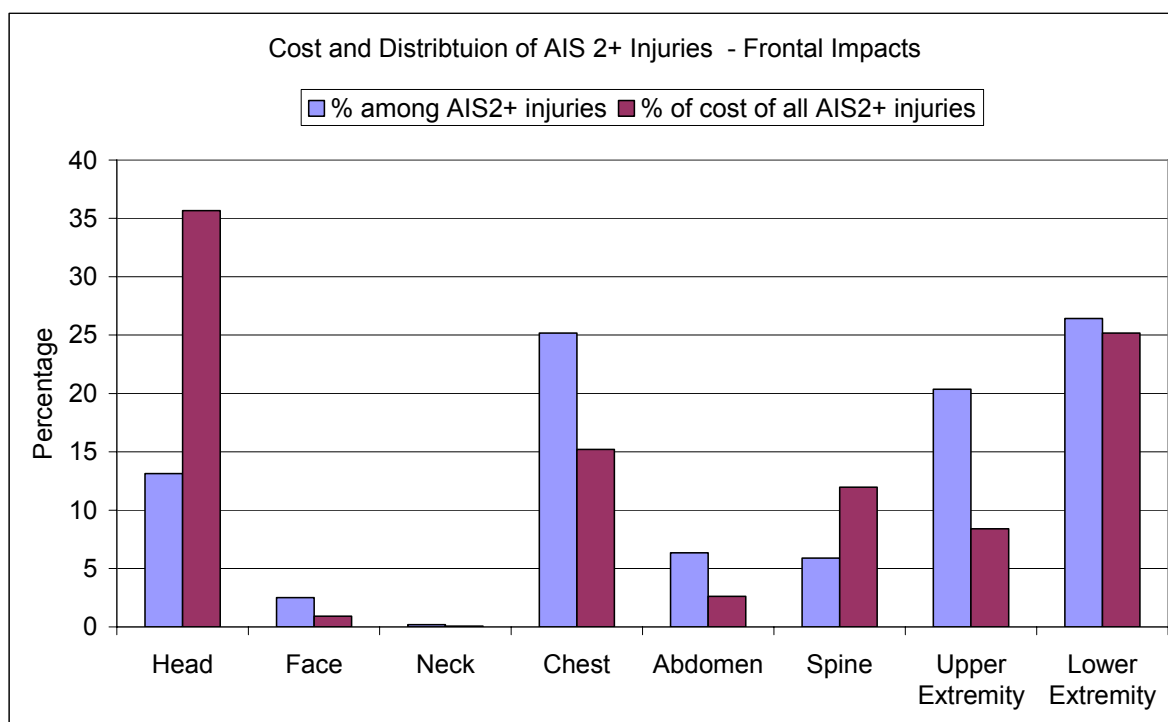
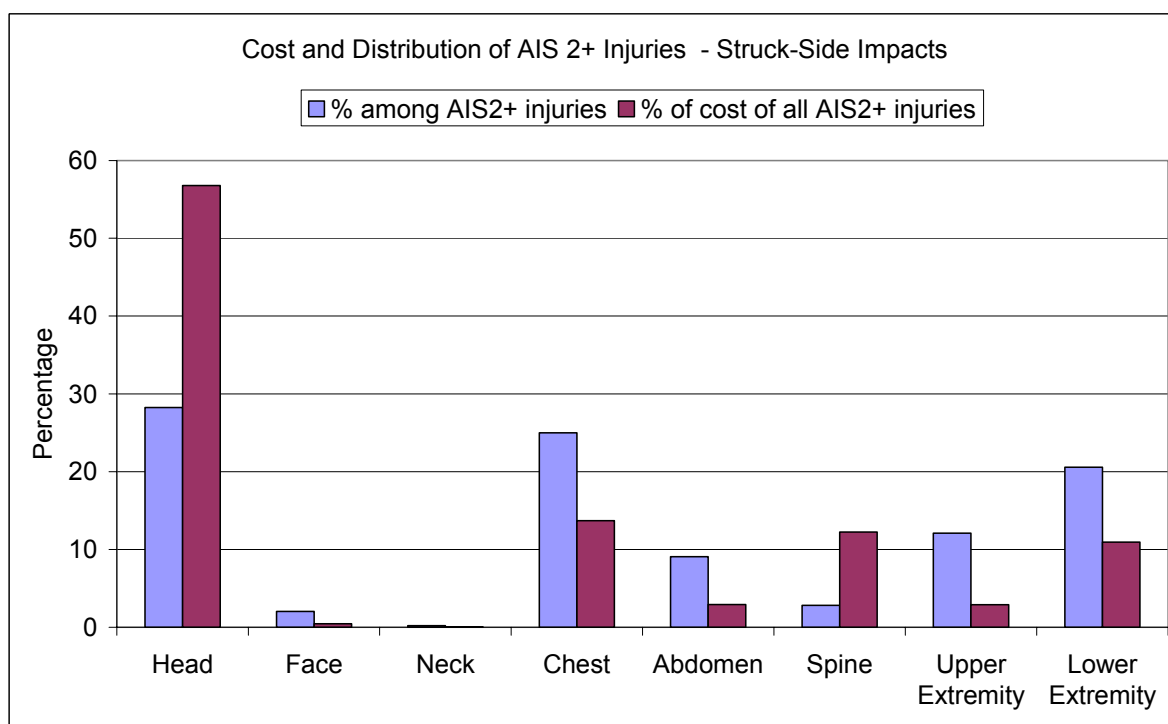
**Figure 3**

Figure 4 shows a comparable analysis to that presented in Figure 3 only this time struck-side impacts are considered. As can be seen from the figures, head and chest injuries are the most common injuries. However, as discussed previously, head injuries are by far the most costly.

**Figure 4**

Conclusions

In newer model cars, when all accident modes and all injury severities are considered, whiplash is by far the most costly single injury type among those experienced by car occupants, though not the most frequent. Injuries to the lower extremity are the most frequent.

When whiplash and slight injuries are excluded from the analysis, injuries to the chest are most frequent followed by those to the lower extremity. However, head injuries remain the most costly due to the associated mortality and severe neurological outcomes.

In frontal impacts lower extremity and chest injuries are the most frequently occurring whilst head injuries remain the most costly. In struck-side impacts head and chest injuries are the most frequent and head injuries the most costly.

Four groups of injury are apparent, representing a combination of either or both frequency and cost. These are whiplash, head injuries, chest injuries and lower extremity injuries. Severe head and chest injuries have a high associated risk of mortality and so reducing these injuries is a priority for reducing fatalities. In terms of countermeasures, already existing technologies (front and side airbags/curtains) have initially been shown to be effective in reducing the severity of head injuries (Kirk 2002, Morris 2005). This should continue to be monitored as the fleet penetration increases. For chest injuries the benefits of chest protection systems (e.g. side airbags) are as yet inconclusive (Morris 2005). Further measures may be required particularly in the case of struck-side impacts. Lower extremity injuries, whilst not necessarily life-threatening are known to have adverse long-term/permanent consequences for those afflicted.

3.3.2 Leg injuries in front and side impacts

Injuries to the lower extremity take on significance in terms of both frequency and cost when car occupants who survive a road accident are considered. Figures 5

and 6 repeat the injury cost analysis for AIS 2+ injuries in front and struck side crashes, this time only including non fatally injured occupants.

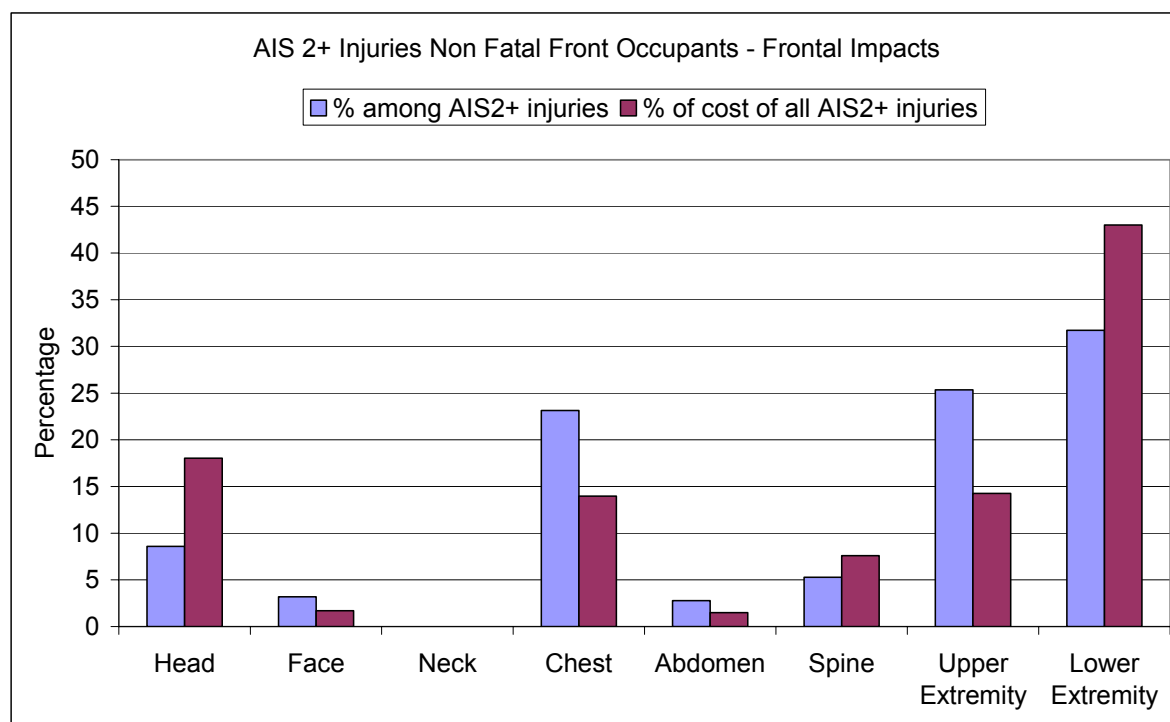


Figure 5

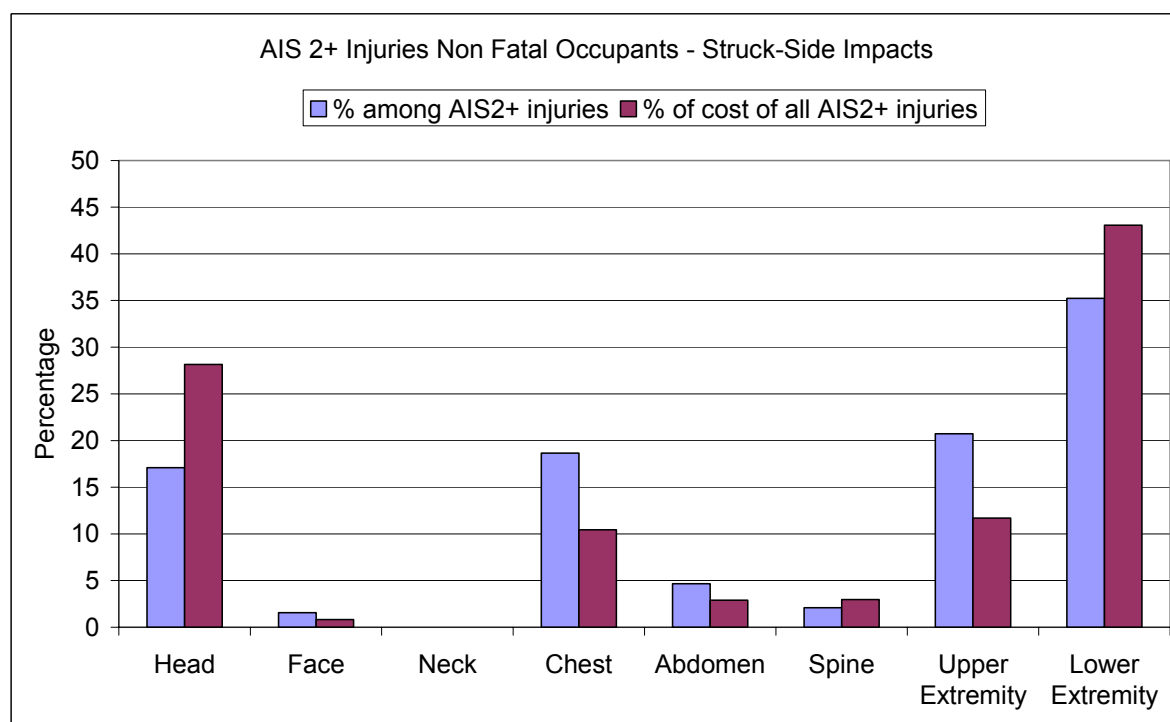


Figure 6

In both front and struck-side impacts lower extremity injuries are the most frequent and the most costly injuries sustained by non-fatal front seat occupants.

An analysis was made of the CCIS data (including phases 4, 5 and 6) to look at possible differences in leg injury types between older (pre 1992) and newer (1998 onwards) designs of vehicles. Both drivers and front seat passengers were considered together as front seat occupants.

Frontal Impacts

Table 5 shows the Maximum AIS score to the leg (including the pelvis) for front seat occupants in frontal impacts.

Table 5: Leg Injury Outcomes to Front Seat Occupants – Front Impacts

Old Cars				New Cars			
maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+	maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+
52.1%	47.9%	17.9%	8.7%	61.4%	38.6%	11.1%	5.4%

Improvements in the rates of maximum AIS score to the leg are seen in new cars compared to old cars.

Considering the type of leg injury, Table 6 shows the distribution of injury type in frontal impacts when comparing older vehicle designs and newer vehicle designs. The percentages are shown as a proportion of the total number of AIS2+ injuries sustained in frontal crashes. For example, in older vehicles, there were 526 individual AIS2+ injuries to all body regions in frontal crashes. Of these, 155 (29.5%) were to the pelvis and lower extremity.

Table 6: Distribution of injury type in frontal impacts – old and new cars

Injury Type	Older Vehicle (N=526 AIS2+ injuries – all body regions)		Newer Vehicle (N=1,122 AIS2+ injuries – all body regions)	
	N	%	N	%
Muscle, tendon, ligament injury	1	0.2	11	1.0
Joint injury	11	2.1	16	1.4
Ankle fracture*	12	2.3	37	3.3
Calcaneus fracture	6	1.1	17	1.5
Fibula fracture (excluding malleolus)	19	3.6	10	0.9
Femur fracture	29	5.5	73	6.5
Foot fracture**	14	2.7	38	3.4
Patella fracture	5	1.0	24	2.1
Tibia fracture	34	6.5	33	2.9
Pelvic fracture	24	4.6	31	2.8
Total	155	29.5	290	25.8

*NB Ankle fracture includes fractures to the talus, malleoli, and ankle fractures not further specified

**Includes tarsal, meta-tarsal and phalange

The above table can be further summarised as follows to show changes in the overall injury type. The proportion indicates the relative frequency of the injury type among all AIS 2+ injuries (N=526 old cars and N=1,122 new cars). The rate of injury type gives the proportion of all belted occupants in frontal impacts with this injury type (N=461 old cars and N=1,628 new cars) irrespective of multiplicity of injury within a given injury type. Additionally the final percentage, injury rate, gives the rate of injury type among all front seat occupants in frontal impacts when multiplicity of injuries within injury type is excluded, i.e. if an occupant has more than one femur injury they will only score once in that injury type.

Table 7: Overall leg injury type in frontal impacts

Injury Type	Old cars			New Cars		
	Proportion of all AIS 2+ injuries	Rate of injury type	Injury Rate	Proportion of all AIS 2+ injuries	Rate of injury type	Injury Rate
Pelvis	4.5 %	5.2%	4.6%	2.8%	1.9%	1.7%
Femur	5.5 %	6.3%	5.6%	6.5%	4.5%	3.9%
Tibia/Fibula	10.1 %	11.5%	6.1%	3.8%	2.6%	2.0%
Foot/Ankle	6.1 %	6.9%	6.1%	8.2%	5.7%	4.1%

As can be seen from Table 7, considering the rates of injury (irrespective of multiplicity of injury type), improvements are seen in the newer cars compared to the older cars for all injury types. The greatest improvement is seen for tibia/fibula injury whilst less dramatic improvements have been recorded for the femur and foot/ankle. This is also the case for the injury rate excluding multiplicity of injury type.

It is still the case however (Figure 5) that AIS 2+ lower extremity injuries remain the most frequent injury type and the most costly injury type among serious injuries sustained by non fatal front seat occupants in frontal impacts.

Considering the proportion of different lower extremity injury types (table 7), in newer cars foot and ankle injuries followed by femur fractures are the most prevalent.

Side Impacts

Analysis of the data on lower extremity injuries for front seat occupants involved in struck-side crashes has also been undertaken.

Table 8 shows the Maximum AIS score to the leg (including the pelvis) for front seat occupants in struck-side impacts.

Table 8: Leg Injury Outcomes to Front Seat Occupants – Struck-Side Impacts

Old Cars				New Cars			
maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+	maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+
38.5%	61.5%	21.8%	11.5%	64.1%	35.9%	14.0%	7.0%

Improvements in the rates of maximum AIS score to the leg are seen in new cars compared to old cars.

Table 9 shows the injury type for AIS 2+ leg injuries in struck-side impacts. The percentages indicate the proportion of each injury type among all AIS 2+ injuries received by front occupants in struck-side impacts.

Table 9: Distribution of injury type in side impacts – new and old cars

Injury Type	Older Vehicle (N=143 AIS2+ injuries – all body regions)		Newer Vehicle (N=498 AIS2+ injuries – all body regions)	
	N	%	N	%
Surface injury	1	0.7	2	0.4
Joint injury	0	0	4	0.8
Ankle fracture*	2	1.4	7	0.2
Calcaneus fracture	0	0	1	0.2
Fibula fracture (excluding malleolus)	2	1.4	10	2.0
Femur fracture	5	3.5	18	3.6
Foot fracture**	0	0	5	1.0
Patella fracture	0	0	0	0
Tibia fracture	4	2.8	12	2.4
Pelvic fracture	19	13.3	44	8.8
Total	33	23.1%	103	20.1%

The above table can be further summarised as follows to show changes in the overall injury type. Again, the proportion indicates the relative frequency of the injury type among all AIS 2+ injuries (N=143 old cars and N=498 new cars). The rate of injury type gives the proportion of all belted occupants in struck-side impacts with this injury type (N=82 old cars and N=405 new cars) irrespective of multiplicity of injury within a given injury type. Additionally the final percentage, injury rate, gives the rate of injury type among all front seat occupants in struck-side impacts when multiplicity of injuries within injury type is excluded.

Table 10: Overall leg injury type in side impacts

Injury Type	Old cars			New Cars		
	Proportion of all AIS 2+ injuries	Rate of injury type	Injury Rate	Proportion of all AIS 2+ injuries	Rate of injury type	Injury Rate
Pelvis	13.3%	23.2%	17.1%	8.8%	10.9%	7.9%
Femur	3.5%	6.1%	6.1%	3.6%	4.4%	4.2%
Tibia/Fibula	4.2%	7.3%	6.1%	4.8%	5.9%	3.2%
Foot/Ankle	1.4%	2.4%	2.4%	1.2%	3.2%	2.2%

As can be seen from Table 10, good improvements are apparent for the pelvis injury rate (both including and excluding multiple injury types) in newer cars compared with older cars. Benefits are also seen for femur and tibia/fibular injury rates. There does not appear to have been an improvement in the rate of foot/ankle injury for front seat occupants in struck-side crashes, but this injury type is relatively

uncommon among AIS 2+ injuries in struck side impacts. The leg injuries comprising the highest proportion of all AIS 2+ injuries in newer cars remain pelvis injuries followed by those to the tibia.

Conclusions

The data indicate that foot/ankle and femur fractures remain an outstanding issue particularly for survivors of frontal crashes. Foot/ankle injuries now comprise 8.2% of all AIS2+ injuries received in frontal impacts. They are an important sub-set of injuries because, although they are not especially life-threatening, some are invariably associated with long-term disability and impairment (for example calcaneous, pilon, Lisfrancs and talus fractures) and for this reason are expensive in nature.

Regarding struck-side impacts, though improvements in the pelvis injury rates are seen in newer cars these remain the most frequent leg injury type among AIS 2+ injuries received in struck-side impacts.

It would be beneficial to examine the mechanism of foot/ankle injuries in frontal crashes in more detail (using techniques developed in the LLIMP project), especially in newer vehicle designs where intrusion is not a factor.

The data on side impacts do not suggest that lower extremity injuries are particularly problematic although it should be highlighted that there is no discernible decrease in injury rates to the femur, tibia/fibula and foot/ankle. This is as expected since this body region is not instrumented in current regulatory crash-test dummies.

3.3.3 Side impacts in relation to the regulatory test procedure

The aim of this analysis is to look at the injury outcome in car to car struck side crashes for front seat occupants in newer model vehicles (1998 onwards) in relation to the characteristics of the crash test procedure. The characteristics under consideration are the direction of force of the impact, the closing speed of the impact and the impacting height of the bullet vehicle in relation to the target vehicle's sill height.

Direction of Force

Three scenarios were analysed; all directions of force including side-swipe type impacts (158 occupants), non oblique angles (3 o'clock and 9 o'clock, 36 occupants) and oblique frontal angles (2 o'clock and 10 o'clock, 40 occupants). Tables 11 to 20 show the distribution of MAIS and Maximum AIS (max AIS) by body region for struck side front occupants for these categorisations.

Table 11: MAIS – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
MAIS 0,1	72.8 %	58.3 %	72.5 %
MAIS 2,3	17.1 %	27.8 %	17.5 %
MAIS 4+	5.7 %	13.9 %	5.0 %
Not Known	4.4 %	0 %	5.0 %

Table 11 shows the maximum injury severity scale score across all body regions (MAIS). The lowest rate of MAIS 0,1 injury outcome (slight or no injury) occurs for the non oblique directions of force and consequently there is a higher rate of Serious injury outcome (MAIS 2,3 (10%) and 4+ (12%)).

Considering the injury outcome across various body regions, Table 12 shows the maximum AIS score to the head.

Table 12: Max AIS Head – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	83.5 %	80.6 %	77.5 %
Max AIS 2,3	10.1 %	13.8 %	17.5 %
Max AIS 4+	1.9 %	5.6 %	0 %
Not Known	4.5 %	0 %	5 %

Serious head injury is most prevalent in non oblique impacts, followed by oblique impacts; both rates are higher than when all directions of force are considered together.

Table 13: Max AIS Neck – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	94.2 %	100 %	92.5 %
Max AIS 2,3	1.3 %	0 %	2.5 %
Max AIS 4+	0 %	0 %	0 %
Not Known	4.5 %	0 %	5 %

Neck injury rates by injury severity are shown in Table 13. Serious neck injury is relatively rare in struck side impacts, however when these do occur they appear most prevalent in oblique impacts. There were no cases of Serious neck injury in non oblique impacts for this sample of accidents.

Table 14: Max AIS Struck Side Arm – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	91.1 %	88.9 %	95.0 %
Max AIS 2,3	4.4 %	11.1 %	0 %
Max AIS 4+	0 %	0 %	0 %
Not Known	4.5 %	0 %	5 %

Table 14 gives the severity and rate of injuries to the struck side arm. Clearly the rate of Serious injury is greatest for non oblique impacts. However when the non struck side arm is considered (Table 15) there are firstly fewer Serious injuries and the rates are similar among the various directions of force.

Table 15: Max AIS Non Struck Side Arm – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	93.0 %	97.2 %	92.5 %
Max AIS 2,3	2.5 %	2.8 %	2.5 %
Max AIS 4+	0 %	0 %	0 %
Not Known	4.5 %	0 %	5.0 %

Table 16: Max AIS Chest – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	84.2 %	72.2 %	87.5 %
Max AIS 2,3	7.0 %	16.7 %	2.5 %
Max AIS 4+	4.3 %	11.1 %	5.0 %
Not Known	4.5 %	0 %	5.0 %

For chest injury (Table 16) again the rate of Serious injury is considerably higher for non oblique impacts (27.8) than for the oblique (7.5) and when all directions of force are considered together (11.3).

Table 17: Max AIS Abdomen– Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	91.0 %	88.9 %	92.5 %
Max AIS 2,3	3.2 %	11.1 %	0 %
Max AIS 4+	1.3 %	0 %	2.5 %
Not Known	4.5 %	0 %	5.0 %

The injury rates and respective severities for abdominal injuries are shown in Table 17. The rate of Serious injury is highest for non oblique impacts, 11.1% compared to 2.5% in oblique impacts and 4.5% for struck side impacts in general.

A similar situation occurs for pelvic injuries (Table 18). Here the rate of Serious injury in non oblique impacts is 13.9% compared with 5% in oblique impacts and 6.3% for struck side impacts in general.

Table 18: Max AIS Pelvis– Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	89.2 %	86.1 %	90.0 %
Max AIS 2,3	5.7 %	11.1 %	5.0 %
Max AIS 4+	0.6 %	2.8%	0 %
Not Known	4.5 %	0 %	5.0 %

Table 19 and Table 20 show the injury rates for the struck side leg and the non struck side leg respectively. Whilst the rate of Serious injury for the struck side leg is much higher for non oblique impacts (11.1%) compared to oblique impacts (2.5%) and struck side impacts in general (3.2%), the rates are lower and more comparable for the non struck side leg (5.6%, 2.5% and 4.4% respectively).

Table 19: Max AIS Struck Side Leg – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	92.3 %	88.9 %	92.5 %
Max AIS 2,3	3.2 %	11.1 %	2.5 %
Max AIS 4+	0 %	0 %	0 %
Not Known	4.5 %	0 %	5.0 %

Table 20: Max AIS Non Struck Side Leg – Struck Side Front Occupants

	All Dof	Non Oblique	Oblique
Max AIS 0,1	91.1 %	91.6 %	92.5 %
Max AIS 2,3	4.4 %	5.6 %	2.5 %
Max AIS 4+	0 %	2.8 %	0 %
Not Known	4.5 %	0 %	5.0 %

Closing Speed

As a measure of the impact severity, the closing speeds (km/h) for side impacts in which there was a car to car impact have been calculated. The closing speeds for struck side occupants in newer model cars are shown in Table 21.

Table 21: Closing speeds, struck side occupants (N=73)

	25th percentile	50th percentile	75th percentile
All severities	34.5 km/h	46 km/h	65.0 km/h
MAIS 2+	43.5 km/h	62 km/h	76 km/h
MAIS 3+	46 km/h	70 km/h	81 km/h
Fatalities	71 km/h	76 km/h	90.8 km/h

When all occupant severities are considered, the 50th percentile closing speed is a little lower than the current test speed (50 km/h). However, selecting on those occupants with Serious injury outcome (MAIS 2+ and MAIS 3+) gives a higher closing speed distribution where the 25th percentile is closer to the current test speed. The closing speed for fatalities far exceeds the current test speed.

It should be noted that the sample size used here is small (73 struck side occupants) since substantial pre selection on a data set comprising only newer cars has been made and both cars in the accident needed to have a recorded DeltaV in order to calculate the closing speed. However the results are in accordance with

previous work (Thomas et al, 2003) presented and referenced in appendix 2, section 10.

Both this and the previous study indicate that Serious injury is prevalent and more frequent at impact speeds exceeding the current test speed and consideration should be given to increasing the test speed in order to better reflect the crash circumstances under which Serious injury still occurs in newer cars.

Impact Height

An analysis was made of car to car impacts where the impact on the struck side was into the passenger compartment i.e. middle third of the car (266 occupants). The analysis was made on an occupant basis to establish the proportion of occupants exposed to conditions where the sill has been overridden.

In 64% of cases, there was direct contact upon the sill, however the variable used in the analysis does indicate whether there was or was not an override of the sill at the same time. In 88 out of the 266 cases examined the bottom of the direct contact of the bullet car was clearly above the sill height for the struck side occupant, a third of cases. This is considered an underestimate of the number of cases since this represents full override and does not include cases where partial override may have occurred. In those cases where full override occurred, over two thirds of the bullet cars have a reported effective stiff structure height greater than 390 mm. The lower stiff structures on car fronts may be set more rearwards so there may be considerable intrusion from override even when there is good later stage structural engagement.

Conclusions:

The analysis of injury severity in relation to the direction of force confirms that, in newer model cars, higher rates of Serious injury outcome for struck side occupants are apparent in non oblique impacts compared with oblique impacts and struck side impacts on the whole. This is particularly the case for the chest, abdomen, pelvis and struck side limbs but not the case for head impacts.

With respect to the impact speed, it is evident that in newer model cars Serious injury outcome occurs at crash speeds above that used in the current crash test. In order to predict and monitor these Serious injuries, consideration should be given to modifying the existing side impact test speed to better reflect that in which Serious injury occurs in real world crash situations.

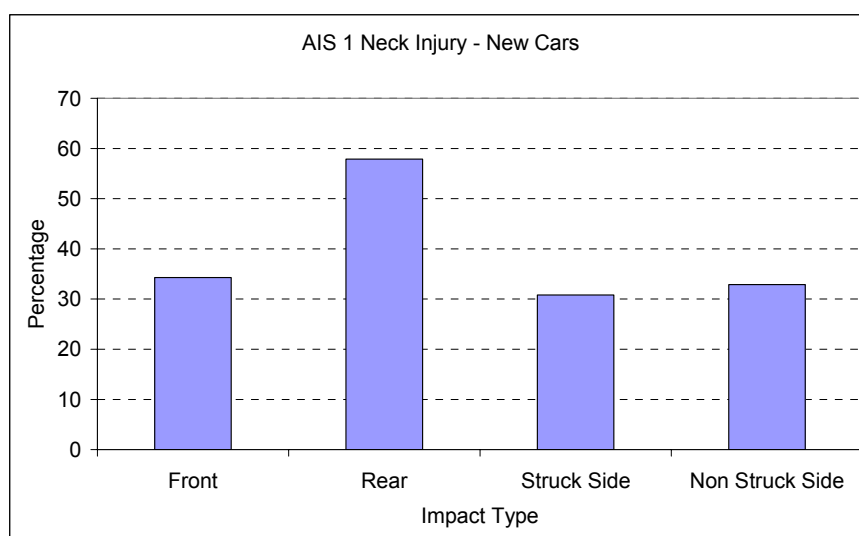
A sizeable proportion of bullet cars contact the case car above sill height. It is anticipated that this proportion will grow as SUV/MPV type vehicles become increasingly prevalent in the fleet. Consideration should be given to the structure and point of impact of the Mobile Deformable Barrier (MDB) in the side impact test procedure in light of the changing vehicle fleet.

Higher rates of serious injury are seen in struck side non oblique impacts compared with oblique impacts. This is the case particularly for the chest with further protection also required for the abdomen, pelvis and struck side limbs.

3.3.4 Whiplash Injury

An analysis has been made of the CCIS data phases 5,6 and 7 to identify the prevalence of whiplash injury among front seat occupants in different impact types and with varying occupant characteristics. Discrimination has been made by vehicle age with the data being separated into older cars (pre 1992) and newer cars (1998 onwards). Results are reported for the newer cars alone to establish the priority areas in the current modern fleet. Comparisons between the newer and older model cars are also presented thus highlighting those areas where dis-benefits in terms of whiplash injury outcome are seen in the new cars.

For the purposes of this analysis, whiplash has been selected as AIS 1 neck injury, the majority of which in the data are indeed whiplash injuries (approximately 96%)

**Figure 5**

Considering how the rate of AIS 1 neck injury varies according to the type of impact occurring (Figure 5), clearly the rate is highest for rear impacts (58%). For front, struck side and non struck side impacts, the rate is typically between 30 and 35%.

Table 22 shows the different types of impacts that passenger cars are involved in on an annual basis (STATS19 vehicle file 2004). This is approximated from the variable 'first point of impact' to the vehicle. Frontal impacts account for 52.5% of all impacts, rear impacts 20.6%, with side impacts comprising 23.4% of the total. Thus, in terms of frequency and associated cost of whiplash injury, frontal impacts present the greatest problem followed by rear impacts and then side impacts.

Table 22: Vehicle first point of impact, cars – STATS19 2004

Impact type	Percent
Front	52.5
Rear	20.6
Side	23.4
None	3.5

Figure 6 shows the AIS1 neck injury rates in frontal impacts when the data are further separated by gender and age. Female front seat occupants and those classified as younger occupants have an above average rate of AIS 1 neck injury for this impact type. Male occupants have a below average rate of whiplash whilst

the older occupants have the lowest rate (24%). A similar pattern is apparent for rear impacts (Figure 7) and stuck side impacts (Figure 8).

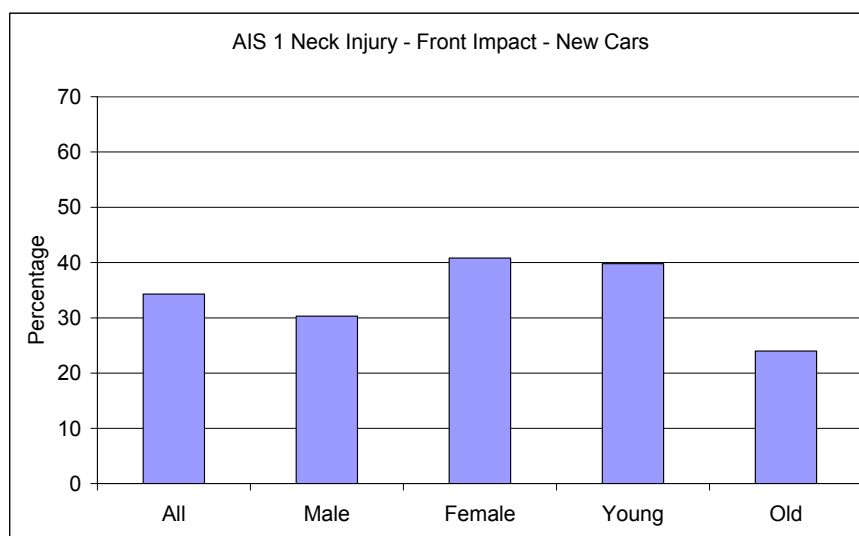


Figure 6

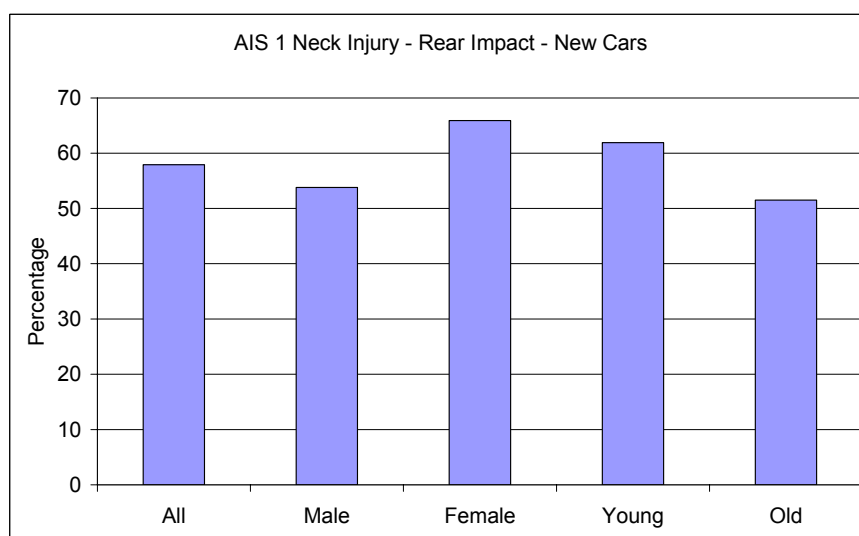
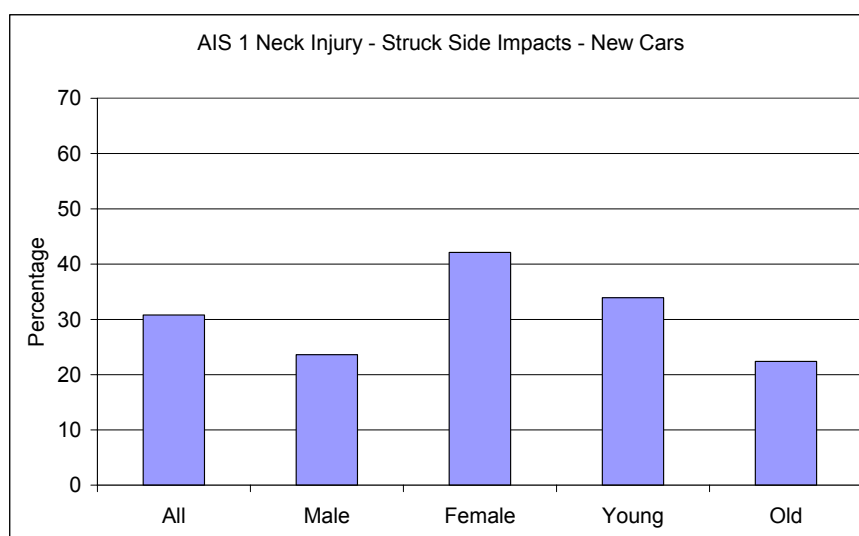
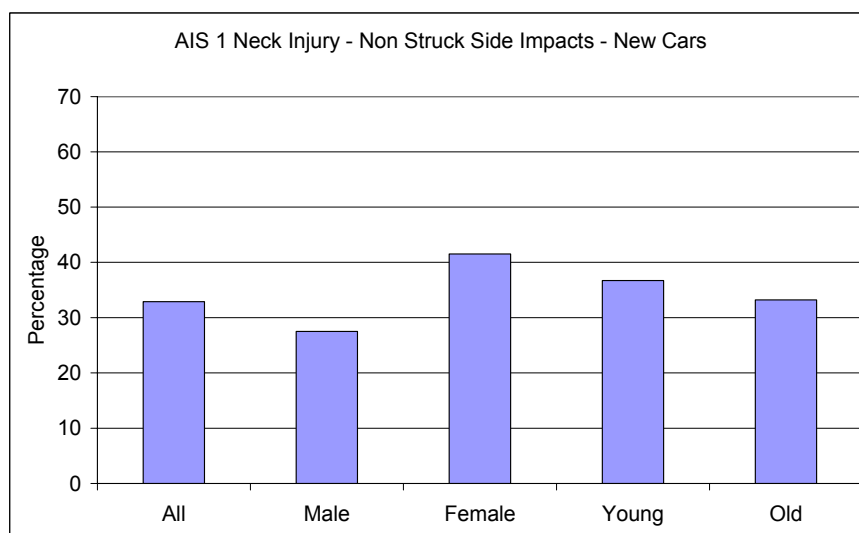


Figure 7

**Figure 8**

For non struck side impacts (Figure 9), each of the female, the younger and the older groups have an above average rate of AIS 1 neck injury with the rate for females being the highest. Male occupants have a below average rate of this type of injury.

**Figure 9**

Comparison Between Older and Newer Cars

Figures 10 to 13 compare the AIS 1 neck injury rates between old and new cars. A score of 0 indicates that the rate of injury was identical in both the older and newer cars. A negative value indicates that the rate is higher in the new cars compared to the older cars whilst a positive value shows an improvement in the newer cars. The magnitude of the score reflects the size of the difference between the two groups.

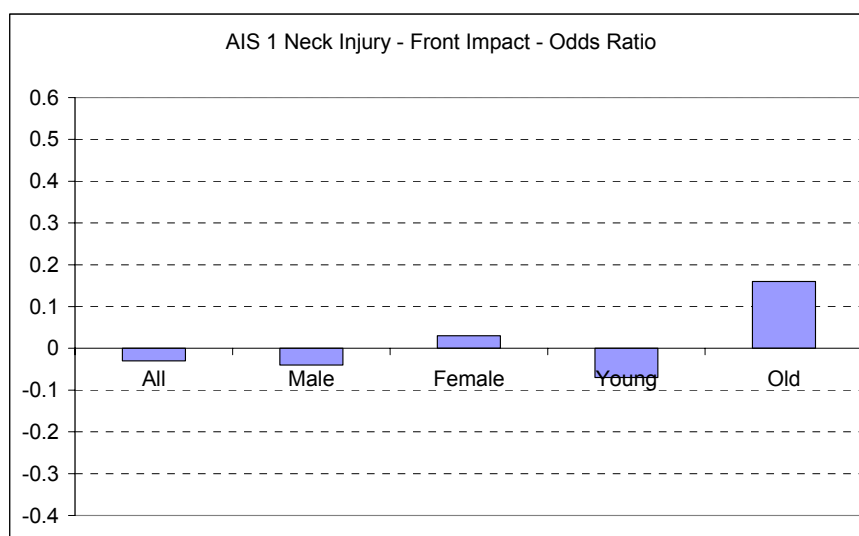


Figure 10

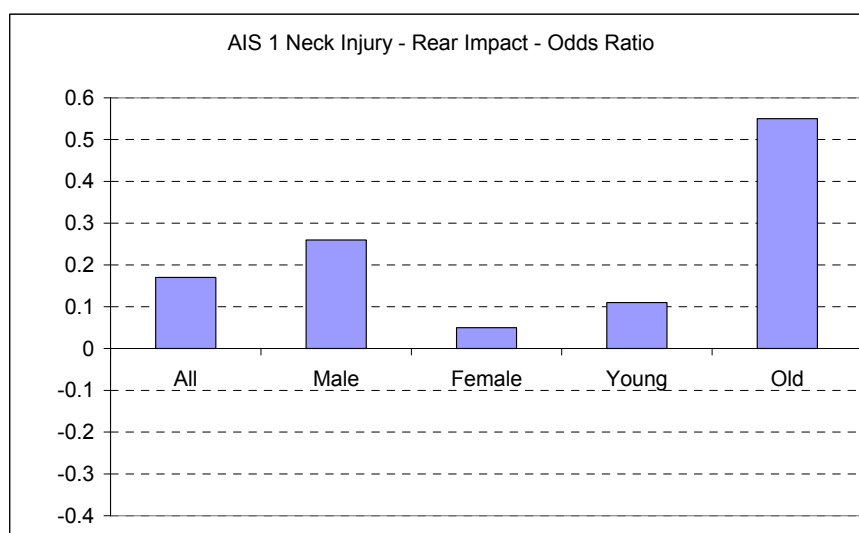


Figure 11

Figure 10 above shows the comparison for frontal impacts. Overall (all occupants) there is a marginal dis-benefit in the rate of AIS 1 neck injury in the newer cars. When front occupants are split by age and by gender then there are dis-benefits for the younger occupants and for the male occupants.

Figure 11 above illustrates the comparison for rear impacts. Clearly the rate of AIS 1 neck injury is better for all front occupants in the newer cars compared with the older vehicles.

Figure 12 compares the new and old cars for struck side impacts. In this case the older occupants are the group where the rate of AIS1 neck injury is higher in the newer vehicles compared to the older vehicles.

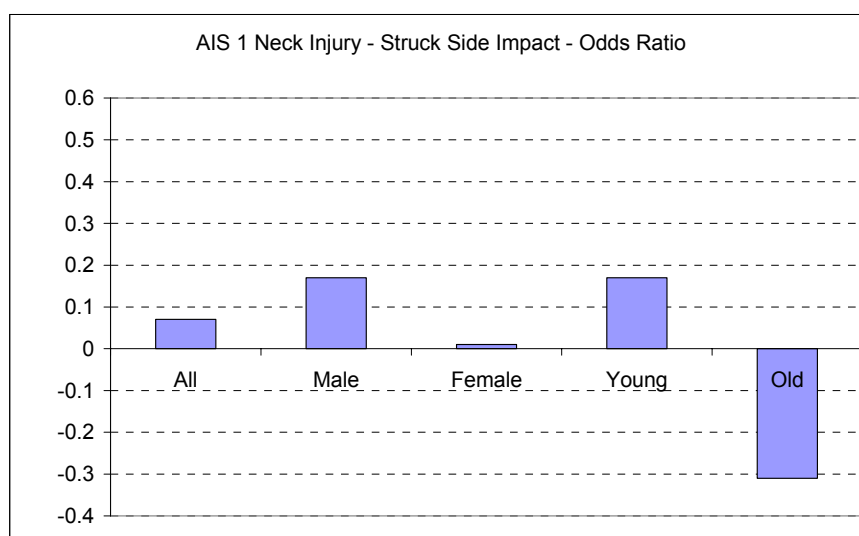
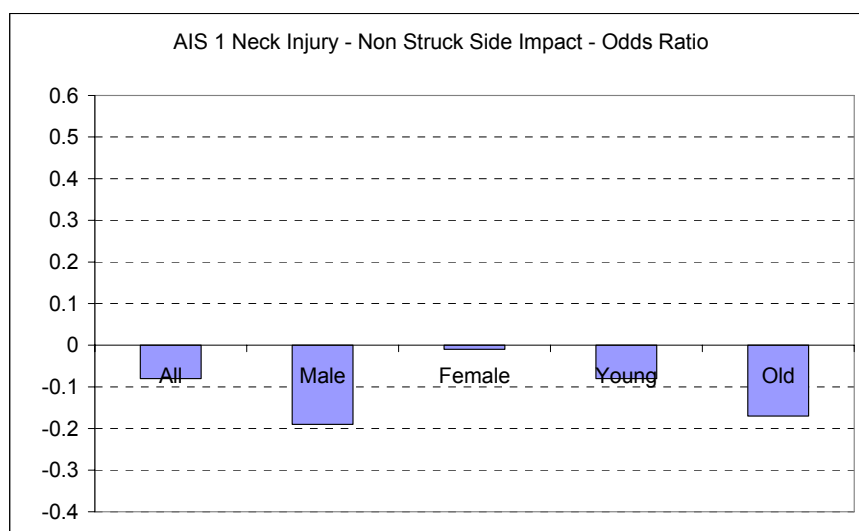


Figure 12

Finally, Figure 13 shows the comparison of neck injury rates in non struck side impacts. Here it is evident that all front occupants are disadvantaged in terms of AIS 1 neck injury outcome in newer cars compared to older cars.

**Figure 13**

Conclusions

The CCIS data is limited in respect to performing a detailed assessment of whiplash injury causation and the effectiveness of modern technology, largely due to reporting effects. The CCIS data allows for self-certification of injuries at the AIS 1 level, this in conjunction with the rise in insurance claims could lead to over reporting of this injury type. Conversely, CCIS operates an injury based sampling procedure where the attending police officer needs to report an injury at the time of the accident for the accident to be included in the CCIS sample. However, often the symptoms of whiplash injury do not become evident until some time after the event. In such crashes where no other injuries occur, the police would classify the accident as damage only and therefore it would not be sampled according to the CCIS protocol.

What is evident however is that whiplash remains twice as prevalent in rear impacts (60%) than other impact types where the rate is typically 30%. Taking exposure to impact type into account however, the majority of people experiencing whiplash will do so in a frontal impact.

Across all of the impact types considered, female front seat occupants have a higher rate of whiplash than male occupants and those front seat occupants younger than 50 years old have a higher rate than those over 50 years old (Figures 6,7,8 and 9).

A comparison of the whiplash rate in newer cars compared to older cars show instances where the AIS 1 neck injury outcome is worse in post-regulatory cars compared to pre-regulatory cars. Specifically this is for male occupants and for younger occupants in frontal impacts, for older occupants in struck side impacts and for all occupants in non struck side impacts. There were improvements in the newer cars for all occupants in rear impacts, perhaps an early indication of the effects of modern seat design aimed at mitigating whiplash injury in this type of impact but this would need to be examined in much more detail before conclusions could be formed.

3.3.5 Rear occupants in all impact types

An analysis was made of the national accident data (STATS19) in order to assess the effect of the introduction of the front and side impact regulation, in parallel with EuroNCAP, on injury outcome for occupants of passenger cars. The full analysis is available in the DfT project report S0221/VF, but a key finding is presented here.

Occupants involved in car to car impacts were examined and the injury outcome in terms of the KSI rate compared between occupants of vehicles distinctly pre and distinctly post-regulation. Comparisons were made between all occupants in a particular seating position, by gender (male/female) and by age (<50 / 50+). Each of the impact scenarios frontal, rear, right side and left side were examined.

Table 23: Summary of National data results – car to car impacts

Drivers	All	Male	Female	Young	Old
Front impact	√	√	√	√	√
Rear impact	√	√	√	√	√
Right impact	√	√	√	√	√
Left impact	√	√	√	√	√
FSP	All	Male	Female	Young	Old
Front impact	√	√	X	√	√
Rear impact	√	√	√	√	√
Right impact	√	√	√	√	X
Left impact	√	√	√	√	√
RSP	All	Male	Female	Young	Old
Front impact	X	X	X	X	X
Rear impact	X	√	X	√	X
Right impact	√	√	√	√	X
Left	√	X	√	√	X

Table 23 summarises the results. Where a tick occurs in a cell the KSI rate was either better or the same in the post-regulatory cars compared with the pre-regulatory cars; where a cross appears then the KSI rate was greater in the older cars than the newer cars.

It can be seen that for drivers, there is an improvement in the rate of KSI outcome in the new cars for all seating positions and for all impact types.

In the case of front seat passengers the majority of seating positions and impact types show an improvement in post-regulatory vehicles, the exceptions being for female front seat passengers in frontal impacts and for older front seat passengers in right side impacts.

For rear seat passengers (RSPs) there are a number of cases where the KSI rate is higher in the newer cars than in the older cars; of particular note is the frontal impact scenario where the data indicate disbenefits for all RSPs irrespective of gender or age. Table 24 shows these KSI rates for RSPs in newer and older cars for frontal impacts together with the percentage change.

Table 24: KSI rates for RSPs in car to car frontal impacts

RSP	All	Male	Female	Young	Old
Old Cars	9.1%	9.4%	8.9%	8.2%	16.9%
New Cars	10.1%	10.6%	9.8%	9.3%	17.5%
% Change	11%	13%	10%	13%	3%

Conclusions

This analysis of the STATS19 data has highlighted a potential problem for rear seat occupants of newer cars (not limited to older occupants) who appear disadvantaged when in a frontal impact in a post-regulatory vehicle compared with an older car. This is however an early result and there are many points to explore before the exact extent and nature of this result can be properly understood.

As a consequence of improved frontal impact protection for front seat occupants by reducing intrusion, vehicles have become stiffer across their frontal structure. This

in turn has the effect of increasing the severity of the crash pulse and resultant forces experienced by the occupants at a given crash speed. Whilst secondary safety measures have been introduced for front occupants (load limiters, pre-tensioners and airbags) this is not the case for those seated in the rear. It is possible therefore that the increased rate of KSI outcome for rear occupants is a result of design changes aimed at improved frontal impact protection.

Further research including an examination of the in-depth data (though the number of cases may be limited) is required in order to determine the crash configuration, injury type and occupant characteristics that result in Serious injury to rear occupants. Once this is established potential countermeasures and effective monitoring of the situation can be considered.

3.3.6 Chest Injuries in front and side impacts

Previous analysis (section 3.3.2) has considered leg injuries in front and side impacts, these being both frequent and costly among non fatal occupants. Life threatening upper extremity injuries are extremely rare however chest injuries are significant in fatality outcome. This analysis looks in more detail at the severity and nature of chest injuries in new cars compared to old cars and examines where the remaining priorities lie.

Frontal Impacts

The distribution of maximum AIS to the chest for front seat occupants in frontal impacts was as follows (Table 25);

Table 25: Chest Injury Outcomes to Front Seat Occupants – Frontal Impacts

Old Cars				New Cars			
maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+	maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+
49.2%	47.5%	17.6%	10.4%	49.0%	45.0%	11.4%	5.4%

- Chest injury rates in 'New' cars have improved for front seat occupants.
- The improvements are particularly noticeable at the maxAIS 2+ and maxAIS 3+ levels.

The chest injury types are shown in Table 26.

Table 26: AIS 2+ Chest injuries front seat occupants in frontal impacts

Injury Type	Old Vehicle (N=526 all AIS 2+injuries)				New Vehicle (N=1,122 all AIS 2+ injuries)			
	N	% all AIS 2+ injuries	Rate of injury %	Injury rate %	N	% all AIS 2+ injuries	Rate of injury %	Injury rate %
Vessel	13	2.5	2.8	2.4	13	1.2	0.8	0.7
Organ	39	7.4	8.5	6.7	80	7.1	4.9	3.3
Skeletal	67	12.7	14.5	12.4	188	16.8	11.5	10.1
Total	119	22.6	-	-	281	25.0	-	-

Table 26 shows the proportion of all injury types in the newer cars compared with the older cars and the rate of injury irrespective of multiplicity of injury among all front seat occupants in frontal impacts (N=461 old cars, N=1628 new cars). The injury rate (as for the leg injuries) gives the rate of the injury type when multiple injuries to an occupant within a given injury type are excluded.

Both the rate of injury and injury rate have improved in newer cars compared with older cars for each of the injury types. Whilst the rates of vessel and organ injuries have more than halved between the two car samples, this is not the case for skeletal injuries. These remain a large proportion of all AIS2+ injuries received in frontal impacts. However, when looking at the data in more detail, it should be noted that over half (54%) of the AIS2+ injuries are fractures to the sternum which are ranked as AIS 2 injuries and, whilst painful, are usually uncomplicated in nature and generally lead to a full recovery in a short space of time. Generally sternum fractures are a by-product of belt-wearing and clearly, whilst no injury is particularly desirable, far worse injury outcomes would be predicted in the absence of belt-wearing. Smart restraint systems tailored to individual characteristics (such as age, weight, height and bone density) are designed to mitigate such injuries. Whilst the data suggest that some skeletal injuries are accompanied by an organ injury, skeletal injuries alone are much more common.

Side impacts

The CCIS data file analysed contained 487 occupants in struck side impacts of which 80% were drivers and 20% were front seat passengers.

The sample was then divided up into the 2 groups – old cars (N=82) and new cars (N=405).

The distribution of chest injury to belted drivers and front seat passengers was as follows (Table 27).

Table 27: Chest Injury Outcomes to Front Seat Occupants – Side Impacts

Old Cars				New Cars			
maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+	maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+
48.8%	46.3%	25.6%	23.2%	57.5%	38.1%	13.7%	12.4%

- Chest injury rates in new cars have reduced for front seat occupants.
- Despite the improvements, a significant number of struck side occupants sustain MAIS 3+ chest injury in newer cars. These injuries are commonly associated with fatality.

For struck side occupants the chest injury types and injury rates (N=82 occupants old cars, N=405 occupants new cars) are shown in Table 28.

Table 28 shows the proportion of all AIS 2+ injuries by front occupants in struck-side crashes in the newer cars compared with the older cars. The rate of injury type irrespective of multiplicity of injury among all front seat occupants in struck-side impacts (N=82 old cars, N=405 new cars) is also shown. The injury rate, as previously, gives the rate of the injury type when multiple injuries to an occupant within a given injury type are excluded.

Table 28: AIS 2+ Chest injuries struck side occupants

Injury Type	Old Vehicle (N=143 all AIS 2+injuries)				New Vehicle (N=498 all AIS 2+ injuries)			
	N	% all AIS 2+ injuries	Rate of injury %	Injury rate %	N	% all AIS 2+ injuries	Rate of injury %	Injury rate %
Vessel	6	4.2	7.3	7.3	13	2.6	3.2	3.0
Organ	25	17.5	30.5	17.1	63	12.7	15.6	9.6
Skeletal	15	10.5	18.3	18.3	47	9.4	11.6	10.6
Total	46	32.2	-	-	123	24.7	-	-

Both the rate of injury and injury rate have improved in newer cars compared to older cars. However, unlike frontal impacts, of the remaining skeletal injuries, only 13% are sternum fractures with 80% being rib fractures (often MAIS 3+). The data also suggest that more often than not, injuries involving rib fractures, which can be penetrating in nature, are accompanied by a serious organ injury thus representing a greater threat to life than a simple sternum fracture.

Conclusions

Chest injuries in side impacts are more common than in frontal impacts; in particular MAIS 3+ injuries are almost twice as common. Whilst a large proportion of injuries in frontal impacts are the likely result of belt loads (i.e. sternum fractures), in side impacts it is more difficult to determine precise injury mechanisms and contact sources. The data suggest that in side impacts often a skeletal injury will be accompanied by an internal organ injury which is a more serious outcome than skeletal injury alone (because laceration of the underlying vessels and organs, including the lungs and pericardium, pose a greater threat to life).

Unlike the situation in frontal impacts, where smart restraint systems are being developed to counter the effects of belt loads, a different problem exists in side impacts. Intrusion and associated velocity of the door is an underlying issue in side impact protection and further understanding of the injury source for chest injuries in

side impacts would be justified together with an assessment of the crash circumstances in which they occur.

This analysis prompted a further investigation into the effectiveness of side airbags in side impacts that, though not carried out within the framework of this project, was published at IRCOB 2005 (Morris, Welsh 2005). Although this paper provided some thought-provoking initial results, a further study would be beneficial.

3.3.7 Child injury data (prepared in conjunction with NPACS)

This section gives the conclusions from a study considering injury risk and restraint issues for child car occupants. The full analysis can be found in Appendix 4.

Injury outcome

National Data (STATS19) shows that when children (less than 12 years old) are injured in cars they are less likely to receive Serious or Fatal injuries than adults (those aged 12 years old and above). Data from CCIS indicates that the head is the most commonly injured body region for CRS restrained children at both AIS ≥ 1 and AIS ≥ 2 injury levels. The extremities are the second most commonly injured body regions.

Impact types compared to adults

The National Data analysis generally shows that children in cars are in the same types of impacts as adults in cars, although proportionally more KSI adults are involved in single vehicle/rollover type accidents. There is no evidence that when children are in a car there are completely different priorities, considering impact/crash scenario, to take in protecting them. There are some differences for child fatalities; proportionally, compared with adults, children are involved in more accidents with large goods vehicles and accidents on roads with a 70 mph posted speed limit. For children, the number of fatalities in rear impacts with large goods vehicles may reflect the higher occupancy of the rear seats. Overall most impacts are frontal impacts with other cars, for both children and adults. For KSI child car casualties, side impacts are the second most common impact type according to the National Data, followed by rear impacts. This is not the case in the CCIS data but

the categorisation of impact type needs further investigation, especially for side impacts.

Promotion of child restraint use

It is clear that child restraints are effective at preventing AIS1 injuries, compared to just seat belts, in the CCIS dataset analysed. However, there is no significant difference in the proportions of MAIS ≥ 2 casualties between the CRS and seat belt groups though case numbers are low. What can be seen from the data is the increased proportion of children with AIS 1 injuries in the seat belt only group, especially to the abdomen. In the cases available here, an increase is not seen in MAIS ≥ 2 abdominal injuries for the seat belt group but it follows that if bruising is possible with only adult seat belts then as crash severity increases more serious abdominal injury is possible.

Helping adults to choose child restraints appropriately and then fit them correctly

Year on year evidence from child restraint checking campaigns in the UK (and in fact across the world) shows that the majority of child restraints examined are incorrectly fitted to some degree. In the campaigns that collect statistics, 30% of CRS are recorded as being fitted in such a way that the potential for injury is increased. It is clear from CCIS that children aged under 3 are still sometimes travelling only in adult seat belts or on an adult's lap. This confirms the importance of the continuing support of NPACS to make the selection of child restraints easier for adults and to promote the continuing improvement of CRS design by manufacturers, especially with regard to instructions and usability. Funding of local checking campaigns that inform parents and improve child safety would also be beneficial.

Increasing use of at least some restraint

It is clear from the CCIS data that 15% of children are recorded as being unrestrained, where positive coding has taken place and hence restraint use is known. It is clear from crash research that injury outcome is worse when adult occupants are unrestrained and there is no reason to believe that this is not also

the case for children. In CCIS, unrestrained children have injury outcomes shifted towards higher MAIS values compared to restrained children. There may be some issue of adult seatbelts causing injury to small children, especially abdominal injury that otherwise may not be seen, but these are likely to be less severe than those to a completely unrestrained child. Educating adults that children should not be unrestrained in cars, and especially cannot be held by an adult on their lap, is important.

Misuse

With the in-depth data available here it is not possible to determine what effect restraint misuse has on injury outcome and therefore what mitigating effect the elimination of the various types of misuse might have. However, whilst these data do not address these issues due to omissions in the data gathered (it is difficult to evaluate misuse in retrospective studies) or low numbers of cases, the understanding of the casualty numbers and the case examples involving misuse support the objectives of NPACS to develop an assessment programme which takes the possibility of CRS misuse into account. In addition there are ongoing activities in the CHILD programme to evaluate the effect of misuse on injury outcome.

Rollover

Of child fatalities in the National Data, 17% occur in circumstances with an element of rollover and the KSI rate (when an injury occurs) is highest for these crashes. It would be appropriate to include the testing of child restraint performance and the fit of the seat belt for larger children in any developments that occur in rollover testing or legislation.

Further Work

OTS Analysis

Even though at present case numbers are low, especially those with Serious injury outcome, the proportion of CRS restrained occupants in the OTS data is reassuring and should be examined again in the future as case numbers grow. Due to the more immediate nature of OTS investigation compared to CCIS, the possibility of recording misuse is greater, especially when the CRS is still at the scene.

Improvements to the sample available for the analysis of child car-occupant injury criteria

It is clear that injury risk analysis for children for different crash scenarios is not possible with currently available UK in-depth data due to the small number of Serious injuries across impact types, restraint types and ages. For example, even though side impact is identified as the second most frequent impact type for KSI child car-occupant casualties it is not possible to carry out detailed analysis of accident circumstance or injury outcome. A detailed study of the effect of the intrusion profile on serious injury outcome would, for example, be beneficial. If the number of cases collected with Serious injury could be increased then a better understanding of injury criteria would be possible. One solution is to look at cases at an International level, a methodology employed in the EC funded CHILD project, or to target specific cases of interest at a National notification level in the U.K. Areas of child safety that would particularly benefit from a focused UK National study include:

- New restraint types, especially ISOFIX or any future revisions to UN ECE R44.
- Side impact performance.
- Performance in rollovers.
- Performance in multiple impacts.
- Interaction with passenger and side airbags, and other advanced protection developments.
- Children with disabilities.
- CRS performance for older children, investigating the appropriateness of weight and height limits set by law.

Impact Categorisation

Individual case studies of multiple, rollover and 'other impact' CCIS and OTS cases to investigate whether they can be comfortably categorised as frontal, side or rear impact would be beneficial to the size of the sub samples available for analysis. This is difficult to achieve at an overall analytical level and requires case review with photographs. In the analysis carried out of in-depth cases it is thought that side impacts may be shifting into multiple, rollover or groups categorised as 'other', such as side swipe impacts. The proportion of side impacts in the National Data is higher than the in-depth data.

Investigation of whether CRS provide good protection in both single impact and multiple impact crashes, especially compared to seatbelts, would be interesting. If energy absorption by the CRS in the first impact causes damage, or there is movement of the CRS, subsequent protection may not be of the level expected.

Restraint Use

An important step in improving the level of analysis possible for child car occupants would be to include seat belt and CRS use as a variable in the STATS19 data collection and for roadside studies of restraint use to be carried out in order to distinguish between seat belt and CRS use. At the present time it is difficult to estimate the casualty reduction benefits of new child restraint use legislation and the advantages advanced CRS systems will bring when the current situation is not fully understood and no exposure data available.

Whilst information relating to restraint use is not available in the National Data, methods to improve the accuracy of the child restraint coding in the in-depth data should be considered. Questionnaires are already sent out to gather information but whether they are sent back or not is outside the control of the projects.

However, contact with the investigating police officer or those who attended the scene may yield information on restraint use or the position of children in the rear so that correlation with physical evidence in the vehicle is possible. There is the possibility in CCIS that occupants are categorised as being 'seat belt only' restrained when in fact there is no evidence that a CRS *was not* present. Contact

with the investigating police officer would be beneficial in making the data on the nature of the restraint used / not used more robust.

In summary, there are possibilities to enhance the data related to CRS use for child occupants in both CCIS and OTS.

3.3.8 Cycle Helmet Use

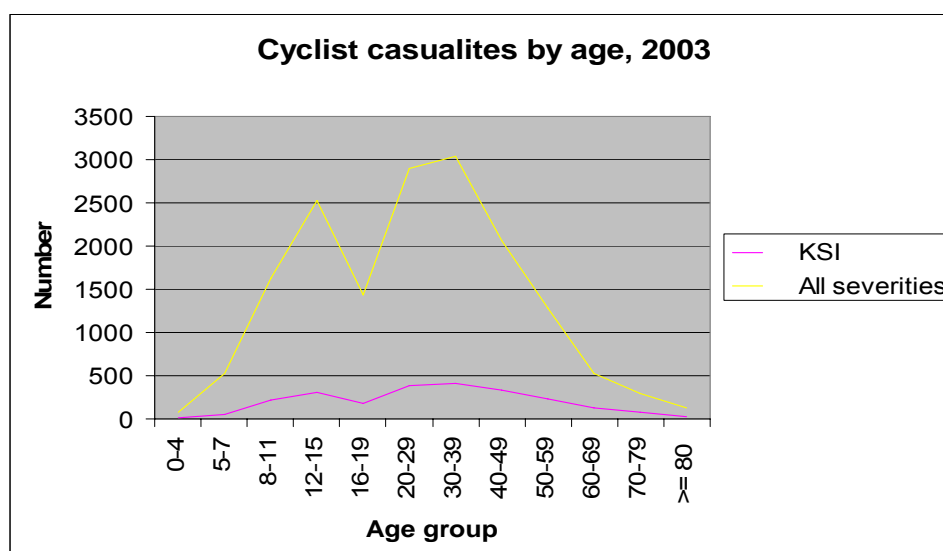
There is continued debate about the effectiveness of cycle helmets in reducing head injuries. In this section the latest statistics on cycling and related injuries are compiled and then a number of studies which consider the issues of cycle helmet effectiveness and the introduction of legislation for compulsory cycle helmet use are summarised.

Statistics

Table 29: Pedal cycle casualties: GB 2003 (National Statistics/DfT 2003)

	Number				
	1994 -1998 Average	2000	2001	2002	2003
Fatal	186	127	138	130	114
Serious	3,546	2,643	2,540	2,320	2,411
Slight	20,653	17,842	16,436	14,657	17,033
Total	24,385	20,612	19,114	17,107	19,558
Pedal cycle traffic¹	40	41	42	44	45
Casualty Rate²					
KSI	92	68	64	56	53
Slight	511	435	391	333	356
All	604	503	455	389	389
¹ 100 million vehicle kilometres.					
² Rate per 100 million vehicle kilometres					

The casualty rate for cyclists has continued to decrease since the 1994 -1998 average baseline despite the distance travelled by bicycle having increased over this period (Table 29).

**Figure 14**

From the data on the age of cyclist casualties, shown in Figure 14, it can be seen that there is a peak in the age group 30 - 39 years for all severities although there were more killed and seriously injured cyclists in the 40 - 49 age group.

There is however some evidence of under reporting of cyclist injuries, particularly in children (DfT, 2002). RoSPA estimate under reporting of between 60% - 90% of cyclist casualties especially if the victim is a child and it is a bicycle only accident.

Table 30: Fatality rate per billion kilometres travelled by mode of travel (STATS19, 2003)

Great Britain	Death rates per billion kilometres travelled			
	1993	1997	2000	2002
Bicycle	46	45	31	29
Pedestrian	70	58	49	44
Car (driver & passenger)	3	3	3	3

From Table 30 above, it can be seen that although the death rate per billion kilometres travelled for cyclists is greater than that for car drivers and passengers, it is less than that for pedestrians. The actual risk itself remains small, amounting to approximately one cyclist death per three million kilometres of cycling. These data may also present a skewed picture as the types of roads used by cyclists and cars are different in terms of type and exposure time. In a Dutch study where the fatality data was adjusted to exclude motorways, the fatality risk was almost twice as much amongst motorists as was found amongst cyclists (Cavill & Davis, 2003).

A study of cycling injuries in Cambridge was conducted over a 3 month period in July 2003. A total of 293 injured cyclists presented during the study period. The most commonly injured were men (65.5%) in isolated bicycle accidents on roads without cycle paths during daylight hours. Only 20.8% of patients wore helmets. The majority of those injured at night (62.5%) had consumed alcohol. Upper limb injuries were most frequently sustained (64%), with an even distribution of lower limb (24%), head (23%) and facial (22%) injuries. Truncal and neck injuries were uncommon. The study concluded that although the use of bicycle helmets contributes to a decrease in mortality from head injuries, this should not be the only focus for decreasing the morbidity associated with cycling accidents. Campaigns for safer cycling practice, more dedicated cycle routes and to discourage cyclists from drinking and cycling are essential to decrease the numbers of these injuries (Davidson, 2005).

RoSPA reported that most cycling accidents happen in urban areas, where most cycling takes place. Nearly three quarters happen at or near a road junction. Around three quarters of cyclists killed have major head injuries and over half of cyclists injured have head injuries. Additionally over half of cyclist casualties suffer arm injuries and around 40% receive leg injuries (RoSPA, 2004). However the accident statistics do not include information about helmet wearing rates.

Surveys by TRL Ltd measuring rates of cycle helmet use were carried out between 1994 and 2002. The results found an increase in overall cycle helmet use on busy roads from 16% in 1994 to 25.1% in 2002. The increase was due to an increase in the number of adults wearing cycle helmets, not children. On minor roads, surveys in 1999 and 2002 found an increase from 8.2% to 9.5% due to a significant increase in adults wearing cycle helmets and a significant decrease in children's wearing rates (Gregory et al, 2003).

The effectiveness of cycle helmets

In 2001 The Royal Society for the Prevention of Accidents (RoSPA) issued a policy statement on cycling in which they recommended that all cyclists wear a cycle helmet that meets a recognised safety standard and stated that cycle helmets,

when correctly worn, are effective in reducing the risk of receiving major head or brain injuries in an accident.

Towner et al (2002), in a review of the efficacy of bicycle helmets concluded that there was a considerable amount of scientific evidence that bicycle helmets are effective in reducing the rate of head injuries to cyclists.

However Curnow (2003) argued that a previous meta-analysis, commissioned by the Australian Transport Safety Bureau (ATSB) and cited by Towner et al (2002), which assessed the efficacy of bicycle helmets against Serious injury and subsequently used in support of legislation for compulsory wearing of helmets, does not provide scientific evidence that standard bicycle helmets of all types protect against brain injury. Curnow asserts that the studies used to provide scientific evidence in the meta-analysis failed to distinguish between the two distinct mechanisms of brain injury, that resulting from skull damage and that due to angular (rotational) acceleration. Consequently as the studies selected failed to take account of rotation as a factor in brain injury, the meta-analysis did not address points made by other studies which has shown that cycle helmets of standard design did not protect against rotational injuries (Curnow, 2003).

Hansen et al (2003) found that the use of hard shell helmets reduced the risk of injuries to the head but children aged less than 9 years who used foam helmets had an increased risk of getting facial injuries. They recommend that all cyclists should use hard shell helmets and studies on the fitting of helmets for young children be undertaken.

Depreitere et al (2004) carried out a study of head injured pedal cyclists but only three of this sample of 86 were wearing bicycle helmets. Recommendations from this study regarding the improvement of bicycle helmet design were that better knowledge of biomechanics is needed; greater head coverage is required and that helmets standards may be insufficient to protect the head in high speed impacts i.e. in collisions with motorised vehicles.

Cook (2004) concluded that it is widely accepted that cycle helmets do offer significant protection against head and upper facial injuries but the merits of compulsory legislation are delicately balanced and he suggests that compulsory bicycle helmet wearing amongst adults could deter cycling which would have a negative impact on health, economic and environmental issues. He suggests that there is a strong case for the introduction of helmet wearing amongst children where arguments for autonomy are weaker and legislation would help address the problems of peer pressure which keeps helmet wearing unfashionable, particularly in the teenage population.

Introduction of legislation

With regard to legislation for mandatory wearing of cycle helmets, RoSPA stated that they did not think such legislation was practical due to low voluntary wearing rates. They also stressed that such legislation should only be considered if there was evidence that cycle helmets reduced cyclist casualties and that voluntary use was sufficiently high to make enforcement practical. They said that there may be stronger evidence for limiting legislation to child cyclists but in all cases there needed to be an assessment of the likely effects of legislation on cycle use (RoSPA, 2001).

The DfT review into the effectiveness of bicycle helmets (Towner et al, 2002) concluded that there are four criteria which should be met before bicycle helmet wearing is enforced:

1. There must be a high level of scientific evidence that bicycle helmets are effective in reducing the rates of head injury to cyclists.
2. The benefits to society and others of mandatory bicycle helmet use must be demonstrated, mandatory bicycle helmets cannot be simply justified to protect individual cyclists.
3. There must be widespread agreement, ideally by a large majority, that the potential benefits of compulsory bicycle helmet use outweigh the infringement of personal liberty and other dis-benefits.
4. There must be good evidence to suggest that compulsory helmet wearing would not make the public health benefits of increased levels of bicycling significantly harder to obtain.

The review concluded that the criteria 1 had been met and such evidence exists that bicycle helmets are effective in reducing the rates of head injury to cyclists. Criteria 2 was harder to demonstrate and the authors stressed that it must be related to a wider debate about the whole cycling environment in which bicycle helmet promotion and legislation is seen as part of a broader package of measures to enhance cyclist safety. Evidence that criteria 3 can be overcome over a period of time had been gathered from countries where compulsory bicycle helmet legislation had been introduced. Regarding criteria 4, there was some evidence that legislation may have resulted in decreased levels of cycling but there were confounding factors and no long term trends (Towner, 2002).

In November 2004, the British Medical Association (BMA) published a report which stated that they would now support the introduction of legislation making the wearing of cycle helmets compulsory for both children and adults. Their recommendations were based on evidence that compulsory cycle helmet legislation has had a beneficial effect on cycle related deaths and head injuries. Additionally they stated that evidence has been presented that the introduction of compulsory legislation does not have a significant negative effect on cycling levels.

The BMA also recommends that all cyclists wear proper fitting helmets which are preferably certified to the Snell B95 standard and consumers are made aware that helmets should be replaced after an accident.

Casualty data are collected by the police but are known to be under-reported. Data on exposure to risk, i.e. the amount of pedal cycle activity, are not systematically collected. Some data on the safety aspects of cycling, e.g. the use of cycle helmets, are collected but not on a comparable basis. A feasibility study is required to develop protocols for the development of data collection systems that would allow for monitoring the safety of cyclists over time.

Further discussion points

- Further investigation is needed into the types of head injuries cyclists suffer and the effectiveness of current cycle helmets against these types of injury.

- Issues of enforcement of legislation, especially where children are concerned, need to be considered.
- A wide variety of other measures can reduce risks to cyclists: cycle route networks; speed management schemes; improved driver awareness and training: cyclist training; conspicuity for cyclists (RoSPA 2004).
- An infrastructure which promotes cycling and provision for cycle helmet is needed to help overcome barriers to cycle helmet use i.e. schools/employers providing storage facilities for cycle helmets (Towner et al, 2002).

3.4 Second PCG Workshop

A full description of the second PCG workshop can be found in Appendix 5.

The workshop opened with a presentation of the further data analysis reported in section 3.3. The PCG members then selected the following topics for consideration in round the table discussions:

- Femur injuries in frontal impacts.
- Foot and ankle injuries in frontal impacts.
- Chest Injuries in side impacts.
- Whiplash in frontal impacts.
- Rear Seat Occupant injuries.

The points arising from the workshop discussions together with those arising from a subsequent meeting with representatives from the vehicle manufacturing industry/suppliers were as follows and represent the **collective opinions** of the PCG members and are intended to complement rather than be based upon the previous data analysis;

3.4.1 Femur injuries in frontal impacts

Femur fractures have found to be an outstanding issue in both in this and another project, 'Bone Scanning for Occupant Safety' BOSCOS project (Hardy et al, 2005). In the CCIS data, some 4.5% of front occupants sustain femur fractures. This injury

type is one of the most commonly occurring and among the most costly AIS2+ injury.

Intrusion remains a possible injury mechanism due to the deficit of space between the occupant and the fascia, particularly for shorter drivers sitting further forward or for those with longer legs where insufficient rearward seat movement is impossible.

There seems to be some uncertainty about both the type and the mechanisms of femur fracture and with this, some doubt over whether the potential for femur fracture would be adequately predicted in current crash-testing requirements.

Currently, the risk of injury is predicted by load-cells positioned in the mid-shaft region of the Hybrid III dummy but this may not be a suitable test device to examine the potential for injury to the distal and proximal femur because of this load-cell positioning. Another issue is that the true mechanism may be more complicated than simplistic axial loading and the Hybrid III dummy may not adequately predict bending as an injury mechanism. There is also the possibility that the current injury criteria for femur loading (10kN) is too unrealistic and should be reduced to a 6kN limit.

Although in-depth accident data can be highly beneficial in terms of problem definition, it may be necessary to take an even more detailed approach whereby femur injury mechanisms are established. This could involve a similar approach to the LLIMP study with Orthopaedic experts and accident researchers working together studying X-rays, clinical notes and vehicle damage details. A pan-European study including data from other accident studies would significantly enhance the understanding of femur fractures since more cases would be available for analysis.

It would appear that knee bolsters and knee airbags offer good potential for injury prevention, as has been found by laboratory crash-testing. However, until the injury mechanism can be fully determined, it is difficult to predict the entire injury prevention benefit of such devices in the real-world or indeed to establish whether there is any potential for unexpected injury from such devices. Other

considerations include double pretensioners, improved seat-pan design and pelvis restraints which may all have a positive effect on occupant kinematics and subsequent injury outcome. However, the indirect effects of such interventions are as yet difficult to predict since they are not prevalent within the vehicle fleet.

A further consideration is that the crash-testing conditions may not match the conditions in which femur fracture occurs (for example, the dummy knee may not contact the facia and therefore may not indicate a risk of injury). Also, the real-world conditions under which such injuries are prevalent are not the same as the crash-testing conditions (for example, angle of impact). Therefore there would be some benefit in studying the whole issue in some detail before any true countermeasure could be developed.

It should be noted that previous studies (e.g. BOSCOS) have found femur fractures to be prevalent across all population groups and not necessarily an older occupant issue.

In summary, despite the gaps in current knowledge, the following suggestions for injury countermeasure apply:

- A modified test procedure including dummy type (including consideration of the THOR dummy), dummy positioning and impact angle.
- A reduction in the femur load criterion (10kN to 6Kn).
- The introduction of knee bolsters / airbags.

However, fundamentally the issue of the injury type and injury mechanism needs to be addressed through further research before the respective benefits of each of these measures could be determined and the most effective solution implemented.

3.4.2 Foot and ankle injuries in frontal impacts

Whilst foot/ankle injuries are not particularly life threatening, they can result in significant levels of impairment to those afflicted and hence represent a burden to society in terms of cost.

Current vehicles which obtain a 5-star rating in the EuroNCAP test procedures usually control intrusion of the footwell and hence reduce the potential for injury. However where this is not achievable, other design solutions include breakaway pedals and footwell airbags. Both of these have the effect of reducing point loading through the foot/ankle region. Knee airbag/bolsters and double pretensioners alter occupant kinematics and early tests have shown that change in kinematics is favourable in terms of foot/ankle injury mitigation.

Such designs could be implemented without the need for regulation. However, the most effective means to ensure compliance with any policy to reduce foot/ankle injury would be through regulatory requirement or through the EuroNCAP test procedure.

Further work is required since there is still a gap in the knowledge concerning the mechanisms of foot/ankle injury. This is particularly true for associated injury tolerances in terms of applied force including dorsi-and plantar-flexion, inversion/eversion, and rotation. The most important implication of this is that there is limited understanding of injury mechanisms for the more severe and hence impairing injuries to the foot/ankle (including Pilon fractures, Calcaneus fractures and major fractures to forefoot including Lisfrancs). Population variance also needs to be taken into account.

Development of a modified test dummy with enhanced measurement capability (such as can be found on the THOR dummy) could potentially be costly in terms of research and development (including enhanced bio-mechanical data needed to calculate risk curves).

There would be development costs to industry in order to make design modifications to meet regulations. The costs would depend on the marginal technologies that may be required. If design solutions were required in order to meet new regulation, there would be a significant effect on the vehicle manufacturing industry since a range of modifications to vehicles might be required. However an alternative cost-effective solution might involve a component testing/virtual testing approach.

In summary, despite the lack of knowledge concerning injury type/mechanism, the following suggestions for possible countermeasures apply:

- Energy absorption vehicle foot wells.
- Foot well airbags.
- Breakaway pedals.
- Knee airbags/knee bolsters.
- Double pretensioners (to prevent submarining).

However, further research is required before each of these measures can be evaluated in terms of their relative benefits and the most effective implemented.

Other Considerations

Measures that control intrusion (in order to mitigate foot/ankle injury) could affect the crash pulse and generate a potential risk of chest injury through restraint system. This is particularly important when taking into account older occupants and those in the rear seats. An increased pulse could also affect child restraint performance and this is another point to consider. Single crash testing also does not take into account population variance and additionally shoe type variation may affect injury risk.

Another consideration is that with introduction of injury mitigation systems, vehicles may become heavier/stiffer hence there are implications in terms of compatibility, fuel consumption, overall cost and pedestrian safety.

3.4.3 Chest injuries in struck side impacts

Despite the enormous improvements to vehicles in terms of safety, most vehicle occupants who are killed in side impact crashes die as a result of sustaining head or chest injury. Whilst there is some activity on-going in terms of head protection (e.g. EEVC proposed test procedure, optional pole-test as part of EuroNCAP, head protection airbags/side curtains), there is no specific procedure to exclusively consider chest protection, although side airbag technology is available.

The remaining problem for chest injury is somewhat surprising since the vehicle industry can meet the requirements of the current regulations governing side impact (i.e. ECE R14) relatively easily and no issues concerning chest injury are detected in compliance testing. This could be because many vehicles are designed such that loading is applied directly from the vehicle B-pillar/door structure to the pelvis thereby removing the potential for loading via intrusion to the thorax by pushing the dummy sideways. However, the same will only apply in real-world situations if the transfer of load from the pelvis to the chest through the lumbar spine is correctly represented in the test dummy. This is probably not achieved in the EuroSID but could be better predicted by the WorldSID dummy.

German data suggests that there has been an increase in clavicle fractures in side impacts with a possible causation factor being transmitted loads via the B-pillar.

Some other factors regarding the side impact test procedure include the following:

- The mass of the Mobile Deformable Barrier (MDB) may be too low (at 950kg).
- The stiffness profile of the MDB does not match that of the modern fleet, (which has become stiffer with the introduction of EuroNCAP).
- The height of the MDB does match that of the fleet and engages too readily on the test vehicle sill.
- Current test procedures only represent car-to-car impacts - however car to pole impacts are an important consideration (especially in other EU Member States) and although EEVC have developed a pole-test procedure, it is applicable only in terms of head protection at this stage.
- The European regulation only requires a dummy in the front struck-side position. There is potential to make better use of other empty seats in order to monitor occupant interaction in the current test.

In summary it is essential that an enhanced understanding of the nature and circumstances of chest injury in side impacts is attained so that suitable countermeasures and/or regulation can reflect the real-world situation.

A number of possible countermeasure options could be developed. These include:

- Pre-crash sensing systems that allow an 'early' deployment of the side airbag to prevent out-of-position occupants.
- Bolstering/padding of internal surfaces such as the door.
- Development of an additional test/tests which take into account the nature and circumstances of real-world conditions.
- Introduction of the WorldSID dummy in compliance testing.
- Use of empty seats in the test procedures.

However, it is not possible at this stage to assess which (if any) would be the most effective measure without gaining a fuller understanding of injury mechanisms and associated crash circumstances. In addition a full evaluation of the effectiveness of side airbags is required.

3.4.4 Whiplash in frontal impacts

Whiplash (also known as soft tissue neck injuries, Cervical Spine Distortions and Whiplash Associated Disorders -WAD) is a term commonly used to describe a number of symptoms that may be experienced by vehicle drivers and passengers involved in crashes. These symptoms most commonly affect the neck and upper shoulder region. Whiplash, whilst rarely life-threatening, can lead to severe pain and suffering and can sometimes result in permanent impairment and general loss of quality of life.

Beyond the human costs, whiplash injuries represent enormous economic costs to society worldwide in terms of insurance claims, loss of productivity and medical care. Current estimates of soft tissue neck injury costs amount to over £1 billion per annum and neck injury claims account for over 80% of the total cost of personal injury claims (Thatcham 2006).

Consequently, there is much research ongoing into the subject in order to examine a number of different aspects. The main research activity areas are as follows:

- Identification of the injury and/or injuries.
- Injury mechanisms.

- Medical treatment options.
- Passenger vehicle countermeasure development (including seat and head restraint design).
- Economic consequences.
- Appropriate test procedures (crash pulse etc).
- Recommendations for future regulation specifically including:
 - Suitable test dummies.
 - Appropriate injury criteria.

Whiplash is one area where current protocols for real-world accident data collection are insufficient to elicit new knowledge on whiplash injury mechanisms.

Furthermore, as things stand, there are fundamental problems with developing countermeasures for whiplash prevention. First of all, it has yet to be established what exactly is the injury or injuries sustained by vehicle occupants when 'whiplash' is diagnosed. For frontal impacts, one of the more challenging aspects of the problem is at what point in the impact the injury occurs – that is, does it occur whilst the head-shoulder complex is in hyper-flexion or on rebound into the seat where hyper-extension is seen? These two issues alone make it difficult to propose and develop injury countermeasures although pragmatic solutions have been implemented to prevent whiplash in rear impacts, with some success. A third issue is that the current regulatory dummy (Hybrid III) is not a good tool for evaluating whiplash injury risk although it will detect risk of Serious neck injury involving fracture of the vertebrae.

Another issue is that of false reporting. As no injury can be detected non-subjectively, it is notoriously difficult to determine whether a claim of whiplash injury is genuine or not.

Therefore, there are a number of outstanding issues that need to be resolved before anything that would have an impact on the stakeholders could be initiated. Of central importance are the following:

- The establishment of the injury or injuries involved.

- The development of better criteria and measuring tools.
- The evolution of an agreed test procedure.

It should be remembered that the solutions under current development for rear impact protection may not be wholly suitable for frontal impact whiplash prevention so although lessons could be learned, there would need to be new initiatives.

Other Considerations

Other considerations include the following:

- The effect of load limiters (and possibly other devices) on head rebound velocity.
- Females are more prone to injury compared to males.
- Follow up studies on whiplash in frontal impacts would be beneficial including psychological assessments.
- Education of vehicle occupants in terms of optimum head restraint positioning is a possible consideration.
- There is a need to monitor changes in vehicle design to look at whether the risk of whiplash in frontal impacts is increasing or decreasing (with stiffer vehicle front-ends).
- It would also be beneficial to look at how many neck injuries occur in crashes at a Delta-V below the airbag deployment threshold.

In summary, it is difficult to propose countermeasures and it may therefore not be possible to undertake any regulatory or remedial action until further knowledge about the issue has been gained.

3.4.5 Rear Seat Occupants

Rear seat occupants have been shown to have an increased rate of KSI outcome in frontal impacts when in post-regulatory (1998 onwards) vehicles compared to pre-regulatory (pre 1992) vehicles. Whilst one explanation for this phenomenon could be the more severe crash pulses experienced since the introduction of stiffer vehicles, this has not been fully explored. Equally little is known concerning the

seat belt wearing rate and specific injury types for rear seat occupants. Whilst estimates of rear seat belt usage rates are around 60%, the rate in the accident population may differ somewhat.

Currently the injury risk to adult rear occupants is not monitored through crash testing, regulatory or EuroNCAP. As a starting point accommodation could be made for a 50th percentile dummy in the rear, but careful consideration should be given to an appropriate dummy taking in to account the characteristics of typical rear seat occupants. This could be achieved by analysis of rear seat occupancy (through roadside survey or other means).

Whilst the provision of protective measures in the form of pretensioners, load limiters and airbags has been introduced for front occupants, this is not the case for those in the rear. It is not however a simple matter to install these measures in the rear or apply the same geometry in the rear as in the front. Rear seats are often required to be folded down or removed completely in order to make space for luggage, causing limitations for anchorage points. It may be possible to integrate the seat belt into the seat but this requires additional seat strength implying heavier seats which is undesirable in a market where cars are marketed on the versatility of their seat position/presence. Load limiters are a potential solution, but the limits that apply in the front are not applicable in the rear because of reduced ride down space when the front seats are adjusted rearwards. Also occupant characteristics are known to vary between the front and rear seating positions. A similar problem is apparent when considering airbags mounted in the rear of the front seats since proximity becomes an issue particularly on the driver's side where seat adjustability has to be accommodated. Pretensioners are a further possibility but it is not clear how this would affect the performance of child restraint systems.

In summary, further definition of the extent and nature of the problem is required before the most appropriate course of action can be established.

A roadside survey could elicit vital information about representative rear seat occupancy. However it is evident that improvements in rear seat occupant protection will only come about through either regulatory requirement or the EuroNCAP programme.

4 Pilot Driver Survey

The aim of the pilot survey was to develop and apply, to a localised sample, a number of questions relating to car safety. A large scale survey based on the pilot questionnaire would provide data relating to the public's general awareness and understanding of safety issues and, in conjunction with accident data, would assist in identifying gaps in actual and perceived safety-related issues which the Department may choose to address through education campaigns or by other means as appropriate.

The questionnaire was based upon a review of similar surveys (Australian Automobile Association (ANOP) surveys into motorists' priorities and attitudes, Social Attitudes to Road Traffic Risk in Europe (SATRE) and the data collected by the Office for National Statistics Omnibus survey for DfT) within the context of the objectives of the project as a whole. The resulting questionnaire comprised of a number of distinct sections. The main findings are presented here; the full report can be found in Appendix 8.

4.1 Sample details and background

100 drivers participated in the pilot survey, 60 of whom were male. The mean age of the respondents was 40 years with a range from 19 to 79 years. More than 95% of the sample lived in the East Midlands, centred on Leicester.

4.2 Relative importance of road safety compared to other national issues

To identify the importance of road safety in comparison to other national issues, the participants were invited to express their relative concern using a five point scale (1 being not concerned at all and 5 being very concerned). It was found that road safety (mean rating 4.13) was second only to the concern for crime rates (mean rating 4.3) and placed ahead of Third World Poverty, Traffic Congestion, Drugs and

Alcohol Abuse, Cancer, Healthcare, Education. Unemployment, European Union, GM foods and Global Warming.

This relatively high concern for road safety was in contrast to the ANOP and General SATRE findings. However when SATRE, survey 2, UK results were isolated a similar trend was found to the results of this pilot.

4.3 Road driver concerns and issues

To identify the importance of road safety in comparison to other factors pertinent to driving, the participants were invited to express their relative concern using the same five-point scale.

Driver behaviour (42%) was the primary concern followed by congestion (32%), cost (17%) and speeding (11%). This was somewhat reflected in ANOP 1999 survey which found that driver behaviour and cost were the primary factors (32% each) followed by road condition (19%), safety (14%) and traffic congestion (14%).

4.4 Factors influencing car purchase

To investigate the extent to which safety is an influencing factor on car purchase, an open-ended question was used i.e. the respondents were given free choice in specifying the factors relevant to them. Safety considerations came third (27 respondents) to cost (34 respondents) and style (32 respondents). Performance, brand/image, comfort, size reliability and environmental considerations followed and were each cited by 10 or more participants.

In a related question where the respondents had to rate the desirability of six factors using the same 1-5 scale described earlier, safety achieved the highest mean rating followed by cost, performance, styling, advanced technology and entertainment.

4.5 Causes of road accidents

When invited to give a free response to what they considered were the main cause of accidents, carelessness and poor driving (behaviour/knowledge/skills) were both cited as major causes (35 respondents each) followed by speed (33 respondents) and distraction (25 respondents). ANOP 2004 and SATRE survey 2 1998 similarly found speed cited as a main causal factor but both found higher ratings for drinking and driving than in this pilot.

4.6 Reducing injuries from accidents

Respondents were invited to provide a free response as to how they thought that injuries resulting from accidents may be reduced. Safety features (airbags, seat-belts, side impact bars, etc) were the main countermeasure (77 respondents) followed by reduced speed (31 respondents) and improved driving (16 respondents). This reflects the ANOP 2004 survey in which safety features were the primary countermeasure given by 75% of the respondents.

4.7 The meaning of the term 'car safety'

An open-ended question was used for the participants to describe what the term car safety meant to them. This was found to vary from person to person and whilst no single definition was found, there was a general meaning focusing on surviving an accident. This related to the safety of the occupants and other road users in the event of an accident and driver behaviour to prevent accident happening. The main responses given were: safety to driver, passengers and other road users (35 respondents), all round safety of the car (24 respondents), airbags (18 respondents), driving style (15 respondents) wearing seat-belt (15 respondents) and impact protection (13 respondents).

4.8 Desired safety features

The participants were asked what safety features they would look for in a car if money was no object. Airbags were the most frequently cited (74 respondents), followed by braking ABS (30 respondents), side impact bars (26 respondents),

seat-belts (24 respondents) and body strength (16 respondents). These results may reflect driver awareness based on recent marketing trends.

4.9 Future car design

The participants had some difficulty in identifying how they thought car design could be improved in the future to reduce the likelihood of accidents happening.

Restricting speed was the most frequently given response (24 respondents), followed by car design (18 respondents) with 15 respondents being unsure.

4.10 Conclusion

Overall car safety is an important concern to drivers and is one that influences their choice of car purchase along with cost considerations. The respondents had a moderate level of general awareness of car safety features and saw these as the main countermeasure against injury resulting from an accident.

5 Conclusions

The conclusions presented in the tables below are drawn from all of the stages of the project. As such, all of the emerging priorities are listed whilst additional mention is given to those that the PCG felt currently had most potential for injury mitigation through secondary safety intervention. It is evident from the STATS19 data that protection of car occupants remains a clear priority for the UK Government. This study has identified a number of key issues relating to car occupant safety that remain in newer model cars. Additionally some issues relating to vulnerable road users have been highlighted.

The following tables summarise the issues that have come to light through data analysis, discussions within the PCG, discussions with DfT and through a review of the literature. Each of these issues is considered a priority. However, significant activity is on-going in some areas, a moderate amount in others whilst for some there is no current activity. The tables show this level of activity and make suggestions for what further could be done and whether there is a need for more research before the issues can be addressed adequately. An indication is also given of previous research projects within the area commissioned by the TTS branch.

It can be seen from the summary tables that in many instances, further research is required before countermeasures for injury reduction can be developed and implemented for the given priority. Conversely, for other priorities there is a substantial amount of ongoing research and development activity in progress, but it is still evident that solutions are not readily available. An underlying theme throughout the priority areas defined is that where there is the potential for improvement in injury mitigation, further definition of the injury mechanism and subsequent improved dummy bio-fidelity is required before regulatory modifications could be defined. It is important to note that since the most likely and effective way to effect fundamental change will be through regulation, this could potentially have a substantial impact on the car industry in the years to come.

FRONTAL IMPACTS						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Compatibility	PCG workshop	No	VC-COMPAT project to study compatibility and develop countermeasures	-Unknown at this stage – depends on outcomes from VC-COMPAT project	Not known – depends on outcome of VC-COMPAT	S095B/VF (1999) S096B/VF (2004) S0214/VE (2006) S0215/VF (2006) S0228/VF (2006) S310C/CA (1999)
Whiplash	CCIS Data analysis PCG workshop Injury cost analysis	Yes	No current activity Much activity for rear impact although results not necessarily transferable	-Determination of injury mechanism -Determination of injury type -Development of suitable injury criteria for Hybrid3	Yes	No activity
Chest injury	CCIS Data analysis PCG workshop Injury cost analysis	Yes	Development of Humanoid FEM Development of injury criteria Sensing systems for OOP Belt use sensors	-Improved biofidelic chest on H3 dummy -Determination of injury mechanism for and crash conditions in which Serious injury still occurs -Further development of smart restraint systems to possibly include Rear Seat Occupants -Use of results from BOSCOS in product development -Evaluation of injury tolerance of older road users	Yes	S080D/VF (1997) S082F/VF (?) S0011VF (2002)
Femur Fractures	CCIS Data analysis Injury cost analysis	Yes	Knee bolsters Knee airbags in some cases but not mandatory. Effects need to be monitored.	-Knowledge about injury mechanisms, tolerance criteria, bio-fidelity, who is afflicted and in what crash conditions	Yes	S082D/VF (2002) S086D/VF (2006) S080D/VF (1997)

FRONTAL IMPACTS CONTINUED						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Head Injury	Injury cost analysis	Yes	Front airbags – shown to be effective	-Continued monitoring of advanced restraint performance	Yes?	S0011/VF (2002) S0013/VF (2002) S084D/VF (2004)
Foot/ankle injury	CCIS Data analysis PCG workshop Injury cost analysis	Yes	Footwell airbags in some cases but not mandatory Reduction of intrusion.	-Knowledge about injury mechanisms, tolerance criteria, bio-fidelity, who is afflicted and in what crash conditions -Performance criteria in crash-testing (using ALEX legform on THOR or Hybrid3 Dummy)	Yes	S082D/VF (2002) S086D/VF (2006)
Restraints in terms of population variance	PCG workshop CCIS Data analysis	Yes	BOSCOS/PRISM projects Small drivers project ISO standard for biomechanics considers age as a factor	-Variable load-limiting belt systems -Use of 5 th percentile H3 dummy in regulatory compliance testing -Biomechanics of injury to older person	Yes	S083F/VF (?) S0114/VF (2004) S0223/VF (2005) S0017/VF (2003)
Rear seat occupants	STATS19 Data analysis	No	No activity	-Further data analysis to establish nature and extent of problem -modification to regulation to include rear seat dummy or dummies -method to encourage rear seat belt use	Yes	No activity

SIDE IMPACTS						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Chest Injury	CCIS Data analysis PCG workshop Injury cost analysis	Yes	Development of Humanoid FEM model Development of sensing systems for OOP Continued introduction of side airbag into fleet	-Evaluation of nature and source of Serious chest injury in side impact -Evaluation of possible modification to regulation to include more stringent test condition -Evaluation of possible modification to barrier interface to reflect change in fleet (e.g increase in SUV) -Evaluation of side airbag performance -Evaluation of chest biomechanics under higher loading rates.	Yes	S0051/VC (2002) S0212/VF (2003) S088D/VC (2000) S0115/VF (2004) S090A/VF (1996) S095A/VF (2002) S0049/VF (2004) S0052/VF (2004) S0220/VF (2006)
Head injury	CCIS Data analysis Injury cost analysis	Yes	This topic was not explored beyond the initial data analysis but previous work has shown initial favourable effectiveness of the side airbag in reducing serious head injury.	-Continued monitoring of the effectiveness of the side air bag for head protection.	Yes?	S084D/VF (2004) S0013/VF (2002) S0015/VF (2004) S094A/VF (1996) S096A/VF (2001) S0114/VF (2004) S090A/VF (1996) S0220/VF (2006)
Lower extremity injuries (including Pelvis)	Injury cost analysis	No	No general activity	This topic was not explored beyond data analysis	Yes?	S0115/VF (2004) S0220/VF (2006)

SIDE IMPACTS CONTINUED						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Whiplash	CCIS data analysis Injury cost analysis	Yes	No specific activity	-Determine injury mechanism	Yes	Nothing specific
Pole impacts	CCIS data analysis PCG workshop	Partially	Optional pole test in EuroNCAP (for head protection only) Active safety systems (e.g. ESP)	-Pole test regulation Monitoring of head protection systems -Development of pre-crash sensing systems	Possible	Possible action in S0220/VF (2006)
Side airbag	CCIS Data analysis IRCOBI paper (Morris. Welsh et al, 2005)	Partially	Refined side airbag technology	-Monitoring of effectiveness of side airbags in real-world situations	Yes	Nothing specific
Compatibility	PCG workshop	No	IIHS test with barrier representing SUV	-Unknown at this stage – depends on outcomes from VC-COMPAT project	Not known – depends on outcome of VC-COMPAT	S095B/VF (1999) S096B/VF (2004) S0214/VE (2006) S0215/VF (2006) S0228/VF (2006)
Non stuck side occupant protection	CCIS data analysis PCG Workshop	Yes	Australian research on Dummy kinematics Belt development	-Data analysis to determine interaction, worst-case scenario, centre console, side airbag effectiveness for NSS occupant -Development of NSS test procedure -Evaluate effect of airbag on NSS occupant	Yes	S0220/VF

REAR IMPACTS						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Whiplash	Data analysis PCG workshop Injury cost analysis	Indirectly	Extensive international on-going activity to determine injury mechanism, suitable injury criteria, suitable dummy	-Continuation of existing research -Evaluate injury reduction effectiveness of different seats and compare with BioRID results.	Yes	S083D/VF (2003) SO110/VF (2004)

OTHER IMPACT TYPES						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Prevention of ejection in rollover crashes	PCG workshop CCIS Data analysis	No	Studies of laminated glazing in side windows Autoliv countermeasure and rollover dummy development	-Development of rollover test – what should the condition be -Consideration of child restraint performance	Yes?	No specific activity
Multiple impacts	PCG workshop CCIS data analysis	Yes	Limited data analysis carried out by Ford UK	-Enhanced data analysis including case review to look at nature and circumstances of crashes -Development of re-inflating airbags -Consideration of child restraint performance.	Yes	No specific activity

OTHER ISSUES						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Child occupant protection	PCG workshop DfT	Yes	NPACS work on child restraint CHILd project	-Improve child restraint wearing rates -Ensure that current child restraint designs can be easily installed and used -Establish notification of accidents on a national basis to increase sample of accidents -Child injury biomechanics and risk curves -Child KSI study	Yes?	S070N/VF (1997) S080E/VF (1999) S0014/VF (2002) S082E/VF (2003) S0012/VF (2004) S0126/VF (2006) S0225/VF (?)
Impairment from crash injury	Injury cost analysis PCG workshop	No	Epidemiological study conducted by Swansea University but not specific to road crashes VSRC PhD but on limited case numbers	-New willingness-to-pay study to accurately predict most impairing/costly injuries in order to define key injury prevention targets	Yes	Nothing specific
Automatic crash notification	PCG workshop	No	No specific activity	-A study of likely benefit of ACN/eCall devices	Yes	Nothing specific
Pedestrian safety	PCG workshop OTS data analysis	Yes	Phase one of directive now in force EuroNCAP pedestrian test OTS project	-There should be analysis of accident data after an appropriate lead-in time -Evaluation of the directive and casualty reduction	No	S220B/VF (1997) S070M/VF (1998) S220C/VF (2003) S071M/VF (1999) S221B/VC (2000) S222C/VF (?) OTS project (?)

OTHER ISSUES CONTINUED						
Issue	Problem Identification By	Considered in Literature Review	What's being Done	What should be done	Further research required?	Previous TTS/ DfT Research Activity & year completed
Motorcyclists	MAIDS Data analysis PCG workshop DfT	Yes	PISa project OTS study Pan-European Industry study	-No activity – results from OTS/MAIDS/PISa should be considered first	No	S110L/VF (2002) S0031/VD (2002) S101H/VD (2002) S0033/VD (2003) S0227/VF (2004) S322E/VF (2002)
Cyclists	DfT Data Analysis	Yes	Specialist study considering helmet effectiveness. TRL survey into cycle helmet wearing rates. ROSPA guidelines on helmet use. DfT review into effectiveness of helmets. Consideration to possible legislation for compulsory helmet use DfT review of collection of cycling data.	-Further understanding of types of head injury and effectiveness of helmet on each type. -Continued promotion of cycle helmet use. -Other measures such as road infrastructure and training.	Yes	S100L/VF (2002)

With regard to the driver survey, some useful points emerged particularly the discrepancy between the subjective importance of safety (low when considered through open ended questioning) and the suggested importance of safety (when safety was included in a list of topics to rank). However, this pilot survey was conducted on a small sample and therefore the results can not be seen as representative of the driving population as a whole. A much larger survey would be required in order to fully establish public opinion and perception.

In summary, this project has identified issues for future consideration as Secondary Safety Priorities. A group of vehicle safety experts have further identified 5 key areas where there is good potential for regulatory/design solutions for injury mitigation. These are:

- Femur fractures in frontal impacts
- Foot and ankle fractures in frontal impacts
- Chest injuries in side impacts
- Whiplash in frontal impacts
- Rear occupant protection in frontal impacts

However, whilst various interventions were suggested, the benefit that these would have in mitigating injury is unclear since injury mechanisms are still largely undefined. It would be unadvisable to simply implement design solutions/develop new regulation without due consideration to the shortfall in current biomechanical knowledge and the limitations of the current test procedures/tools in predicting injury outcome under real world crash conditions.

Finally, it is important to recognise that the five topics listed above do not form an exhaustive list of priority areas and reference should be made to the tables in the conclusion section of this report.

6 References

ANOP Research Services Pty Ltd (2004) Safer Roads – Key results of July 2004 National Survey, Australian Automobile Association.

ANOP Research Services Pty Ltd (2000) The motorists' view in 2000 – Report on October 2000 ANOP National Survey, Australian Automobile Association.

ANOP Research Services Pty Ltd (1999) Motorists' priorities and attitudes – Executive summary report on 1999 ANOP National Survey, Australian Automobile Association.

BMRB Social Research (2003) Department for Transport Omnibus Survey – 2003, Department for Transport.

http://www.dft.gov.uk/stellent/groups/dft_science/documents/page/dft_science_027759-01.hcsp#P24_405

Broughton, J et al "The Numerical Context for Setting National Casualty Reduction Targets" TRL Report Number 382, Transport Research Laboratory, 2000.

Cavill N, Davis, A. Cycling and Health. A Briefing Paper for the Regional Cycling Development Team. National Cycling Strategy. 28 Feb 2003.

Cook A, Mind your head. The data and debate on bicycle helmet effectiveness. Significance, Vol. 1, 4, pp 162 - 163.

Curnow, W.J. The efficacy of bicycle helmets against brain injury. Accident Analysis and Prevention 2003; 35(2): 287-292.

Davidson, JA. Epidemiology and outcome of bicycle injuries presenting to an emergency department in the United Kingdom. European Journal of Emergency Medicine. 2005 Feb; 12(1): 24-9.

DfT (2005). Compendium of Research Projects 2004 /2005. Department for Transport, London.

Depreitere, B, Van Lierde, C, Maene S, Plets C, Vender Sloten N J, Van Audekercke R, Van Der Perre G, Goffin J. Bicycle related head injury: a study of 86 cases. Accident Analysis and Prevention; 2004;36 (4):561-7.

Gregory K, Inwood C, Sexton B (2003) Cycle Helmet Wearing in 2002. Summary of TRL Report 578, TRL Ltd.

Hansen K S, Engesaeter LB, Viste A. Protective effect of different types of bicycle helmets. Traffic Injury Prevention; 2003;4(4):285-90.

Hardy R et al. BOSCOS – Development and Benefits of a Bone Scanning System IRCOBi proceedings Prague 2005.

Hopkin J and Simpson H (1995) Valuation of Road Accidents TRL Research Report 163 TRL.

http://www.cabinetoffice.gov.uk/regulation/ria/ria_guidance/index.asp

Lowne, R "Post-2000 Targets; Review of Possible Vehicle Safety Measures". TRL Report Number PA3410/98.

Morris, A. Welsh R, et al Head and Chest Injury Outcomes in Struck-Side Crashes IRCOBi 2005.

PPAD 9/033/128 Policy Evaluation Programme Vehicle Safety Standards: Improving Car Crashworthiness.

Quimby, A. & Vilnitis, I (2004) Social Attitudes to Road Traffic Risk in Europe (SATRE 3): Results of UK Survey – Version 1
Department for Transport.

RoSPA (2001). Cycling Policy Statements - February 2001.

<http://rospa.com/roadsafety/advice/cycling/policy.htm>.

RoSPA (2004). Cycling Accidents. Facts and Figures.

http://www.rospa.com/roadsafety/advice/cycling/cycling_accidents.htm

SARTRE (1998) The attitude and behaviour of European car drivers to road safety – SARTRE 2 reports – Part 3 and Part 4 INRETS for FERSI (Forum of European Road Safety Research Institutes) and DGVII of the European Union.

SARTRE (1994) European drivers and traffic safety , INRETS.

Thatcham 2005 <http://www.thatcham.org/ncwr/>

Thomas P, et al Real-world crash performance of recent model cars – next steps in injury prevention; IRCOB 2003.

Towner E, Dowswell T, Burkes M, Dickinson H, Towner J, Hayes M. (2002). Bicycle helmets: review of effectiveness (No. 30).

http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/pdf/dft_rdsafety_pdf_507998.pdf

University of Nottingham, TRL, ESRI LLIMP lower limb injury and methods of prevention. A collaborative research project www.lboro.ac.uk/esri

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