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FIMCAR
II - Accident Analysis

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EXECUTIVE SUMMARY

For the assessment of vehicle safety in frontal collisions compatibility (which consists of self and partner protection) between opponents is crucial. Although compatibility has been analysed worldwide for years, no final assessment approach has been defined to date. Taking into account the European Enhanced Vehicle safety Committee (EEVC) compatibility and frontal impact working group (WG15) and the EC funded FP5 VC-COMPAT project activities, two test approaches have been identified as the most promising candidates for the assessment of compatibility. Both are composed of an off-set and a full overlap test procedure. In addition another procedure (a test with a moving deformable barrier) is getting more attention in today's research programmes.

The overall objective of the FIMCAR project is to complete the development of the candidate test procedures and propose a set of test procedures suitable for regulatory application to assess and control a vehicle's frontal impact and compatibility crash safety. In addition an associated cost benefit analysis should be performed.

The specific objectives of the work reported in this deliverable were:

- Determine if previously identified compatibility issues are still relevant in current vehicle fleet
  - Structural interaction
  - Frontal force matching
  - Compartment strength in particular for light cars
- Determine nature of injuries and injury mechanisms
  - Body regions injured
  - Injury mechanism
    - Contact with intrusion
    - Contact
    - Deceleration / restraint induced

The main data sources for this report were the CCIS and Stats 19 databases from Great Britain and the GIDAS database from Germany. The different sampling and reporting schemes for the detailed databases (CCIS & GIDAS) sometimes do not allow for direct comparisons of the results. However the databases are complementary – CCIS captures more severe collisions highlighting structure and injury issues while GIDAS provides detailed data for a broader range of crash severities. The following results represent the critical points for further development of test procedures in FIMCAR

<u>Compatibility issues</u>

- Poor structural interaction has been observed to be a problem in the current vehicle fleet. The dominant structural interaction problems in car-to-car impacts are over/underriding of car fronts and low overlap. However, fork effect is seen more in car-to-object impacts because of impacts with narrow objects.
  - In CCIS, structural interaction problems were identified in 40% of fatal and 36% of MAIS 2+ injured cases. However, it is only in cases where there was intrusion present (25% of fatal and 12% of MAIS 2+ cases) that it can be said definitely that improved structural interaction would have improved the safety

performance of the car. This is because in cases with intrusion improved structural interaction will increase the energy absorption capability of the car's front-end and thus reduce the intrusion. This, in turn, will help decrease the casualty's injuries caused by contact with intrusion. In cases without intrusion improved structural interaction will change the shape of the compartment deceleration pulse which may or may not help decrease the casualty's injuries depending on the response of the restraint system.

It should be noted that in 23% of the CCIS fatal cases the accident severity was so high that it was not possible to determine whether or not a compatibility issue had occurred.

- Frontal force and/or compartment strength mismatch issues between cars in the current fleet appear[1] to be less of an issue than poor structural interaction.
    - In CCIS, for all accidents, force and/or compartment strength mismatch problems were identified for 8% of fatal and 2% MAIS 2+ survived occupants in CCIS. However, it should be noted that force and/or compartment strength mismatch problems can only be objectively identified for accidents in which there is compartment intrusion into the vehicle.
    - In CCIS, for car-to-car impacts force and/or compartment strength mismatch problems identified for 9% of fatal and 3% MAIS 2+ survived occupants
- Compartment strength of vehicles is still an issue in the current vehicle fleet.
    - Occupants with injuries caused by contact with intrusion CCIS 25%, GIDAS 12% of MAIS 2+ injured occupants
    - When an occupant sustains an injury caused by 'contact with intrusion' in the majority of cases it is the most severe injury, often a leg or thorax injury but sometimes a head or arm injury.
- In a matched pair analysis of car-to-car impacts a relationship was found between mass ratio and driver injury severity, namely the higher the mass ratio the higher the driver injury severity (note: mass ratio above 1 means that the partner vehicle is heavier). However, no such relationship was found between mass ratio and intrusion. The implications of this are that intrusion (and hence compartment strength) is not the major contributory factor to more severe injuries in the lighter car in a car-to-car impact. However, it should be noted that the data sample used for this analysis was relatively small and hence confidence in this result is limited. In addition the result may have been confounded by the age of the vehicle (newer vehicles generally have better compartment integrity) and the age of the occupant.
- Compartment strength is a particular problem in collisions with HGVs and objects, with these collisions having a high proportion of fatal and MAIS 2+ injuries
    - In CCIS, 31% of car-HGV cases resulted in intrusion in the car, compared to 25% for car-to-car cases
    - In GIDAS, 20% of car-HGV cases had MAIS 2+ injury severity for the car occupant, compared with 7% for car-to-car cases

[1] Note: structural interaction problems could be masking frontal force mismatch problems

Injury patterns

- AIS 2+ injuries to the thorax are the most prevalent. AIS 2+ injuries are also frequently sustained by the head, legs and arms.
  - Over 80% of fatally injured occupants and 35% of MAIS 2+ survived occupants sustained AIS 2+ thorax injuries in CCIS
- AIS 2+ injuries related to the restraint system (i.e. those caused by loading of the occupant by the seatbelt or airbag to decelerate him and prevent greater injury by contact with other car interior structures) are present in a significant proportion of frontal crashes, regardless of whether intrusion was present or not.
  - Over 40% MAIS 2+ occupants sustained AIS 2+ injury attributed to restraint loading in both CCIS and GIDAS datasets.
- Analysis of injury mechanisms in CCIS found that 45% of MAIS 2+ injured occupants had an AIS 2+ injury related to the 'restraint system', 40% had an AIS 2+ injury caused by 'contact with no intrusion' and 25% had an AIS 2+ injury caused by 'contact with intrusion' In the majority of cases these injuries were the most serious injuries that the occupant had.
  - When the most severe injury was related to the 'restraint system' the injury was mainly to the thorax (62%) with some to the arms (21%) (clavicle fractures).
  - When the most severe injury was related to the 'contact no intrusion' the injury was mainly to the legs (42%) with some to the arms (30%) (clavicle fractures) and thorax (12%).
  - When the most severe injury was related to the 'contact with intrusion' the injury was mainly to the legs (46%) and thorax (30%).
- For accidents for which there is intrusion, for MAIS 2+ injured occupants AIS 2+ injuries to the legs are the most prevalent
  - Where intrusion was present about 70% MAIS 2+ occupants sustained AIS 2+ leg injuries in CCIS
  - Note: about 40% sustained AIS 2+ thorax injuries
- AIS 2+ injuries resulting from contact with intrusion occur in a large proportion of cases where compartment intrusion is present
  - 65% of MAIS 2+ occupants in cars with intrusion sustained AIS 2+ injury attributed to contact with intrusion (CCIS)
- High proportion of fatal and MAIS 2+ injuries in cases with high overlap (>75%)
  - In GIDAS, 41% of MAIS 2+ survived were in high overlap cases
  - In CCIS, 40% of MAIS 2+ survived and 31% of fatal occupants were in crashes with high overlap
- GIDAS analysis showed that the proportion of MAIS 2+ injuries due to acceleration loading (i.e. injuries related to the restraint system caused by loading of the occupant by the seatbelt or airbag to decelerate him and prevent greater injuries by contact with other car interior structures) increased for higher overlap cases, whilst proportion of MAIS 2+ injuries due to contact with intrusion increased for lower overlap cases
  - In GIDAS 25% of MAIS 2+ survived were in low overlap cases indicating possible issues with low overlap and/or narrow object impacts. However, much lower percentages were seen in car-to-car impacts and CCIS data.

- Greater proportion of fatal and MAIS 2+ injuries for elderly occupants compared with other age groups
  - In CCIS dataset, occupants over 60 years old represent 18% of injured occupants, however account for 52% of fatalities and 25% of MAIS 2+ survived occupants
- In GIDAS, serious injuries (AIS 2+) due to acceleration loading (restraints) could be identified to occur more often for women than men and are linked with slightly higher proportions for front passengers than drivers.

1 INTRODUCTION

1.1 FIMCAR Project

For the real life assessment of vehicle safety in frontal collisions the compatibility (described by the self and partner-protection level) between the opponents is crucial. Although compatibility has been analysed worldwide for years, no final assessment approach was defined. Taking into account the EEVC WG15 [Faerber 2007] and the FP5 VC-COMPAT [Edwards 2007] project activities, two test approaches are the most promising candidates for the assessment of compatibility. Both are composed of an off-set and a full overlap test procedure. However, no final decision was taken. In addition, another procedure (tests with a moving deformable barrier) is under discussion in today's research programmes.

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

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

1.2 Objective of this Deliverable

The objectives of this work for this deliverable were:

- Determine if previously identified compatibility issues are still relevant in current vehicle fleet
  - Structural interaction
  - Frontal force matching
  - Compartment strength in particular for light cars
- Determine nature of injuries and injury mechanisms
  - Body regions injured
  - Injury mechanism
    - Contact with intrusion
    - Contact
    - Deceleration / restraint induced

1.3 Structure of this Deliverable

This deliverable starts with a 'Background' section in which previous relevant accident analysis work is reviewed. Next the 'Approach' section describes the basis for how the analysis work was performed. This is followed by the 'Description of Accident Databases' section which describes the GB CCIS and German GIDAS accident databases used for the analysis work performed. The results of the GB accident analysis work using the CCIS database and the German accident analysis work using the GIDAS database are described in the 'GB Accident Analysis' and 'German Accident Analysis' sections respectively. This is followed by a discussion section in which the results of the GB and German analyses are compared, which in turn is followed by the 'Summary of Conclusions' section.

2 BACKGROUND

Compatibility research has depended on the use of accident data to identify both the critical issues that safety issues making up compatibility as well as indicating the size of the problem. The FIMCAR project is the continuation of previous research undertaken in Europe but has also made an important step forward – specifically looking at the safety of newer model vehicles.

The earlier work in EEVC WG 15 [Faerber 2007] and VC-Compat [Edwards 2007] was based on accident data collected before 2004-2005. This time period was shortly after UNECE Regulation 94 became mandatory for all newly registered European vehicles (1st Oct 2003). This presents two issues for interpretation of the data. The first is that the accident data set available contained very few vehicles that were built after 2000. New vehicle models are not involved in accidents in significant numbers until a few years have elapsed. The second issue is that the new vehicles introduced between 1998 and 2003 did not necessarily have to meet Regulation 94 (phase in period). Thus the accident data available in previous research contained a range of vehicle designs that did not meet current regulations.

The accident analysis and benefit approach taken in VC-Compat is presented in Figure 2.1. The target population was based on pessimistic or optimistic assumptions of which vehicle occupants would benefit from compatibility improvements. These assumptions were based on accident configuration parameters such as the crash severity, expressed in EES/ETS,[2] the direction of vehicle loading and the degree of overlap. From the GB and German approaches documented in [Edwards 2007] a European estimate of the benefit for compatibility was estimated to be a 4%-8% reduction in fatalities and a 5%-13% reduction in serious injuries for car-to-car crashes.

A strategy for the accident analysis conducted in FIMCAR, developed from the GRSP informal working group on frontal impact, was that accident analysis should be limited to vehicles fulfilling Regulation 94. The main focus of FIMCAR has been to continue using the detailed databases available in the UK and Germany in order to study specific crash mechanisms that influence vehicle safety. The remainder of this section will report the recent research activities relevant to the FIMCAR project.

[2] Equivalent Energy Speed (describing the deformation energy by the velocity which would be necessary to generate the deformation) / Estimated Test Speed (test speed of the vehicle against a rigid fixed barrier that would cause the same deformation)
Note: EES and ETS are very similar measures

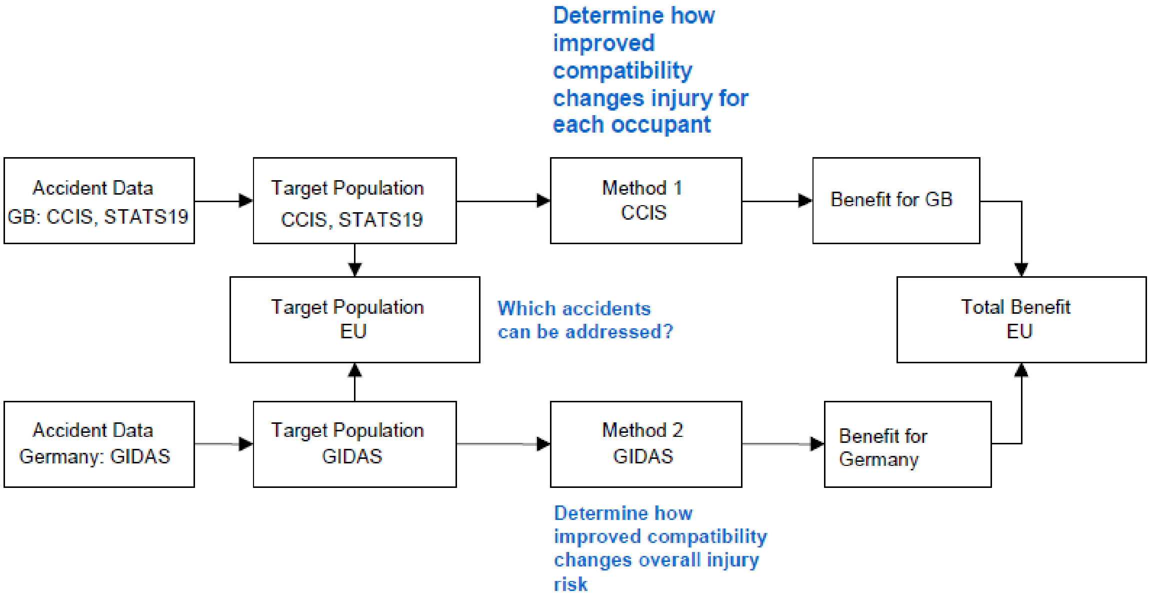

Figure 2.1: Accident and Benefit Analysis Approach in VC-Compat [Edwards 2007].

2.1 Informal Working Group on Frontal Impact (UNECE-WP29/GRSP)

France made a proposal to change the frontal impact legislation – Regulation 94 – within the UNECE framework of the 1958 agreement. This agreement applies to signatory countries that include the European Union. As part of the proposal, France presented accident statistics identifying the Severity Rate indicator (SR) and Mortality Rate indicator (MR) [Chauvel 2009]. These terms were used in an analysis of vehicle models where all accidents involving a specific make and model of vehicle were collected. These terms are defined as:

$$SR = \frac{(N_{Fatalities} + N_{Severe\ Injuries})}{(N_{Fatalities} + N_{Severe\ Injuries} + N_{Minor\ Injuries + N_{Not\ Injured}})}$$

$$MR = \frac{(N_{Fatalities})}{(N_{Fatalities} + N_{Severe\ Injuries} + N_{Minor\ Injuries + N_{Not\ Injured}})}$$

The concepts of Severity Ratio and Mortality Ratio were further developed to describe the self and partner protection level of a particular vehicle model as explained below. When the numerator is the number of casualties in the reference vehicle model and the denominator is the total injuries in the sample then the term reflects the self-protection of that vehicle model. It is the conditional probability of injury for an occupant of the reference model given a crash. Conversely, if the numerator is the number of casualties in vehicles struck by the reference vehicle, the aggressivity of the vehicle is quantified as the conditional probability of injury when struck by the reference vehicle in a crash. Two countries submitted information to the working group, France and Germany.

2.1.1 Informal Working Group on Frontal Impact: French Data

The analysis of the French national database (ONISR) was restricted to R94 compliant vehicles and required at least one police reported injury. Belted front seat occupants involved in frontal crashes were collected for the years 2005-2008. With the selection criteria approximately 1800 car-to-car crashes and 861 single vehicle crashes were identified [Chauvel 2009].

The French data showed a higher SR for smaller vehicles in car-to-car collisions although the results are not statistically significant. Similarly, heavier vehicles tended to be more aggressive to the collision partners. This is visualised in Figure 2.2. Ideally a car should have a balanced self and partner protection, indicated by the diagonal blue line. Vehicles above the line have better partner protection than self protection and cars below the line are the opposite [Chauvel 2009].

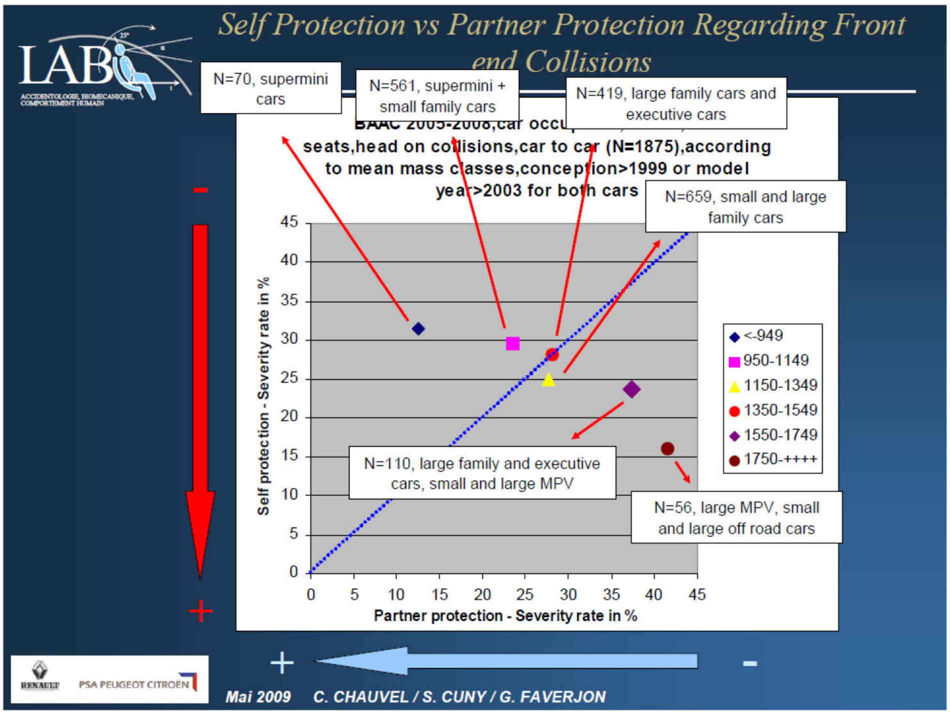

Figure 2.2: Self and partner protection data from France [Chauvel 2009].

The French analysis included an evaluation of vehicle safety in single vehicle collisions. It was shown that the injury risk was essentially identical for all vehicles contrary to the results for car-to-car crashes. The final stage in the analysis was an estimate of the benefit if a new frontal test procedure could harmonise the test severity so that it was less sensitive to mass. If the SR value for all vehicles could be harmonised to one value through improved test procedures, fatal and serious injuries in frontal impacts would be reduced by 40% in France [Chauvel 2009].

The data in Figure 2.2 provides information on the combined effect of mass, geometry, and vehicle architecture but does not identify the role of each of these parameters on compatibility.

2.1.2 Informal Working Group on Frontal Impact: German Data

Similar to the French contribution to the working group, BASt conducted an analysis of the German national statistics (police reports) to identify characteristics of the German accidents and performance of vehicles within the fleet [Pastor 2009/1; Pastor/2].

An analysis of the car-to-car accidents produced similar results to that in France, smaller vehicles had higher frequencies of injuries than larger vehicles. The German analysis further analysed the influence of the crash partner to establish the role of other vehicle parameters. A “matched pairs” analysis was used to establish a ranking of the relative safety of the different vehicles and quantify the relationships between the vehicle models. Through the analysis, different options for countermeasures were analysed:

a) Do nothing
b) Just add „crashworthiness“ to small cars to reach high NCAP level
c) Increase „crashworthiness“ of all cars to high NCAP level
d) Do nothing but adjust restraint system to female
e) Do nothing but adjust restraint system to female and elderly occupants
f) Better „crash energy distribution“

The results indicated that benefits became noteworthy after item d) on the list. In other words, just changing the self-protection of vehicles had little benefit unless it was combined with improvements to the restraint system to address non-standard occupants. Better crash energy distribution was also identified as a potential for improvement but it was difficult to identify a test method that produced this effect.

The analysis was further refined and it was noted that the collision partner was critical in determining the injury risks. In terms of frequency, smaller cars tend to hit smaller cars due to the distribution of vehicle masses in the fleet. There was a tendency for more serious injuries when smaller car collide with heavier cars. There was a slight overrepresentation of fatal injuries in small vehicles when colliding with large vehicles. The difference in mass between vehicles appeared to be less relevant than the sex and age of the person injured.

Single vehicle frontal crashes were the largest subgroup in the German data. The data was analysed to establish the importance of different variables such as vehicle age, occupant characteristics, accident location, etc. The first point of note (for single vehicle frontal crashes) was that there was no influence of vehicle mass on the injury risk. The most critical parameters linked to occupant casualty were the occupant age, vehicle age, and object struck. Interestingly, the newer vehicles were more likely than older vehicles to be involved in frontal impacts than side impacts which may be a result of ESC.

2.2 European Accident Analysis for DG-Enterprise

A substantial investigation of frontal accidents [Richards 2001] was conducted by TRL in conjunction with BASt and Lab to investigate GB, D, and FR data, respectively. The analysis was extensive, broken into 3 main tasks of

1) Taxonomy of frontal impacts
    a. National Data
    b. In-depth Data
2) Case Analysis of the Effectiveness of UNECE R94

3) Compatibility

The main conclusions of interest to FIMCAR in point 1) were that a substantial number (approximately 2/3) of fatalities and serious injuries could be addressed by improving Regulation 94. The frontal impact configuration that was most common was an offset impact with direct loading of one longitudinal which the Regulation 94 test represents. The second most common configuration involved direct loading of both longitudinal which is represented by a full width test. Impacts with light goods vehicles (LGV) were significant in all three countries and should be addressed in future safety regulations.

The national data from GB and Germany suggests that the casualties related to impacts with narrow objects are small (5-6% in GB and 10-16% in Germany) and suggests that a specialised pole impact would not address a substantial part of the total target population.

The cumulative collision severity distribution of the current accidents, expressed in EES/ETS, shows that only small gains in safety would be achieved if the current regulation test severity was increased to correspond to the Euro NCAP test severity.

As noted previously for the German analysis in the GRSP informal working group, the occupant age and sex are relevant issues with elderly people being overrepresented in the fatality statistics for lower severity impacts. Many female and elderly casualties are reported in the front seat passenger position.

The most serious injuries were connected to the thorax and many were related to loading by the restraint system. Cases with higher injury severities had many injuries attributed to contact with intruding structures. Chest injuries were more common for elderly occupants.

The activities addressed in Task 2) (a review of 48 fatally injured occupants in CCIS) was conducted to observe vehicle performance in the individual cases. In this sample, 17 fatalities were attributed to high impact severity (11 significantly higher than current test conditions). There were 13 occupants that were judged as vulnerable. There were 14 occupants associated with different types of compatibility issues where over/underride of different vehicle types was reported.

To evaluate the effectiveness of R94, 25 CCIS occupants were identified that experienced an impact type and severity represented in the regulation. For these occupants injury outcome was worse than expected compared to the injury risk measured by dummies in Euro NCAP tests when the vehicle's structural performance was worse than that observed in Euro NCAP tests. Therefore, it was thought that the cause of the worse than expected injury outcome was that the structural performance of the vehicle was worse in the accident than in the Euro NCAP test, This in turn was thought could have been caused by poor structural interaction and / or a frontal force matching problem (i.e. a compatibility problem) in the accident.

2.3 European Union Projects THORAX/COVER

Parallel to FIMCAR, two ongoing projects are also investigating occupant safety with a focus on injury biomechanics and injury risk measurement and criteria. The COVER project (Coordination of Vehicle and Road Safety Initiatives) [Cover Project 2013] and the THORAX project (Thoracic injury assessment for improved vehicle safety) [Thorax Project 2013] provided their summarised findings in project deliverables [Carroll 2009/1] and [Carroll

2009/2]. The data looked at the types and causes of injuries to the thorax and provided information about the factors influencing injury risk. The data reviewed in COVER/THORAX was essentially the same sources as for the previously reports. TRL, BAST, and LAB reviewed injuries in frontal impacts with modern vehicles.

Some general observations were that females and people over 52 years old had a higher risk of torso injuries. German data suggested that people 150-180 cm tall and weighing 40-60 kg were statistically most likely to have AIS 1 torso injuries. Although the same trend was present, the results were not statistically significant at higher AIS levels. The seating position seemed to influence the injury risk as the front seat passenger (not driver) had the most severe injuries even when on the non-struck side of the vehicle. These occupants were also mostly female. Rear seat passengers also reported torso injuries as the most common injury and these occupants tended to be smaller and younger occupants. A comparison of AIS 3+ torso injuries observed in the accident data compared to the vehicle's performance in Euro NCAP showed that Euro NCAP test data overestimates the restraints system effectiveness with or without a force-limiting belt.

2.4 Summary External Findings

Previous and ongoing research external to FIMCAR identified safety issues in frontal crashes. Mass influences crash performance by influencing both acceleration and intrusion. There is always a higher delta-v (and thereby higher accelerations) in small cars when they strike larger vehicles. Larger cars and smaller cars also have different energy absorbing and force level management issues that can result in larger deformations and intrusions in smaller cars. The mass issues could not be easily separated in the reviewed research.

In two studies, the real world vehicle performance was lower than that predicted by standard tests. These differences could be related to structural interaction issues as well as occupant vulnerability.

All the data reflect a range of impact configurations where the amount of the frontal structure was in contact with the collision partner. The two most common accidents can be represented by a combination of full width and offset tests. Narrow object and small overlap crashes were observed but did not represent a more significant portion of the accidents or casualties.

The most relevant injury issue that is appearing in the accident data are thorax injures, particularly for female and older occupants. Improvements in the structural performance of the vehicle must be measured using an appropriate test device and a small female test dummy may be a good solution. New injury risk functions and modifications for older occupants are desirable but beyond the scope of FIMCAR.

Further accident analysis in FIMCAR should focus on the structural behaviour issues of cars, in particular identification of structural interaction issues as well as resolving the specific issues related to vehicle mass (acceleration or stiffness/force level) to further develop test procedures.

3 APPROACH

The following in-depth accident databases were used for this work to provide a European perspective:

- GB Cooperative Crash Injury Study (CCIS) analysed by TRL with support from Chalmers
- German In-Depth Accident Study (GIDAS) analysed by BASt
- Pan European Accident Database (PENDANT) analysed by Chalmers.

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

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

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

Unfortunately, during the course of the work it was found that the PENDANT database did not contain a large enough number of appropriate cases to be able to provide statistically meaningful results. Hence, the remaining Chalmers effort was re-directed to analysis of the GB CCIS accident database.

4 DESCRIPTION OF ACCIDENT DATABASES

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

4.1 Great Britain

4.1.1 STATS19 National Accident Statistics

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

STATS19 is, in principle, the national database in which all traffic accidents that result in injury to at least one person are recorded, although it is acknowledged that some injury accidents are missing from the database and a few non-injury accidents are included. The database primarily records information regarding where the accident took place, when the accident occurred, the conditions at the time and location of the accident, details of the vehicles involved and information about the casualties. Approximately 50 pieces of information are collected for each accident [Baghat 2009].

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

4.1.2 CCIS Detailed Accident Database

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

Accidents were investigated according to a stratified sampling procedure, which favoured cars containing fatal or seriously injured occupants as defined by the British Government definitions of fatal, serious and slight. In order for an accident to be included in the study, a "newer" car must have been involved – one that was 7 years old or younger at the time of the accident. The stratified sampling procedure means that CCIS records a relatively large number of fatal and serious accidents, which are often the most interesting from an injury prevention point of view.

4.2 Germany - GIDAS

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

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

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

4.3 Europe - PENDANT

Pan-European Co-ordinated Accident and Injury Databases (PENDANT) is an in-depth crash injury database using STAIRS [Vallet 1999] protocols enhanced with CARE data [European Commission 2013]. It contains data on 1100 accidents from 8 European countries (Table 1) including:

- Frontal impacts
- Side impacts
- Rollovers
- Rear impacts
- Non-struck side impacts
- Pedestrian crashes.

Table 1: Cases Collected by the PENDANT Teams

	Accident	Vehicle	Occupant	Pedestrian
Sweden	150	264	355	0
France	132	201	296	0
Germany	171	328	424	21
Austria	75	152	229	8
Netherlands	175	326	235	18
UK	200	290	445	2
Finland	80	126	153	6
Spain	127	197	232	13
Total	1110	1884	2369	68

The data was collected during the PENDANT project (2003-2006). Inclusion criteria were that at least one car in the accident was built after 1998 and at least one personal injury was attributed to the accident. A more detailed description of the database and its major findings can be found in Lenard *et al.* 2006 [Lenard 2006].

5 GB ACCIDENT ANALYSIS

The GB accident analysis used the CCIS accident database and was performed mainly by TRL. Chalmers helped to perform some of the detailed case analysis.

5.1 Approach

The GB analysis consisted of the following three steps:

- Select data set for analysis
  - Using appropriate selection criteria a data set was formed for the analysis ensuring that as far as was possible only Regulation 94 compliant vehicles (or those with an equivalent safety level) were included.
  - The main characteristics of this data set and an equivalent national (STATS19) data set were compared to quantify any biases in the CCIS data set. This was necessary to help ensure that the results of the compatibility analysis performed were interpreted correctly.
- Overall analysis
  - The detailed characteristics of the CCIS data set were investigated.
  - An analysis was performed to quantify the magnitude of compartment strength issue. The analysis determined the proportion of casualties for which there was significant compartment intrusion (defined as greater than 10 cm) and investigated the characteristics of the accidents in which these casualties were involved compared to casualties in accidents without intrusion.
  - A matched pair analysis was performed to investigate if the compartment strength issue quantified above was a bigger issue for lighter cars compared to heavier cars.
  - An additional analysis was performed to determine the nature of the casualty's injuries, the injury mechanisms and the relationship of the injury mechanism with intrusion.
- Detailed case analysis
  - A detailed case analysis was performed to quantify the nature and magnitude of structural interaction and frontal force matching problems.

5.2 Data Selection

The following criteria were used for the initial selection of the accident data set:

- Occupant in car (M1) or car derived van
- Car involved in 'significant' frontal impact without significant rollover
- Car registered in year 2000 onwards and UNECE Regulation 94 compliant (or equivalent safety level)
  - Note: Cars which met this age criterion were selected even if they impacted an older car in a car-to-car impact. However, for some parts of the analysis (e.g. matched pair analysis) an additional selection criterion that both cars must meet this age criterion was used.

To determine whether or not a car was Regulation 94 compliant the following steps were taken:

- Determine registration date of car

- For cars registered 1st Oct 2003 onwards then legislation mandates that it is compliant.
- For cars registered from 1st Jan 2000 to 1st Oct 2003 checks were made to determine safety level of vehicle. These checks included check of performance in Euro NCAP tests (if available) and checks when new models were introduced (if a car was sold after Oct. 2003 then it was assumed that the case vehicle was Regulation 94 compliant).

The distribution of casualties in the initial CCIS dataset by injury severity and impact partner is shown in Table 2. The characteristics of this CCIS data set and an equivalent STATS19 data set were compared to quantify any biases in the CCIS data set. This was necessary to help ensure that the results of the compatibility analysis performed were interpreted correctly. It was found that the CCIS data set has a higher proportion of HGV/bus impacts, a lower proportion of narrow object impacts and a bias towards older occupants (see Appendix A).

Table 2: Casualties in initial CCIS dataset by injury severity and impact partner.

	Fatal	**MAIS 2+ survived**	**MAIS 1**	***Total***
Car - Wide object	32	95	208	335
Car - Narrow object	4	42	100	146
Car - Car	30	309	974	1313
Car - Light Goods Vehicle	5	44	97	146
Car - HGV / PSV	22	56	87	165
Car - Other	0	3	7	10
Total	93	549	1473	2115

The following further selection criteria were used to select the final CCIS data set used for the compatibility analysis:

- Front seat adult (over 12 years old) occupants
- Belted occupants
- MAIS 2+ injured occupants (for some parts of the analysis)

The distribution of casualties in the final CCIS dataset by injury severity and impact partner is shown in Table 3.

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Table 3: Casualties in final CCIS dataset by injury severity and impact partner.

	Fatal	**MAIS 2+ survived**	**MAIS 1**	***Total***
Car - Wide object	9	50	117	176
Car - Narrow object	1	16	57	74
Car - Car	23	226	714	963
Car - Light Goods Vehicle	2	31	55	88
Car - HGV / PSV	13	39	61	113
Car - Other	0	3	7	10
Total	48	365	1,011	1,424

5.3 Overall Analysis

5.3.1 Data Set Characteristics

The characteristics of the CCIS dataset were analysed. The results are shown in Figure 5.1 to Figure 5.9. Some of the main findings of this analysis were that:

- A high proportion of the occupants were involved in crashes with an ETS less than 60 km/h (where ETS was known), although over 25% of the fatally injured occupants were in crashes with ETS greater than 60 km/h (Figure 5.1).
- There is a higher proportion of fatally injured occupants in the HGV / PSV impact partner group compared to other groups indicating the more injurious nature of HGV / PSV type impacts. There is also a slighter higher proportion of fatally injured occupants in the car to wide object impact partner group indicating the slightly more injurious nature of this type of impact. (Figure 5.2).
- A high proportion of fatal and MAIS 2+ survived injured occupants (30% of fatal and 40% of MAIS 2+ survived) were in crashes with a high frontal overlap (75-100%) (Figure 5.3).
- Although the occupants in the “Over 75” age group made up a low proportion of the occupants in the dataset, they were a high percentage of fatal and MAIS 2+ survived occupants compared to the other age groups, i.e. they were over-represented (Figure 5.5).

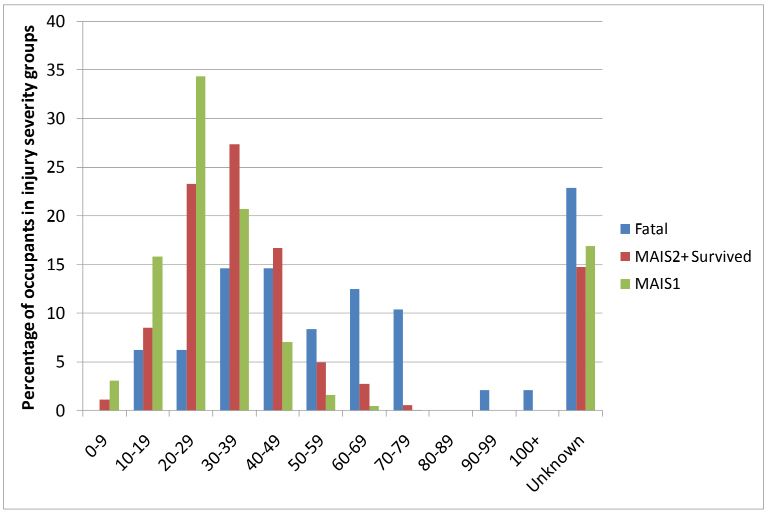


Figure 5.1: Percentage of occupants in injury severity groups against ETS (km/h).

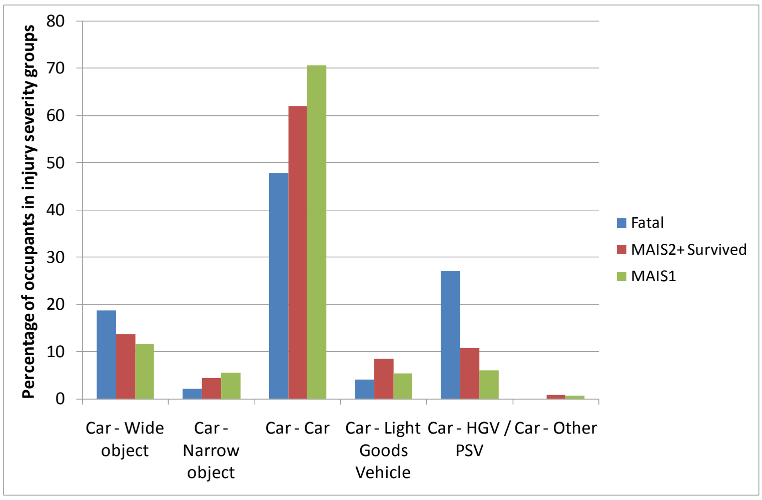


Figure 5.2: Percentage of occupants in injury severity groups against impact partner.

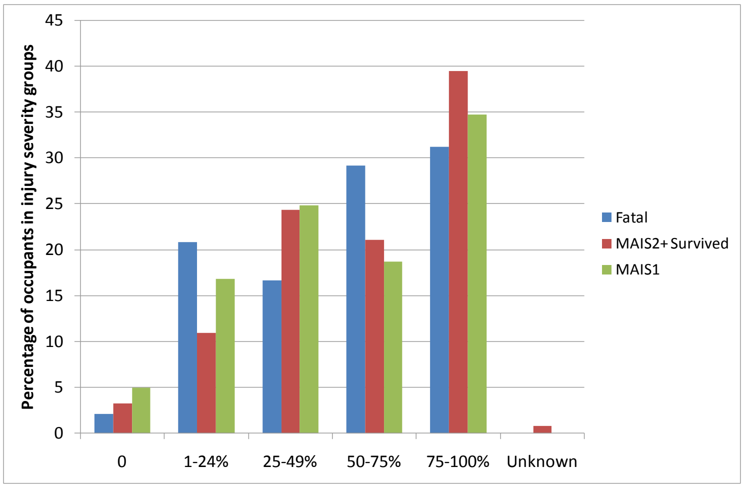


Figure 5.3: Percentage of occupants in injury severity groups against vehicle frontal overlap.

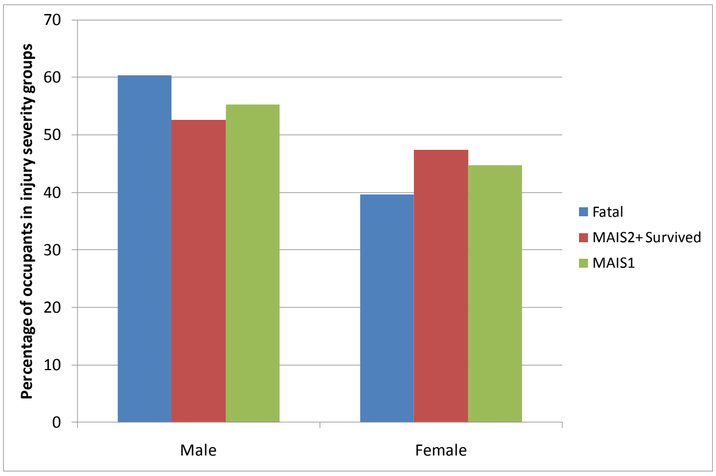


Figure 5.4: Percentage of occupants in injury severity groups by gender.

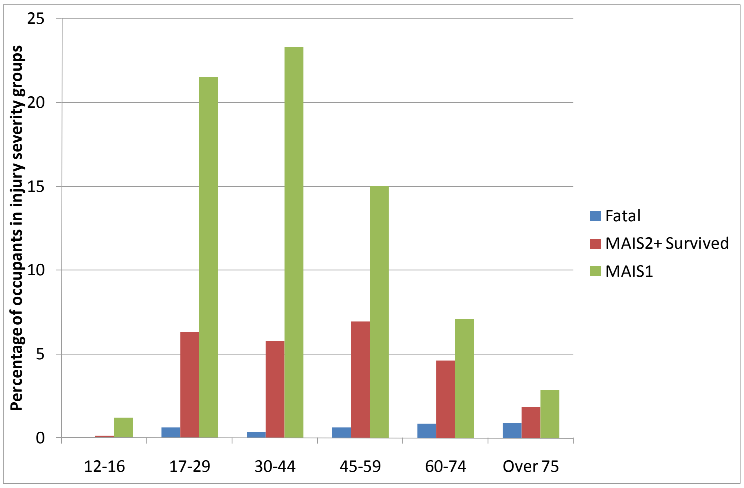


Figure 5.5: Percentage of occupants in injury severity groups against occupant age.

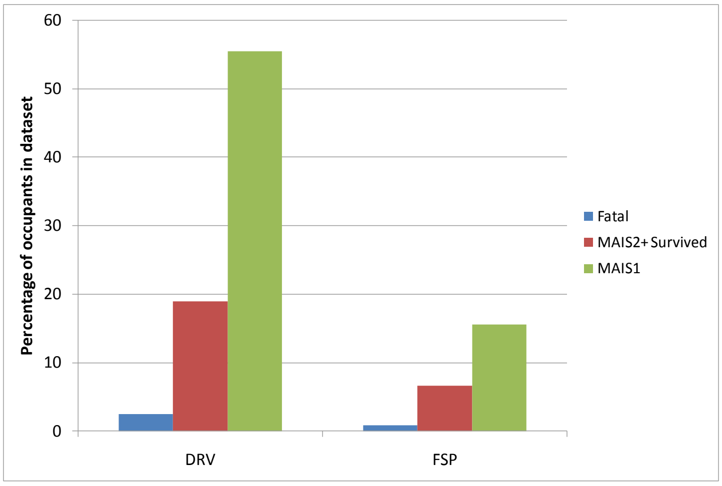


Figure 5.6: Percentage of occupants in injury severity groups against seating position.

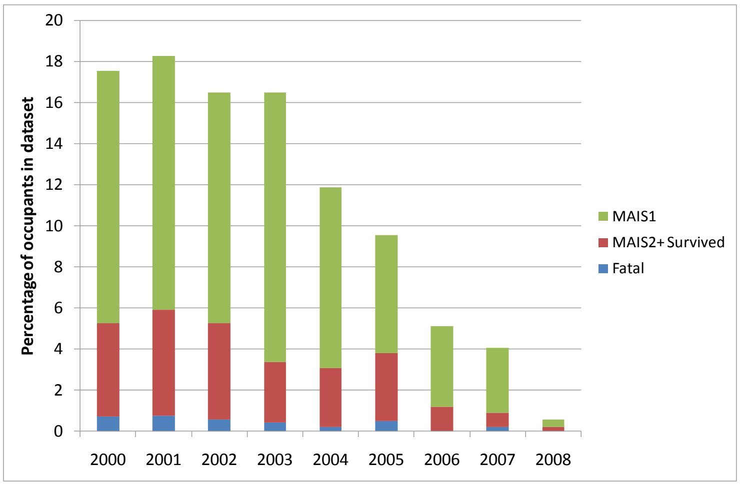


Figure 5.7: Percentage of occupants in injury severity groups against vehicle age.

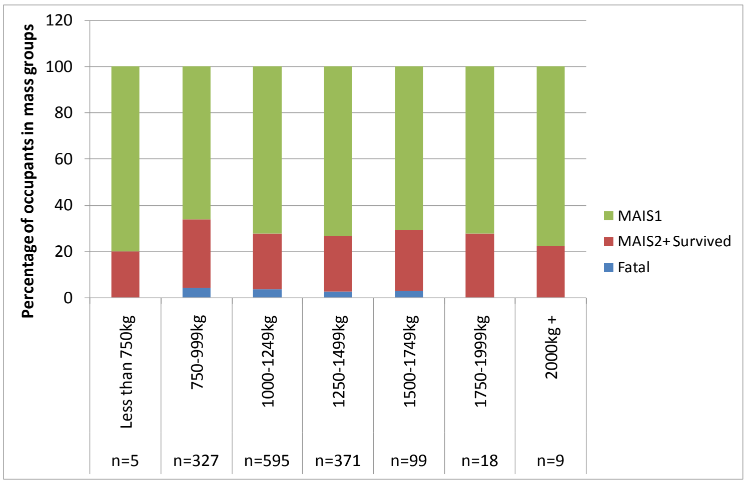


Figure 5.8: Percentage of occupants in injury severity groups against vehicle mass.

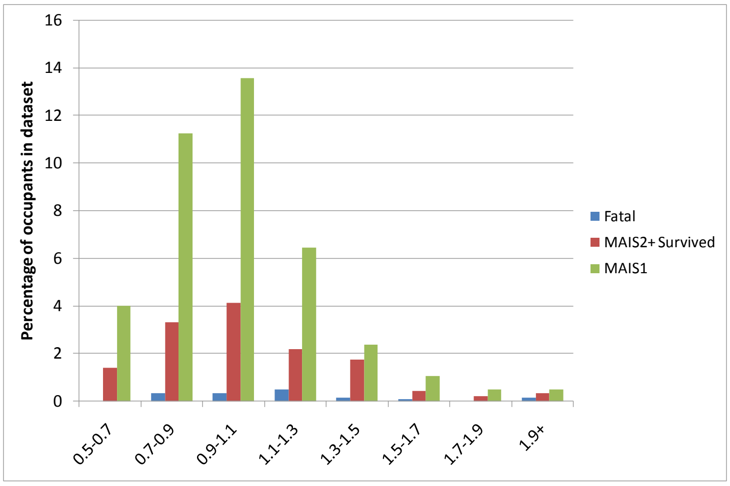


Figure 5.9: Percentage of occupants in injury severity groups against vehicle mass ratio – vehicle mass ratio less than 1.0 indicates that the partner vehicle is lighter.

5.3.2 Compartment Strength

For this analysis only MAIS 2+ injured occupants were considered.

In CCIS measurements of the vehicle interior are recorded in order to determine the reduction in available space for the occupant caused by intrusion. These measurements are taken at the footwell, knee contact areas on the facia/dashboard, and at the base of the windscreen/A-pillar. In addition, the reduction of the door aperture between the A and B-pillars is recorded.

For the purposes of this study to obtain an indication of the compartment strength issue it was determined whether an occupant had been exposed to intrusion or not. Small levels of intrusion of just a few centimetres were considered unlikely to have a significant effect on an occupant, and therefore intrusion was only considered to be present if a significant level was measured. It was decided that a vehicle would be considered to have sustained intrusion if there was at least 10 cm reduction in space recorded at any of the measurement points described above. In order to have had an effect on the occupant, this intrusion would have to have occurred on the same side of the vehicle as the occupant.

Using the methodology described above for determining if intrusion was present, the proportion of the occupants in the dataset who had intrusion present on their side of the vehicle was calculated (Table 4). This showed that approximately 56% of fatal occupants and 21% of MAIS 2+ survived occupants had intrusion present. Comparing across the different accident configurations showed that intrusion was present in approximately 25% of crashes with objects, cars and light goods vehicles, and in over 30% of crashes with HGVs and PSVs.

Table 4: Proportion of occupants in the dataset with intrusion present on their side of the vehicle.

	Fatal		MAIS 2+ survived		Overall	
	No. of occupants	**% of cases with intrusion**	**No. of occupants**	**% of cases with intrusion**	**No. of occupants**	**% of cases with intrusion**
Car - Wide object	9	55.6	50	20.0	59	25.4
Car - Narrow object	1	100.0	16	18.8	17	23.5
Car – Car	23	56.5	226	21.2	249	24.5
Car - Light Goods Vehicle	2	50.0	31	22.6	33	24.2
Car - HGV / PSV	13	53.8	39	23.1	52	30.7
Car - Other	0	0	3	0	3	0.0
Total	48	56.3	365	21.1	413	25.2

Further analysis of the dataset was undertaken to identify any factors which may have been a factor in the presence of intrusion. In particular, the ETS (Estimated Test Speed), frontal overlap, vehicle mass and mass ratio with the collision partner were investigated.

Analysis of the presence of intrusion with respect to ETS showed that the proportions of occupants in vehicles with intrusion increased as the ETS increased as shown in Figure 5.10. It was also observed that a high proportion of the cases with intrusion were observed for ETS less than 60 km/h.

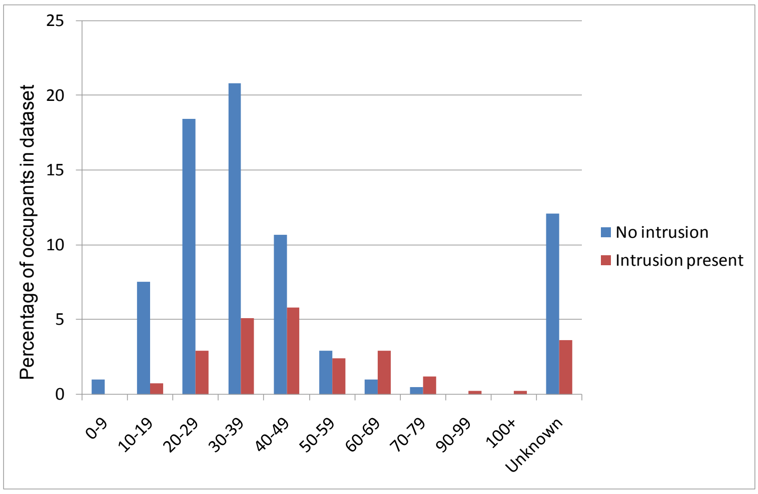


Figure 5.10: Percentage of occupants in dataset with and without intrusion against ETS (km/h).

Frontal overlap in CCIS is measured from one of the front corners of the vehicle. An overlap of "0" denotes that neither corner of the vehicle front was contacted (for example, a narrow impact between the longitudinal rails). Investigation of intrusion with respect to frontal overlap (Figure 5.11) showed that a lower proportion of cases with intrusion was present for crashes with a high frontal overlap (75-100 percent).

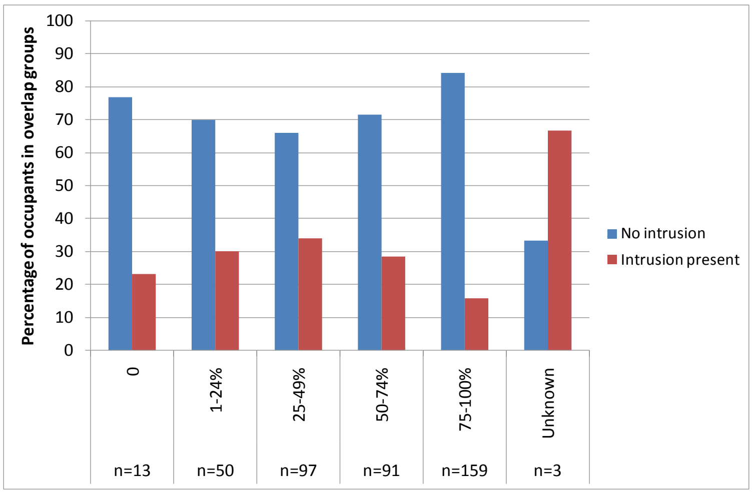


Figure 5.11: Percentage of occupants in dataset with and without intrusion against frontal overlap.

5.3.3 Matched Pair Analysis

To investigate issues related to mass ratio in car-to-car impacts a matched pair data set was used. This was necessary to ensure that the occupant injuries and performances of both cars in the impact were taken into account. The criteria used to select the matched pair data set from the initial CCIS data set described in Section 5.2 were:

- Front seat adult (over 12 years old) occupants
- Belted occupants
- MAIS 2+ injured occupants in at least one of the vehicles
- Both vehicles Regulation 94 compliant or equivalent

This resulted in a matched pair data set containing 34 accidents involving 68 vehicles. Only the driver injuries were considered in the following analysis.

Figure 5.12 shows the driver injury severity with mass ratio. A strong trend of an increase in driver injury severity with increasing mass ratio can be seen. This indicates that in a car-to-car impact the driver of the lighter car is more likely to sustain a more severe injury than the driver of the heavier car.

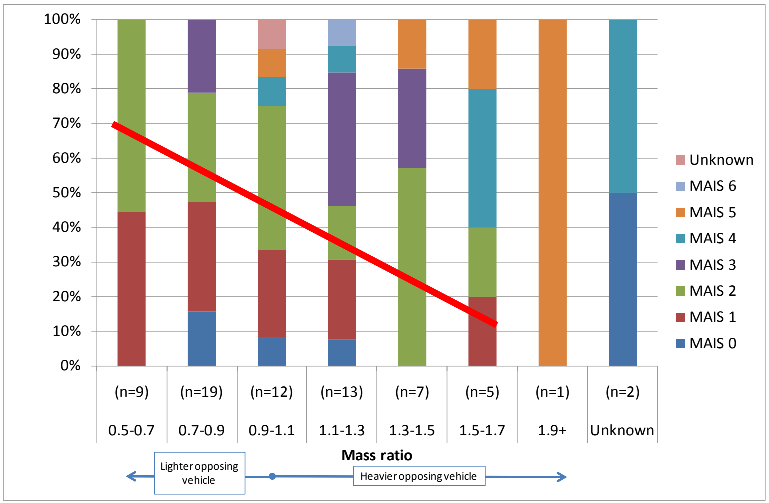


Figure 5.12: Driver injury severity with mass ratio.

This is in agreement with the results of previous studies such as the EC accident analysis for DG Enterprise which shows an increase in the aggressivity of vehicles with increasing mass from an analysis of French and German national data.

The main contributory factors to the increase in injury severity with increasing mass ratio have been described in previous analyses. They are:

- The increase in delta-v experienced by the occupants of the lighter car and associated increase in deceleration related injuries due to conservation of momentum.
- The higher likelihood of intrusion in the lighter car and associated increase in injuries related to intrusion.

If intrusion was the major and primary contributory factor, then one would expect to observe a similar trend of intrusion with mass ratio to that observed for driver injury severity with mass ratio. However, no such trend was observed (Figure 5.13). The implications of this are that intrusion is not the major contributory factor. However, it should be noted that the data sample used was relatively small and hence confidence in this result is limited. In addition, the result may be confounded by factors such as the age of the vehicle (newer vehicles generally have better compartment integrity) and the age of the occupant. A larger data sample would be needed to be able to remove these confounding factors.

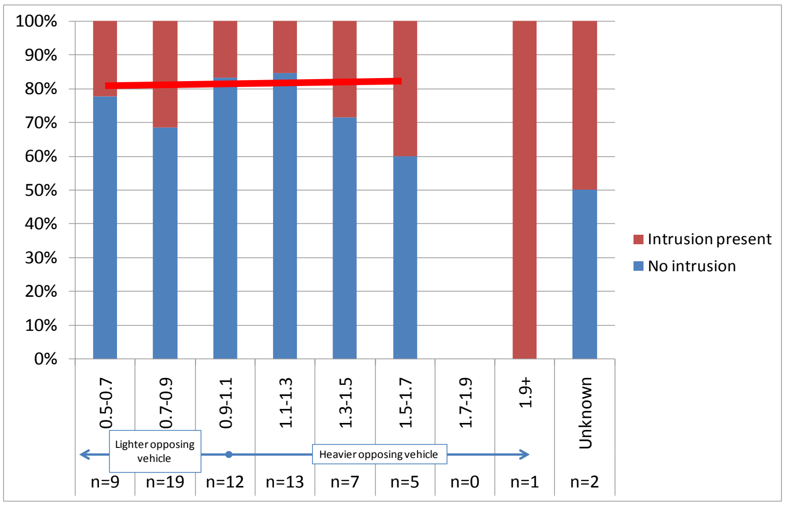


Figure 5.13: No intrusion / intrusion present with mass ratio.

5.3.4 Injury Patterns

An analysis of the specific injuries sustained by the vehicle occupants in the CCIS dataset was undertaken in order to understand if any patterns could be identified for injuries that were a particular issue in frontal impacts. In particular, the analysis of how injury patterns may be affected by the presence of intrusion was undertaken. Investigations into both the body injury distribution and the causation of the injuries were undertaken.

5.3.4.1 Injury Patterns and Intrusion

The distribution of the injuries relating to different body regions was undertaken. Only AIS 2+ injuries were taken into consideration for this analysis. This showed that over 80% of the fatal occupants in the dataset had sustained an AIS 2+ injury to the thorax, with approximately 65% sustaining AIS 2+ injury to the abdomen (Figure 5.14). Similar proportions of fatal occupants (approximately 55 percent) sustained AIS 2+ injuries to the head, arms and legs. For MAIS 2+ survived occupants, thorax injuries were also the most prevalent injuries alongside injuries to arms and legs. One possible reason for the high proportion of AIS 2+ arm injuries was that the shoulder was included in the arm body region, so injuries such as an AIS 2 fractured clavicle (collar bone) were included in the arm body region.

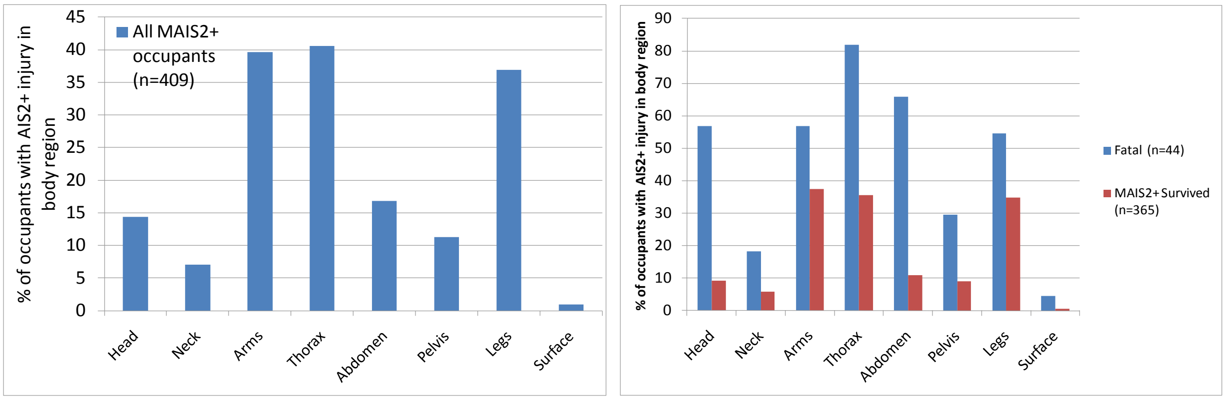


Figure 5.14: AIS 2+ body injury distribution, showing percentage of MAIS 2+ occupants sustaining an AIS 2+ injury in each of the body regions for all MAIS 2+ injured occupants and broken down for fatal and MAIS 2+ survived occupants.

Comparison of the occupant's body injury distribution in different accident types showed that a higher percentage of AIS 2+ head injuries occurred in car to heavy vehicle (HGV/PSV) crashes than other accident types, whilst leg, arm and thorax injuries appeared to be more prevalent in car to vehicle crashes than car to object crashes (Figure 5.15).

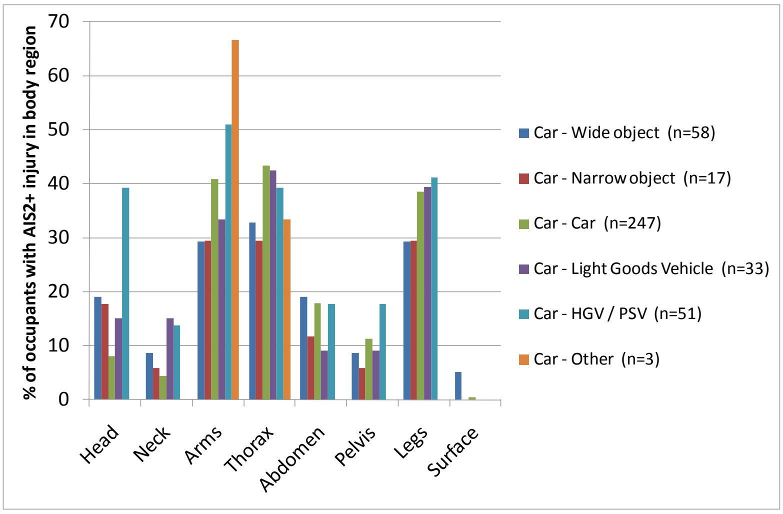


Figure 5.15: Body injury distribution for different accident types.

Analysis of the body injury distribution for the different occupant age groups showed that the percentage of occupants with AIS 2+ thorax injury increased substantially as occupant age increased, with approximately 25% of occupants under 44 years old sustaining AIS 2+ thorax injury compared to over 70% of occupants over 75 years old (Figure 5.16).

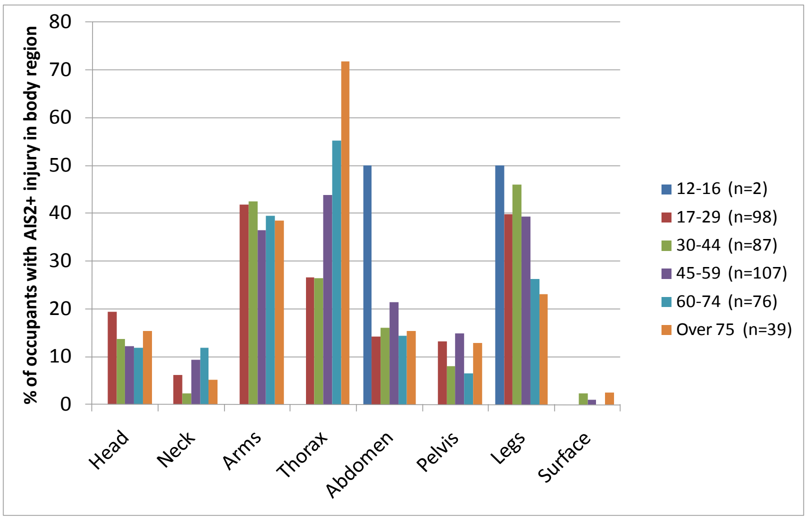


Figure 5.16: AIS 2+ body injury distribution for occupant age groups.

The comparison of body injury distribution for drivers and front seat passengers showed that drivers sustained a higher percentage of AIS 2+ leg and head injuries, most likely due to the presence of the steering wheel and pedals, whilst front seat passengers sustained a higher percentage of AIS 2+ abdomen and thorax injuries, possibly due to loading from the restraint system under deceleration (Figure 5.17).

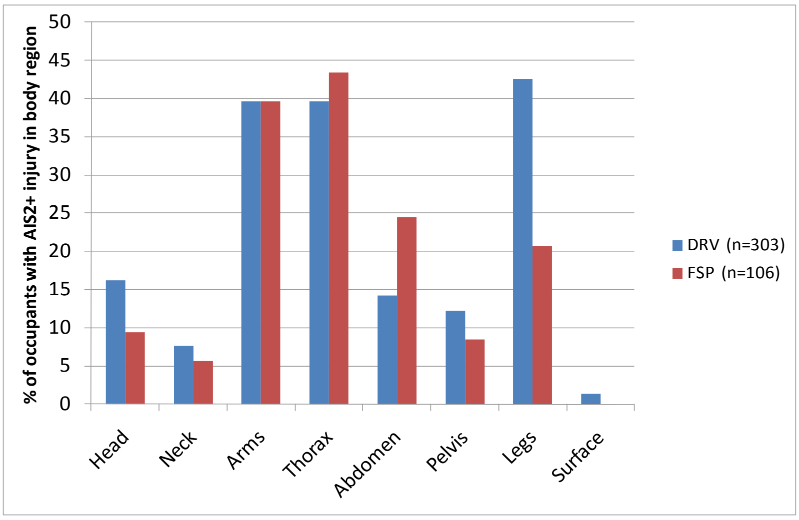


Figure 5.17: AIS 2+ body injury distribution for occupant seating position.

The body injury distribution appeared to be reasonably similar for male and female occupants, although male occupants sustained a slightly higher percentage of AIS 2+ head and leg injuries (Figure 5.18).

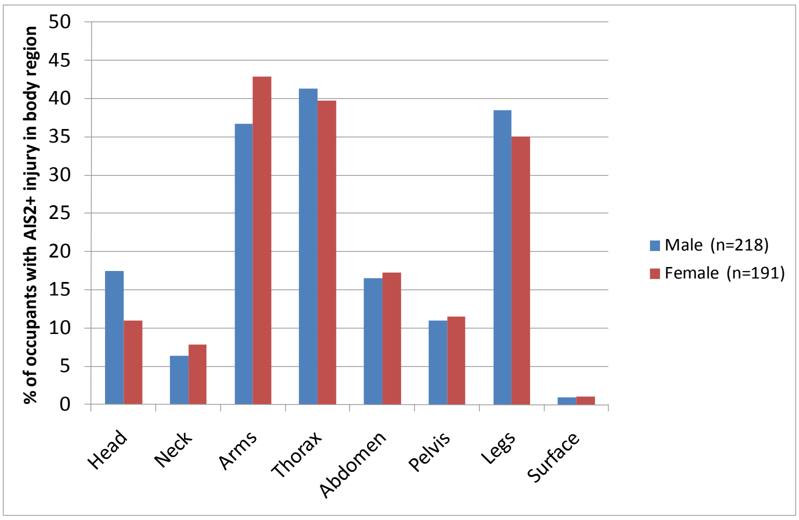


Figure 5.18: AIS 2+ body injury distribution for occupant gender.

The effect of intrusion into the occupant compartment on the injuries sustained by the occupants was investigated, which showed an increase in the percentage of occupants sustaining AIS 2+ injuries to all body regions in the presence of intrusion (Figure 5.19). This increase was most significant for the legs, where over 70% of MAIS 2+ occupants sustained AIS 2+ injuries when intrusion was present compared to just over 20% when no intrusion was recorded. Significant increases were also observed for the head, abdomen and arms, whilst only a slight increase was observed for thorax injuries.

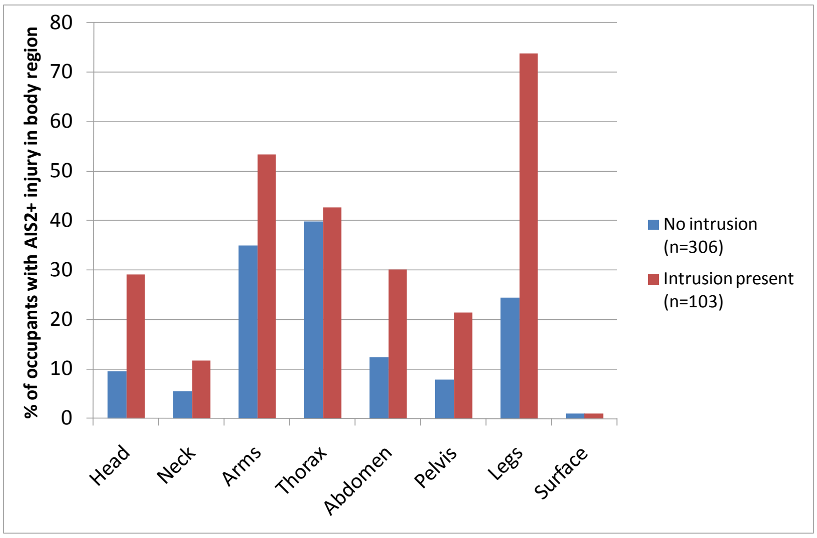


Figure 5.19: AIS 2+ body injury distribution for intrusion.

It was also observed that the presence of intrusion had a significant effect on the number of individual AIS 2+ injuries that the occupants sustained. Figure 5.20 shows how over 60% of MAIS 2+ occupants in vehicles where intrusion was not present only sustained a single AIS 2+ injury, with almost 90% sustaining 3 or fewer AIS 2+ injuries. Only approximately 16% of MAIS 2+ occupants in vehicles where intrusion was present sustained a single AIS 2+ injury, meaning that over 80% had sustained multiple AIS 2+ injuries.

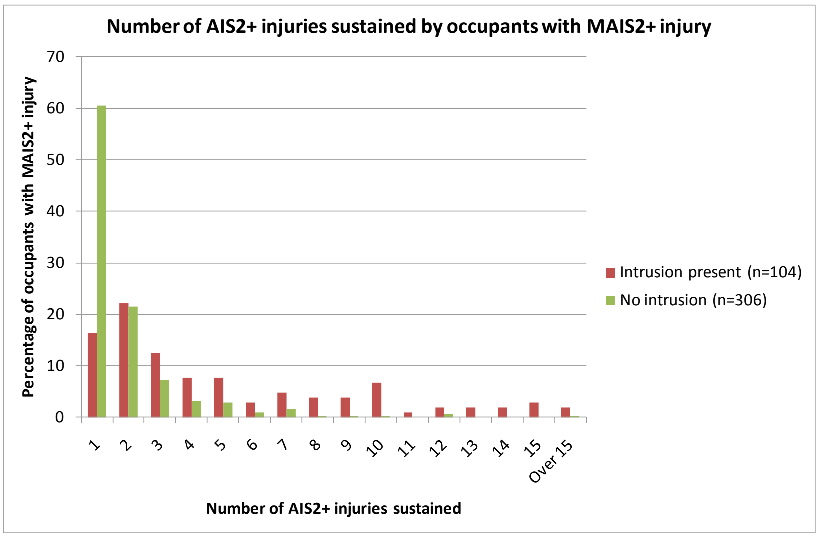


Figure 5.20: Number of AIS 2+ injuries sustained by MAIS 2+ occupants for intrusion.

This analysis indicated that the presence of intrusion into the occupant compartment corresponded with a significant increase in the number of AIS 2+ injuries sustained by the occupant in a crash. However, it must be remembered that the presence of intrusion is closely related to the severity of the accident as shown in Figure 5.10.

5.3.4.2 Injury Causation

In the CCIS database each injury is attributed a causation code depending on how the investigators had determined that the injury had been caused. For example, an occurrence of multiple rib fractures may have been attributed a causation code relating to the seat belt, whilst a fracture to the tibia or fibula may have been attributed to contact with the facia. In addition, the investigators also determined whether the injury causation directly related to contact with a component that had intruded into the compartment.

For the purposes of this investigation these causation codes were grouped into six general categories:

- “Restraint” – for causation codes relating to seat belts and airbags;
- “Contact No Intrusion” – for causation codes relating to contact with an interior component of the occupant’s vehicle which had been determined by the investigators as not having intruded into the compartment;
- “Contact Intrusion” – for causation codes relating to contact with an interior component of the occupant’s vehicle which had been determined by the investigators as having intruded into the compartment;
- “Non-Contact” – for injuries where no contact with any component was made (e.g. whiplash);
- “Unknown causation” – for injuries where the investigators could not determine the cause of the injury;
- “Other object” – for causation codes that related to contact with another object inside or outside the vehicle, such as unrestrained loads, an opposing vehicle or an external object such as a tree or lamppost.

It should be noted that the classification of 'restraint' injuries does not imply that there was a problem or issue with the restraint system that caused the injury, or that not using a restraint would have resulted in a reduction in injuries. These injuries were likely to have been due to the loading of the occupant from the restraint system during the deceleration of the vehicle, and therefore could also be described as 'acceleration loading' injuries.

The percentage of MAIS 2+ injured occupants in the dataset who sustained AIS 2+ injuries related to each causation category are shown in Figure 5.21. The labels on each of the columns in the graph show the actual number of occupants who sustained an AIS 2+ injury in each category. It should be noted that any occupant who sustained multiple AIS 2+ injuries with different causations was recorded once in each relevant causation category.

This analysis showed that just about 45% of all the MAIS 2+ injured occupants in the dataset sustained at least one AIS 2+ injury where the causation was the restraint system, which was the most prevalent injury causation category. Approximately 25% of the occupants sustained an AIS 2+ injury directly related to contact with intrusion. This reduced to 16% if vehicles with intrusion less than 10 cm were classified as having no intrusion.

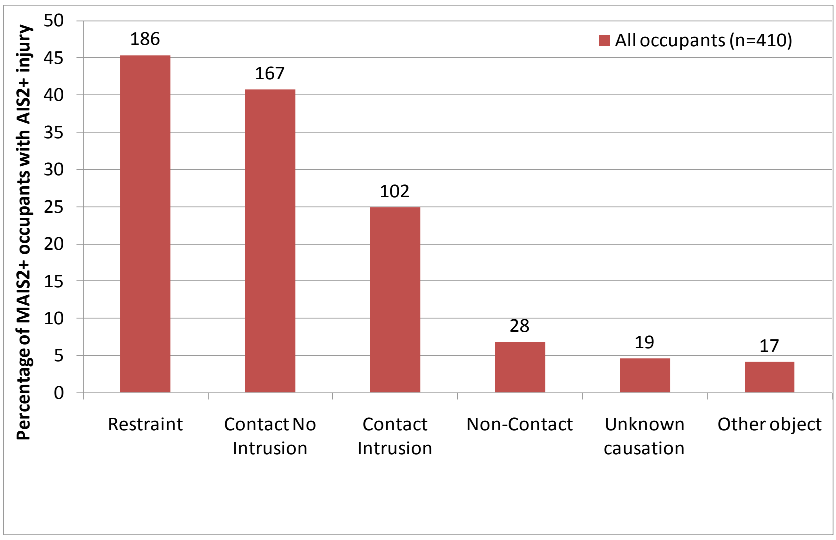


Figure 5.21: AIS 2+ injury causation for MAIS 2+ injured occupants in dataset.

When the injury causation was analysed with respect to intrusion, it was observed that approximately 65% of the MAIS 2+ occupants that were in a vehicle with intrusion sustained an AIS 2+ injury from contact with intrusion (Figure 5.22). However, it was also observed that between 35 and 40% of the occupants in vehicles with intrusion sustained AIS 2+ injuries in each of the causation categories relating to the restraints or contact with no intrusion.

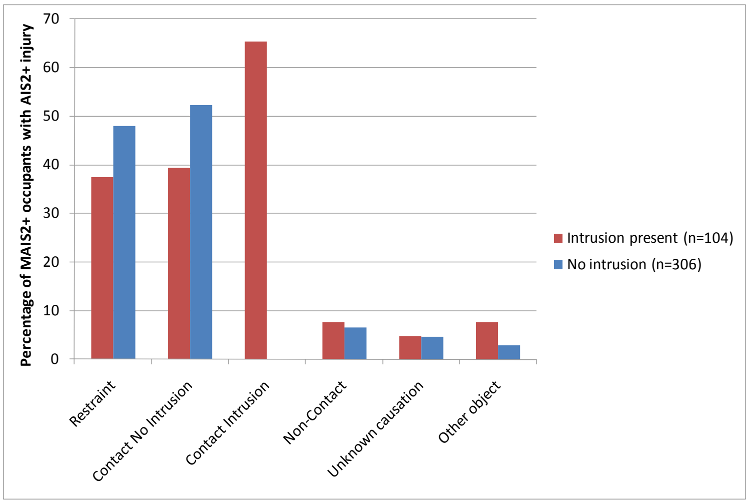


Figure 5.22: AIS 2+ injury causation for MAIS 2+ occupants in dataset with respect to intrusion.

Further analysis was performed to investigate the cause of the most severe injury received by the occupant. The purpose of this was to determine how relevant the injuries associated with ‘contact with intrusion’ were compared to the other injuries that the occupant had, i.e. is the injury associated with contact with intrusion generally the most severe injury the occupant has or does the occupant generally have another injury which is more severe.

When the cause of the most severe injury received by the MAIS 2+ injured occupants in the data set was analysed it was seen that the most severe injury was caused by ‘contact with intrusion’ for 22% of MAIS 2+ injured occupants (Figure 5.23). From the analysis above it was shown that 25% of occupants received an AIS 2+ injury caused by ‘contact with intrusion’. Hence it can be concluded that if an occupant received an injury caused by contact with intrusion, in the majority of cases (88%) it was the most severe injury received by that occupant.

It should be noted that there are some duplicates in Figure 5.24 for occupants who received more than one most severe injury by more than one cause, e.g. an occupant who received an AIS 3 leg injury caused by contact with intrusion and an AIS 3 thorax injury caused by the restraint system. In the total sample, there were 38 (out of 409) duplicates.

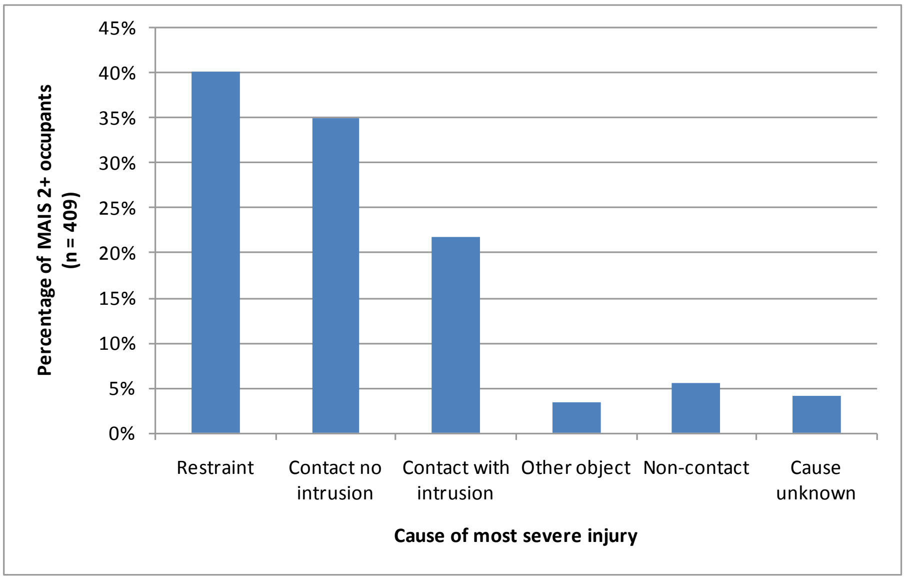


Figure 5.23: Cause of most severe injury for MAIS 2+ occupants in dataset.

If this graph is broken down into vehicles which had intrusion (defined as intrusion > 10 cm) and those that did not, it shows that even for vehicles which had intrusion in a significant number of cases (approx. 25%) the occupant's most severe injury was related to the 'restraint system'. It should be noted that some occupants in vehicles with no intrusion have injuries related to 'contact with intrusion'. The reason for this is that intrusion is defined as > 10 cm, so these vehicles will have had intrusion < 10 cm.

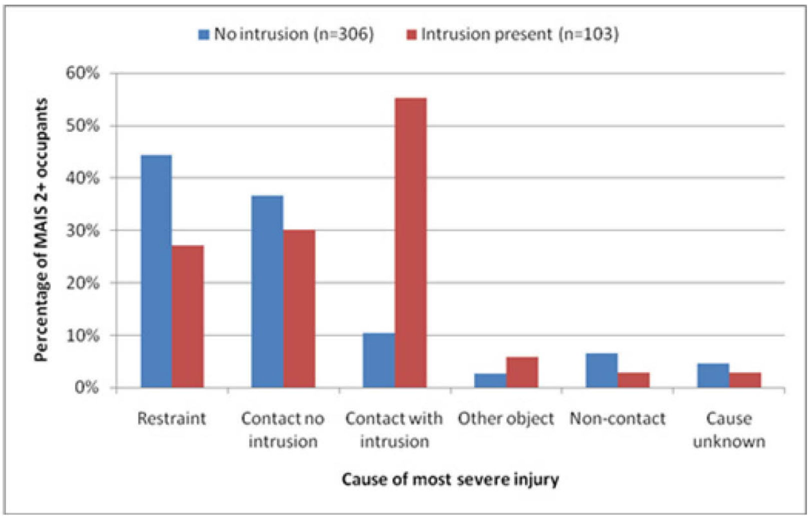


Figure 5.24: Cause of most severe injury for MAIS 2+ occupants in dataset broken down for vehicles where intrusion was present (defined as intrusion > 10cm) and not present.

Additional analysis selected injuries with specific causes and investigated what body region was injured. It was found that for occupants whose most severe injury was caused by 'contact with intrusion,' the injury was mainly to the legs (46%) with some to the thorax 30%) (Figure 5.25). For occupants whose 'most severe' injury was attributed to the 'restraint system', the injury was mainly to the thorax (62%) with some to the arms (21%) which were mostly clavicle fractures[3] (Figure 5.26). Similarly for occupants whose most severe injury was attributed to 'contact no intrusion' the injury was mainly to the legs (42%) with some to the arms (30%) and thorax (12%) (Figure 5.27).

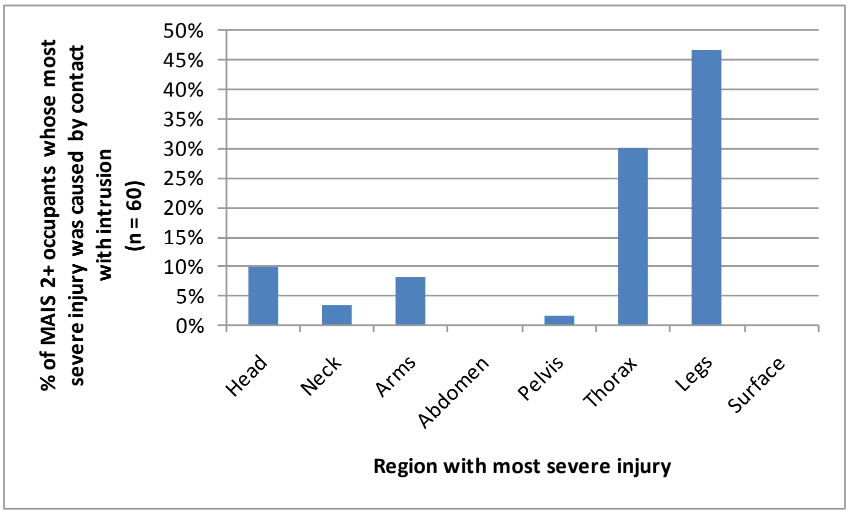


Figure 5.25: Distribution of 'most severe' injury by body region for MAIS 2+ belted occupants with their most severe injury caused by 'contact with intrusion'.

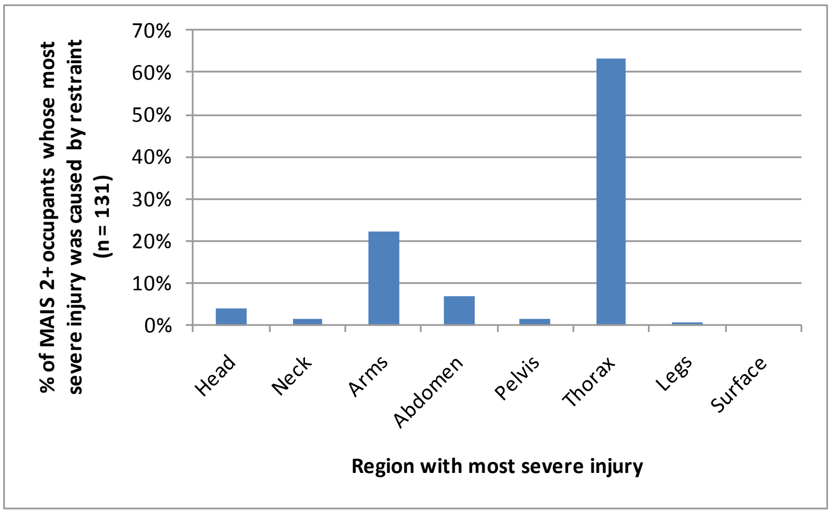


Figure 5.26: Distribution of 'most severe' injury by body region for MAIS 2+ belted occupants with their most severe injury related to the 'restraint system'.

[3] Please note:

- The clavicle is defined as part of the arm for the AIS classification.
- In general, clavicle fracture is related to seatbelt loading.

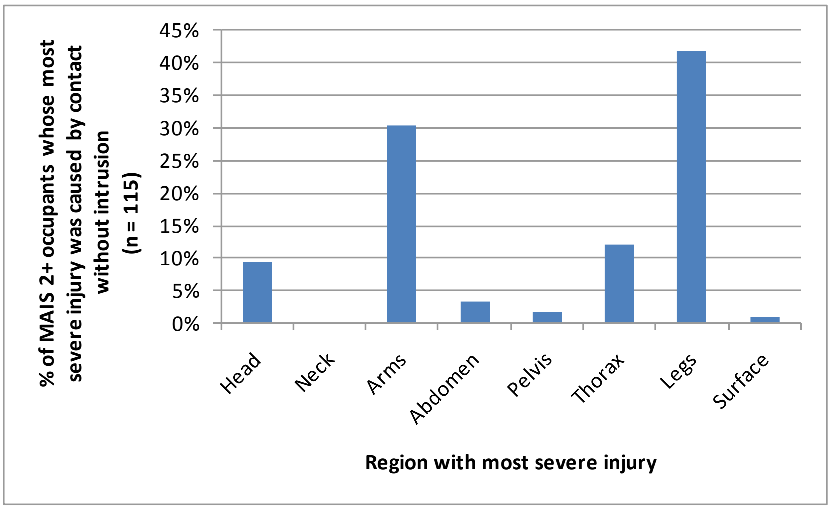


Figure 5.27: Distribution of 'most severe' injury by body region for MAIS 2+ belted occupants with their most severe injury caused by 'contact without intrusion'.

5.3.4.3 Investigation of Restraint Injuries

An additional data set was formed for this analysis which consisted of MAIS 2+ injured occupants who had an AIS 2+ injury caused by the restraint system. The characteristics of this data set were compared with full data set (i.e. all MAIS 2+ injured occupants) in the analysis below.

The distribution of AIS 2+ injuries by body region injured for MAIS 2+ occupants with an AIS 2+ injury caused by the restraint system was compared with the distribution for all MAIS 2+ injured occupants. This showed that 60% of MAIS 2+ occupants with restraint injuries sustained thorax injuries compared to 40% for all MAIS 2+ injured occupants (Figure 5.28). This indicates that the thorax injuries are related to the restraint system.

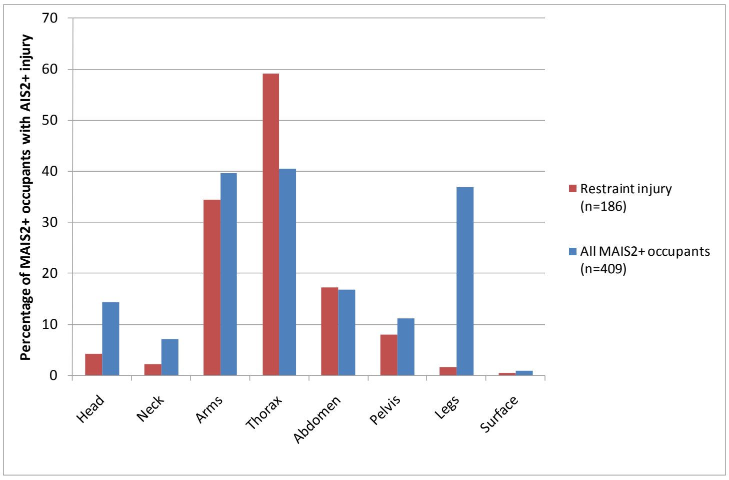


Figure 5.28: Comparison of distribution of MAIS 2+ occupants with restraint injuries with all MAIS 2+ occupants by body region injured.

A comparison of the distribution of MAIS 2+ injured occupants with restraint injuries and all MAIS 2+ injured occupants with overlap shows a higher proportion of the restraint group in higher overlaps (Figure 5.29). This indicates that in higher overlap impacts occupants are more likely to sustain a restraint related injury.

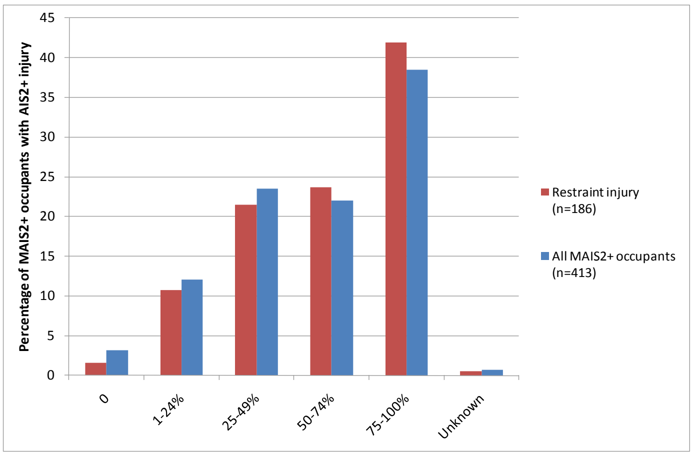


Figure 5.29: Comparison of distribution of MAIS 2+ occupants with restraint injuries with all MAIS 2+ occupants by overlap.

A comparison of the distribution with age of all MAIS 2+ injured occupants and MAIS 2+ injured occupants with restraint injuries shows a larger proportion of older occupants in the restraint injury group (Figure 5.30). This indicates that older occupants are more likely to sustain a restraint related injury.

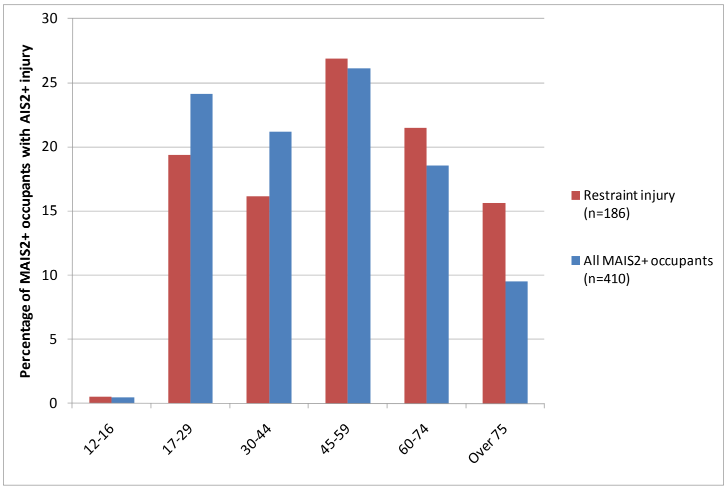


Figure 5.30: Comparison of distribution of MAIS 2+ occupants with restraint injuries with all MAIS 2+ occupants by age.

A comparison of the distribution with gender of all MAIS 2+ injured occupants and MAIS 2+ injured occupants with restraint injuries shows a slightly larger proportion of female occupants in the restraint injury group (Figure 5.31). This indicates that female occupants are slightly more likely to sustain a restraint related injury.

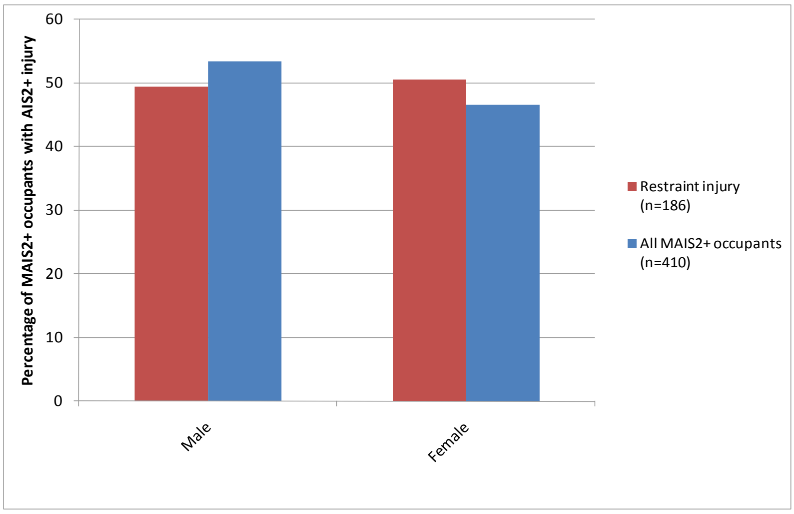


Figure 5.31: Comparison of distribution of MAIS 2+ occupants with restraint injuries with all MAIS 2+ occupants by gender.

A comparison of the distribution with seating position of all MAIS 2+ injured occupants and MAIS 2+ injured occupants with restraint injuries shows a slightly larger proportion of front seat passengers in the restraint injury group (Figure 5.32). This indicates that front seat passengers are slightly more likely to sustain a restraint related injury. This could possibly be because they are less likely to sustain a leg injury because there are no pedals on the passenger side.

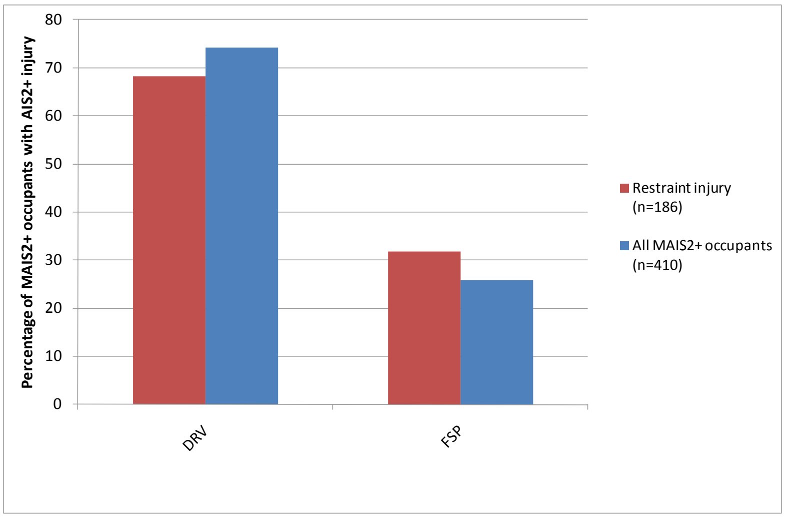


Figure 5.32: Comparison of distribution of MAIS 2+ occupants with restraint injuries with all MAIS 2+ occupants by seating position.

In summary the analysis shows that older people are more likely to sustain an AIS 2+ restraint related injury and these injuries are more likely to occur in higher overlap impacts. Also, female and front seat passengers are slightly more likely to sustain this type of injury and these injuries are more likely to be thorax injuries.

5.3.5 Conclusions CCIS Analysis

5.3.5.1 Data Set Characteristics

- A high proportion of fatal and MAIS 2+ survived injured occupants (30% of fatal and 40% of MAIS 2+ survived) were in crashes with a high frontal overlap (75-100%)
- Although the occupants in the "Over 75" age group made up a low proportion of the occupants in the dataset, they were a high percentage of fatal and MAIS 2+ survived occupants compared to the other age groups, i.e. they were over-represented
    - Occupants over 60 years old represent 18% of injured occupants, however account for 52% of fatalities and 25% of MAIS 2+ survived occupants
- There is a higher proportion of fatally injured occupants in the HGV / PSV impact partner group compared to other groups indicating the more injurious nature of HGV / PSV type impacts. There is also a slighter higher proportion of fatally injured occupants in the car to wide object impact partner group indicating the slightly more injurious nature of this type of impact.
- A high proportion of occupants were involved in crashes with an ETS less than 60 km/h, although over 25% of the fatally injured occupants were in crashes with ETS greater than 60 km/h.

5.3.5.2 Compartment Strength

- For MAIS 2+ injured occupants intrusion (> 10 cm) was present for 25% of them (56% of fatal occupants and 21% of MAIS 2+ survived occupants).
    - There was more intrusion present in impacts with HGVs / PSVs (30%) and smaller overlap impacts.
    - A high proportion of the cases with intrusion were observed for ETS less than 60 km/h.

5.3.5.3 Matched Pair Analysis

A strong trend of an increase in driver injury severity with increasing mass ratio was seen which indicates that in a car-to-car impact the driver of the lighter car is more likely to sustain a more severe injury than the driver of the heavier car. Possible contributory factors to this are the increased delta-v experienced by the driver of the lighter car and the increased likelihood of intrusion in the lighter car. No trend was observed in vehicle intrusion with increasing delta –v. The implications of this are that vehicle intrusion is not the major contributory factor and by default the increased delta –v experienced by the driver of the lighter car is. However, it should be noted that the data sample used was relatively small and hence confidence in this result is limited.

5.3.5.4 Injury Patterns

- AIS 2+ injuries to the thorax are the most prevalent. AIS 2+ injuries are also frequently sustained by the head, legs and arms
    - Over 80% fatally injured occupants and 35% MAIS 2+ survived occupants sustained AIS 2+ thorax injuries
- AIS 2+ thorax injuries appeared to be much more prevalent for older occupants compared to younger occupants.

    - 25% of occupants under 44 years old sustained AIS 2+ thorax injury compared to over 70% of occupants over 75 years old
- AIS 2+ head injuries were sustained by a significantly higher proportion of occupants in car to HGV impacts than in the other accident types.
- Drivers in the dataset were found to have a different pattern of AIS 2+ injuries compared to front seat passengers, with drivers experiencing more AIS 2+ injuries to the legs and head most likely due to contact with the facia/steering column or the steering wheel/airbag.
- AIS 2+ injuries resulting from deceleration loading of the occupant by the restraint system are present in a significant proportion of frontal crashes, regardless of whether intrusion was present or not
    - Over 40% MAIS 2+ occupants sustained AIS 2+ injury attributed to restraint loading
- For accidents for which intrusion was present, AIS 2+ injuries to the legs were the most prevalent
    - Where intrusion was present about 70% MAIS 2+ occupants sustained AIS 2+ leg injuries
    - Note: about 40% sustained AIS 2+ thorax injuries
- The investigation of intrusion with respect to occupant injuries showed that intrusion had a significant effect on AIS 2+ injuries sustained by the occupants. The proportion of occupants with AIS 2+ injuries in each of the body regions increased significantly when intrusion was present, although the smallest increase was observed for AIS 2+ thorax injuries. In addition, it was found that a significantly higher percentage of the MAIS 2+ injured occupants who were subjected to intrusion had multiple AIS 2+ injuries compared to those who were not subjected to intrusion. However, it must be remembered that the presence of intrusion is closely related to the severity of the accident.
- Analysis of injury mechanism found that 45% of MAIS 2+ injured occupants had an AIS 2+ injury related to the 'restraint system', 40% had an AIS 2+ injury caused by 'contact with no intrusion' and 25% had an AIS 2+ injury caused by 'contact with intrusion' In the majority of cases these injuries are the most serious injuries that the occupant had.
    - When the most severe injury was related to the 'restraint system' the injury was mainly to the thorax (62%) with some to the arms (21%) (mainly clavicle fractures).
    - When the most severe injury was related to 'contact no intrusion' the injury was mainly to the legs (42%) with some to the arms (30%) and thorax (12%).
    - When the most severe injury was related to the 'contact with intrusion' the injury was mainly to the legs (46%) and thorax (30%).
- AIS 2+ injuries resulting from contact with the intrusion occur in a large proportion of cases where compartment intrusion is present. In the majority of cases (over 80%) this injury is the most severe injury received by the occupant.
    - 65% of MAIS 2+ injured occupants in cars with intrusion greater than 10 cm sustained AIS 2+ injury attributed to contact with intrusion
    - 25% of all MAIS 2+ injured occupants received an AIS 2+ injury attributed to contact with intrusion. Note: this includes cases where the vehicle intrusion was less than 10 cm. If these cases are excluded the percentage reduces from 25% to 16%.

- The analysis of MAIS 2+ injured occupants with restraint related injuries compared to all MAIS 2+ injured occupants found that:
  - There was a larger proportion of older people in the restraint related injury group indicating a greater prevalence of this type of injury for older people.
  - There was a larger proportion of higher overlap impacts in the restraint related injury group indicating a greater prevalence of this type of injury in high overlap impacts.
  - There was a slightly larger proportion of female and front seat passengers in the restraint related injury group although this could be at least partially caused by the larger number of female front seat passengers.

5.4 Detailed Case Analysis

Compatibility is a complex issue but, as mentioned previously, can be broken down into three subtopics: structural interaction, frontal force levels and compartment strength. Structural interaction is a measurement of how well vehicles interact in frontal impacts. If the structural interaction is poor, the energy absorbing front structures of the vehicle may not function as designed leading to a risk of compartment intrusion at lower than designed impact severities. In general, frontal force levels are currently related to vehicle mass. As a consequence, small vehicles absorb more than their share of the impact energy as they are unable to deform the heavier vehicle at the higher force levels required. Compartment strength is closely related to frontal force levels but is nevertheless distinguished since it is such an important issue for self-protection. Matched frontal force and compartment strength levels would ensure that both vehicles in an impact absorb their share of the kinetic energy without compartment intrusion in either vehicle. This would reduce the risk of injury for the occupant in the lighter vehicle.

In order to understand whether compatibility issues such as structural interaction and frontal force / compartment strength matching were still present in the current vehicle fleet, a detailed case analysis was necessary. This was because these types of compatibility problems can only be identified through a detailed analysis which includes examination of photographic evidence of both vehicles.

5.4.1 Approach

The analysis was performed at an occupant level, i.e. each occupant was considered separately as opposed to each accident.

The analysis was divided into two parts, an analysis of fatal cases and an analysis of MAIS 2+ survived cases.

For each part of the analysis, cases were divided into ones where intrusion was present and ones where intrusion was not present. The reasons for this were:

- For the investigation of structural interaction it was only for the cases where intrusion was present that it could be determined definitely that poor structural interaction was directly linked to the injuries. This is because there are two consequences to poor structural interaction. The first is a decrease in the energy absorbing capability of the vehicle’s frontal structures because the vehicle’s structures are not loaded and hence do not collapse in the designed manner. The second is a change to the deceleration pulse of the vehicles passenger compartment which generally becomes more back loaded with a longer ride-down distance. Hence, in the cases where there was poor structural interaction and intrusion it could be assumed that improving the structural interaction would improve the energy absorption capability of the vehicle's front structures which in turn would reduce the intrusion. It was assumed that this would be beneficial for the occupant's safety. However, in the cases where there was poor structural interaction and no intrusion it could be assumed that improved structural interaction would alter the vehicle's deceleration pulse but it could not be determined definitely whether or not this would be beneficial for the occupant's safety.

- For the investigation of frontal force / compartment strength matching it was only for the cases where there was intrusion present in at least one vehicle that it could be determined definitely whether or not a problem was present. This is because for cases with no intrusion in either vehicle it is known that the vehicles have absorbed the impact energy in their frontal structures. Hence the frontal force and compartment strength levels are matched adequately at least for that particular accident case.

Intrusion present was defined previously, i.e. greater than 10 cm of intrusion measured at any of the following points; footwell, knee contact areas on the facia/dashboard, the base of the windscreen/A-pillar and reduction of the door aperture between the A and B-pillars greater than 10 cm. It should be noted that because the analysis was performed at an occupant level, the presence of intrusion was defined on the basis of the intrusion measured on the injured occupant's side of the vehicle (i.e. intrusion in the vicinity of the occupant). As a result, if there was over 10 cm of intrusion on the nearside of the car but less than 10 cm intrusion on the offside where the occupant was seated, then the case would be categorised as no intrusion present.

For each injured occupant the related accident was studied in detail. This included the assessment of the photographic records from each case, the intrusion levels present in each vehicle and the overall accident configuration (including ETS, vehicle mass, mass ratio, etc.) in order to determine whether one of the compatibility issues was present or not, i.e. structural interaction or frontal force and/or compartment strength matching.

Three types of structural interaction issue were identified:

- Over/underride
  - This is caused by the main rails of one vehicle riding over or under the main rails of the other vehicle. It can be the result of misalignment of a vehicle's main structures and / or poor stability of them. A classic example is the high structures of an SUV overriding the lower structures of a car. The distinguishing features of over/underride are the deformation and / or compartment intrusion profiles of the vehicles. Its presence can be identified from high deformation above the main rails and lower deformation below the rails on one vehicle and vice-versa on the other vehicle. Often the intrusion profile of the occupant compartment reflects this as well, e.g. higher deformation at the waist rail level and lower deformation at sill level on one vehicle and vice-versa on the other vehicle.

- Fork effect
  - This is caused by the bumper beam and other cross car structures being too weak to spread the load from the rails. The consequence of this is that these structures deform a lot or break which in turn allows the rail of one car to penetrate into the structure of the other car. This results in the crash loads not being transmitted into the car in the designed manner which in turn results in a decrease in the energy absorption capability of the car's frontal structures. The distinguishing features of the fork effect are large local deformations and/or breaking of the bumper beam and other cross car structures.
- Low overlap
  - This is caused by the overlap of the impact being so low that the main rails of the vehicles do not overlap and hence do not form a main load path in the crash. This results in greater loading of the vehicle's side structures through load paths such as the wheel to sill and sometimes direct loading of the A-pillar footwell area of one vehicle by the rails and bumper crossbeam of the other vehicle. The consequence of this is often high compartment intrusion in one or both cars. The distinguishing features of low overlap are little deformation of the main rail structures and large deformations of the vehicles side structures.

As mentioned above frontal force and/or compartment strength matching issues in car-to-car crashes could only be identified when there was intrusion in at least one of the vehicles. The distinguishing feature used to identify the issue was a large difference in the intrusion levels of the two vehicles involved in the accident. This could be no intrusion in one vehicle and over 10 cm intrusion in the other vehicle or 10 cm of intrusion in one vehicle and 30 cm of intrusion in the other vehicle. In car-to-object impacts only compartment strength issues could be identified. The distinguishing feature used to identify these issues was intrusion in a low severity impact.

It should be noted that frontal force and/or compartment strength problems were only identified in cases where no structural interaction problem was identified. This is because it was known that the structural interaction problem would have at least being a contributory factor to the frontal force and/or compartment strength problem but it could not be determined whether or not it was the main factor. Hence to avoid possible double counting of problems it was decided to only count frontal force / compartment strength problems when structural interaction problems were not present. This approach does have the problem that it may underestimate the degree of the frontal force / compartment strength problem.

To help the reader understand better the approach taken to identify compatibility problems, examples of cases in which compatibility issues were identified are given in the 'Results' sections below.

It should be noted that for some cases it was not possible to identify whether or not a compatibility issue was present because any evidence of it was masked by high vehicle deformation resulting from the high severity of the accident. These cases were categorised as high severity.

5.4.2 Data Sample

The initial dataset to be used for this analysis was as described in Section 5.2, as had been used for the previous analyses. As mentioned above, the analysis was undertaken in two parts. First, the cases where an occupant was fatally injured were investigated for all accident types, giving 48 occupants (Table 5). There were a total of 45 accidents in this dataset, as there were two fatalities in three of the accidents (two in car to HGV cases and one in a car-to-car case).

Table 5: Analysis group for detailed case analysis of fatally injured occupants

	Fatal
Car - Wide object	9
Car - Narrow object	1
Car – Car	23
Car - Light Goods Vehicle	2
Car - HGV / PSV	13
Car – Other	0
Total	*48*

After this analysis, a further investigation of crashes was undertaken involving MAIS 2+ survived occupants in car-to-car and car-to-object crashes. However, in the original dataset there were 226 occupants in car-to-car crashes and 66 in car-to-object crashes, which was too many to analyse on a case-by-case basis. In addition, the car-to-car crashes in the dataset contained collisions with older, non-R94 compliant, cars and crashes in configurations that were not frontal to frontal. Therefore only those car-to-car crashes where both vehicles were R94 compliant and the impact configuration was frontal to frontal were analysed in detail. This gave an analysis group of 104 occupants as shown in Table 6. Due to the presence of multiple MAIS 2+ survived occupants in some crashes, this related to 42 car to wide object crashes, 18 car to narrow object crashes and 33 car-to-car crashes.

Table 6: Analysis group for detailed case analysis of MAIS 2+ survived occupants

	MAIS 2+ survived
Car - Wide object	48
Car - Narrow object	18
Car - Car (Front-Front) Both R94 compliant	38
Total	*104*

5.4.3 Results: Fatal Case Analysis

Each of the accident cases containing the 48 fatally injured occupants was investigated. The results of the analysis showed that, out of the 48 fatal occupants (in 45 vehicles), 28 occupants (56%) had intrusion present on their side of the vehicle. These 28 occupants were in 28 vehicles, meaning that just over 60% of the vehicles containing fatally injured occupants sustained intrusion.

Further analysis identified structural interaction problems in 19 out of 48 cases (40%) as shown in Figure 5.33. However, it is only in 12 of these cases where there was intrusion (25%) that it can be said definitely that improved structural interaction would have improved the safety performance of the car. Seven of these cases were over/underride and 5 were low overlap. Frontal force / compartment strength problems were identified in 4 cases (8%) which indicate that this is much less of an issue than structural interaction. However, it should be noted that poor structural interaction may mask frontal force / compartment strength matching problems. It is interesting to note the high proportion of high severity cases (11 cases 23%) for which the vehicle's deformation was so great that it masked any compatibility issue that may have been present.

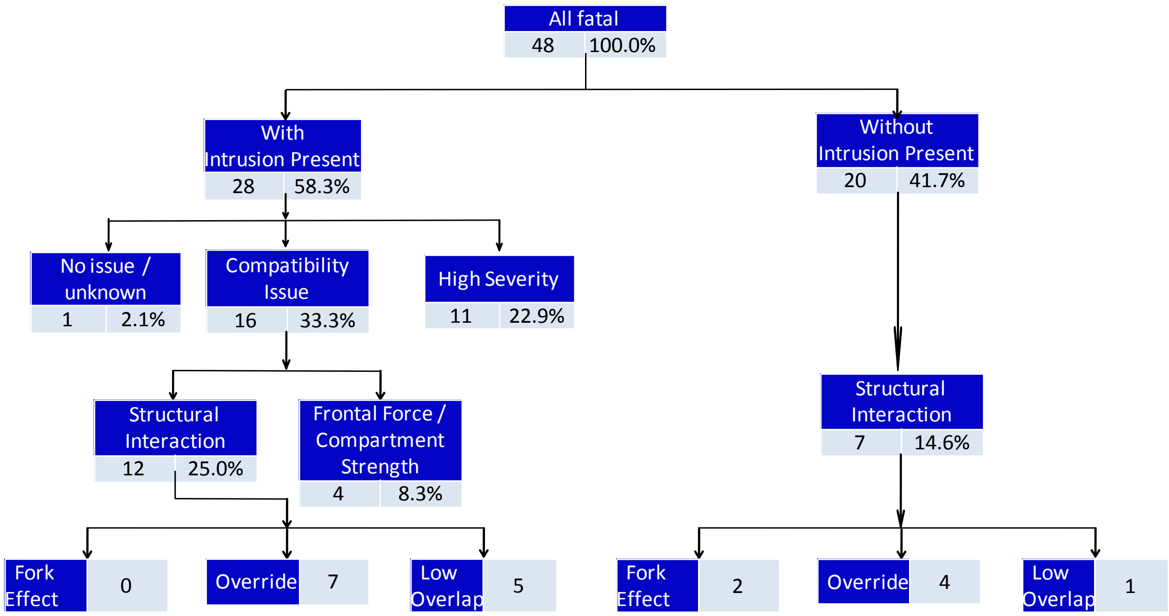


Figure 5.33: Identification of compatibility issues for all fatal cases.

The analysis was subsequently focused on only car-to-car impacts, of which there were 23 fatally injured occupants in 22 vehicles in the dataset (Figure 5.34).

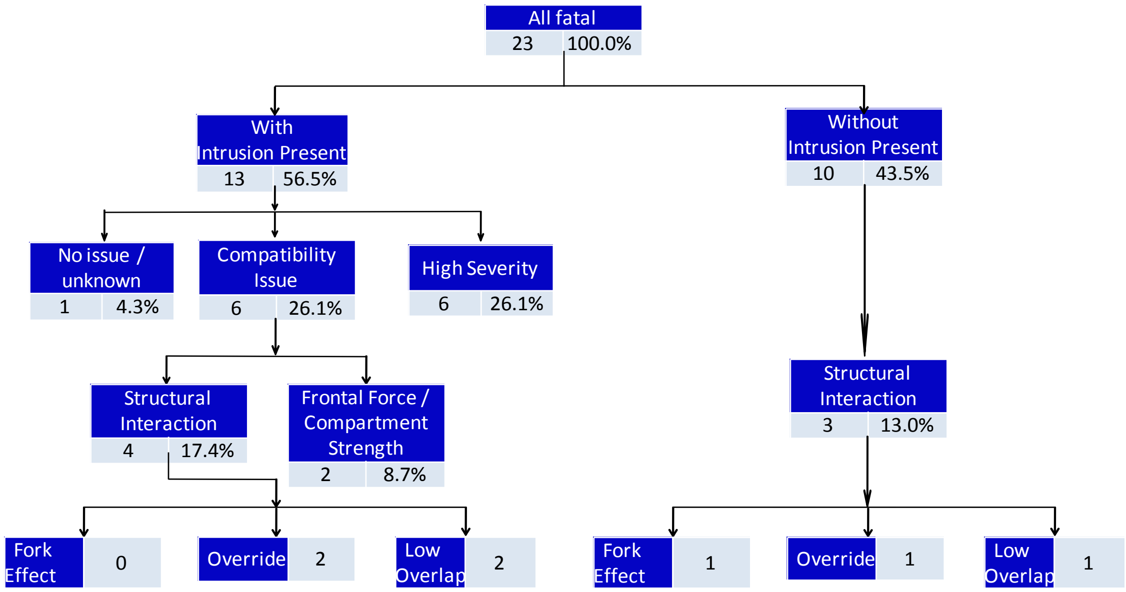


Figure 5.34: Identification of compatibility issues for car-to-car fatal cases.

Intrusion was present for 13 occupants (56%) in 13 vehicles. Structural interaction problems were identified in 7 cases (30%) although it is only in 4 of these cases where there was intrusion (17%) that it can be said definitely that improved structural interaction would have improved the safety performance of the car. Two of these cases were over/underride and 2 were low overlap. Frontal force / compartment strength problems were identified in 2 cases (9%). There was also a high proportion of high severity cases (6 cases 26%) for which the vehicle's deformation was so great that it masked any compatibility issue that may have been present.

An analysis was also performed for car-to-object impacts but there were only 10 occupants in these accidents (Figure 5.35).

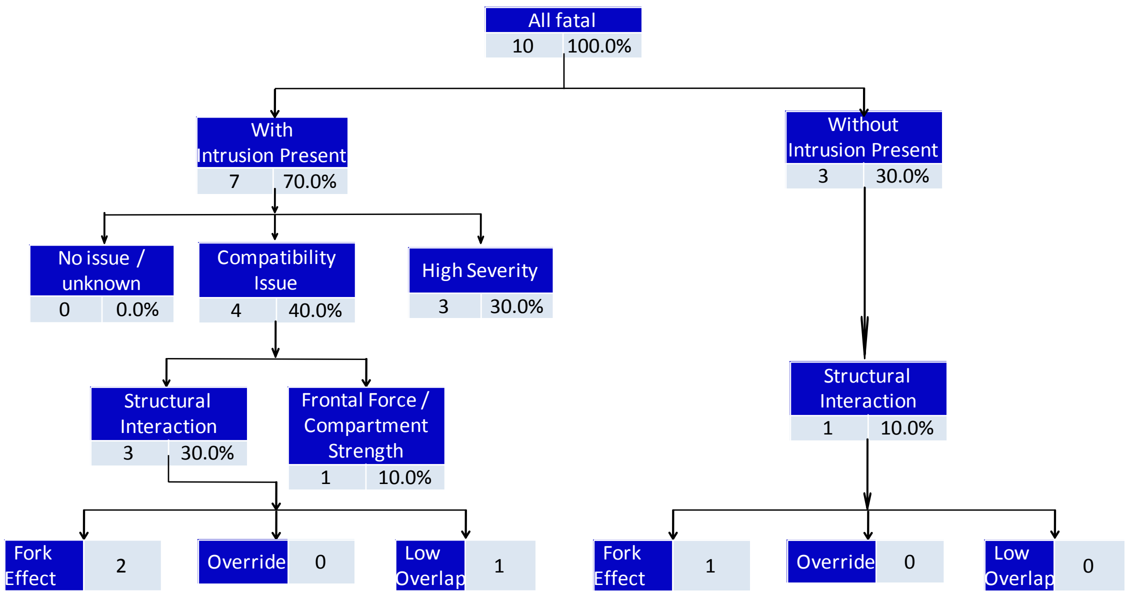


Figure 5.35: Identification of compatibility issues for car-to-object fatal cases.

5.4.3.1 Case Study Examples

This section provides a few examples of case studies in which compatibility issues were identified.

SUV overriding car

In this case a frontal crash between a small car and an SUV resulted in the overriding of the smaller car and subsequent compartment collapse. The mass ratio of the crash from the perspective of the smaller car was approximately 1.9. The driver of the smaller car sustained MAIS 5 thorax injuries as well as multiple AIS 2+ injuries to other body regions, whilst the driver of the SUV sustained MAIS 2 leg injuries. The details and photographs of the vehicles involved are shown in Figure 34.

V1 – Vauxhall Corsa (2002)	**V2 – Mitsubishi Shogun (2003)**
	
980kg kerb mass 55% overlap 46km/h ETS 27cm Facia intrusion 11cm Footwell intrusion Driver (Male, 49) MAIS 5 Thorax [+multiple AIS 3/4]	2000kg kerb mass 48% overlap 33km/h ETS 3cm Facia intrusion 12cm Footwell intrusion Driver (Male, 29) MAIS 2 Legs

Figure 5.36: SUV overriding car (Vauxhall Corsa vs. Mitsubishi Shogun).

Poor structural interaction (Over/underride) between cars of same make and model

In this case two cars of the same make and model were involved in a frontal crash where both vehicles impacted on the nearside of the front structure (not the driver's side in the UK). Despite these vehicles being of the same make and model, and therefore having identical frontal structures, there was a significant difference in the deformation of both the frontal structures and the occupant compartment. The deformation of the vehicles indicated that one car (V1) had overridden the opposing car (V2). This has resulted in significantly more intrusion in the overridden car, and subsequently a worse injury outcome for the driver in this car, despite being seated on the opposite side of the car to the highest levels of intrusion. This case clearly indicated that poor structural interaction is possible between identical cars that are both compliant with R94. The case details are shown in Figure 35.

V1 – Ford Mondeo (2002)	V2 – Ford Mondeo (2001)
	
1423kg kerb mass 51% overlap 26km/h ETS 19cm Facia intrusion (near/side) 17cm Footwell intrusion (n/s) No intrusion on off/side Driver (Male, 32) MAIS 2 Shoulder	1384kg kerb mass 50% overlap 46km/h ETS 90cm Facia intrusion (n/s) 118cm Footwell intrusion (n/s) 18cm Facia intrusion (o/s) 5cm Footwell intrusion (o/s) Driver (Male, 53) MAIS 5 Chest

Figure 5.37: Over/underride Ford Mondeo v Ford Mondeo.

Frontal force mismatch between large and small car

This case was a frontal impact between a small car and a large car with an overlap of approximately 60-70 percent. This impact resulted in the overcrushing of the smaller car and subsequent compartment collapse, whilst the larger car had no recorded intrusion. The driver of the smaller car sustained MAIS 5 injury to the thorax, as well as AIS 4 head injury, whilst the driver of the larger car only sustained MAIS 1 injury to the thorax. The case details are shown in Figure 36.

V1 – Peugeot 206	V2 – Mercedes S320

	
910kg kerb mass 67% overlap 59km/h ETS 29cm Upper Facia intrusion (o/s) 19cm Knee contact intrusion (o/s) Driver (Female, 68) MAIS 5 Thorax & AIS 4 Head	1925kg kerb mass 57% overlap 28km/h ETS No intrusion Driver (Female, 40) MAIS 1 Thorax

Figure 5.38: Frontal force / compartment strength mismatch Peugeot 206 vs. Mercedes S320.

5.4.4 Results: MAIS 2+ Survived Case Analysis

A detailed case analysis of the CCIS accidents was conducted for the cases were a MAIS 2+ injury was recorded but excluding the fatal accidents reported in the previous section. The results are presented in terms of all cases, car-to-car impact cases and car-to-object impact cases. In total accidents with 100 MAIS 2+ injured occupants in R94 compliant vehicles were analysed.

The results of the MAIS 2+ survived analysis are presented in the figures below. The first, Figure 5.39, gives the combined results of car-to-car and car-to-object collisions. Intrusion was present in 31 of the 100 cases where occupants had MAIS 2+ injuries.

Structural interaction problems were identified in 36 cases (36%) although it is only in 12 of these cases where there was intrusion (12%) that it can be said definitely that improved structural interaction would have improved the safety performance of the car. Three of these cases were fork effect, 4 were over/underride and 5 were low overlap. Frontal force / compartment strength problems were identified in 2 cases (2%).

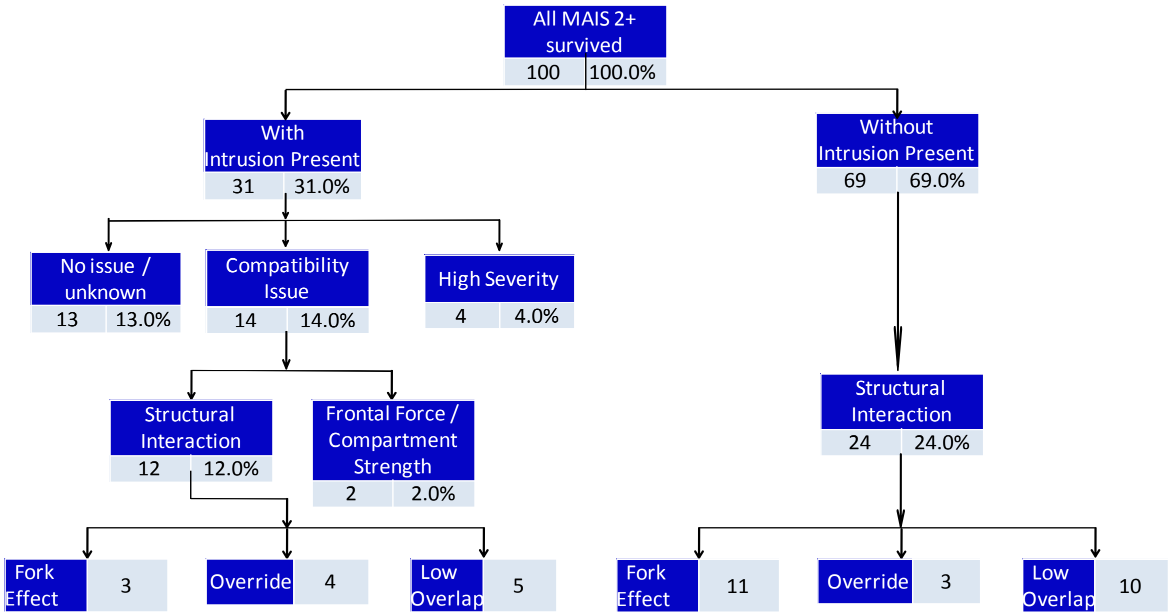


Figure 5.39: Identification of compatibility issues for all MAIS 2+ survived crashes.

A breakdown for the 39 MAIS 2+ survived occupants in car-to-car accidents is shown in Figure 5.40. As for all impacts discussed earlier, a significant portion of the car-to-car crashes involve intrusion and in about half of them compatibility issues were found. Structural interaction issues were identified in 15 cases (38%) although it is only in 9 of these cases there was intrusion (23%).

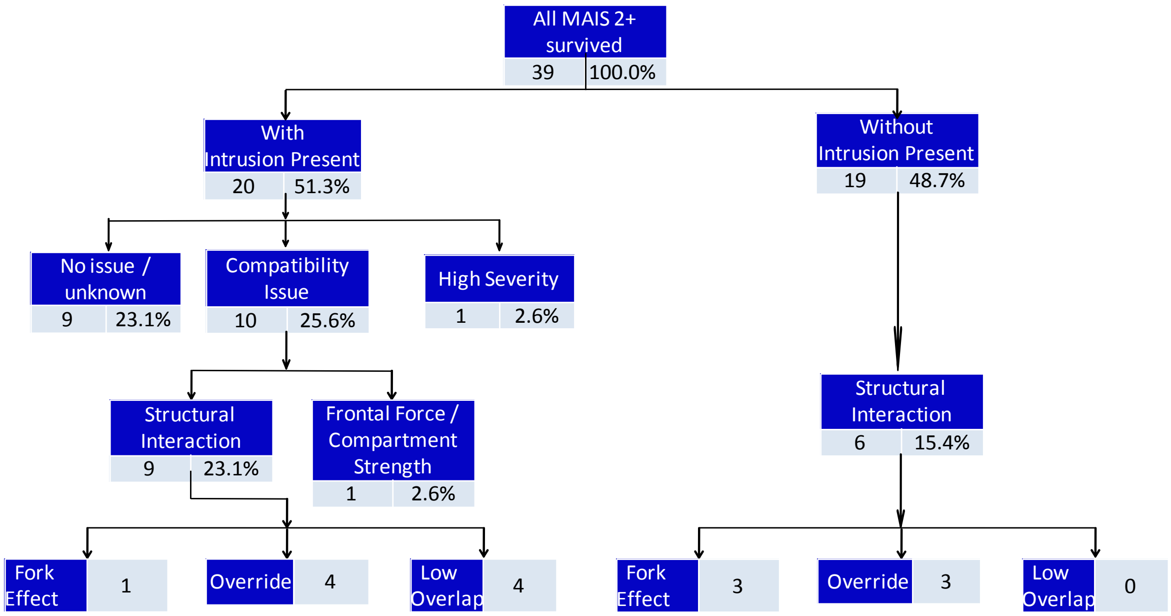


Figure 5.40: Identification of compatibility issues for MAIS 2+ survived car-to-car crashes.

Override was the largest structural interaction issue when intrusion/non-intrusion cases are combined. In four cases there was static geometry information for the vehicles. One case involved 2 identical cars so nominally the static alignment should be exact. The remaining 3 cases had nominal vertical overlaps of less than 50 mm (measured at the crash cans).

The final main category of MAIS 2+ cases to consider was the case when the car hits fixed objects. Both wide and narrow objects crashes are summarised in Figure 5.41 where injuries with and without intrusion are identified. These were the majority of the cases reported earlier in Figure 5.39.

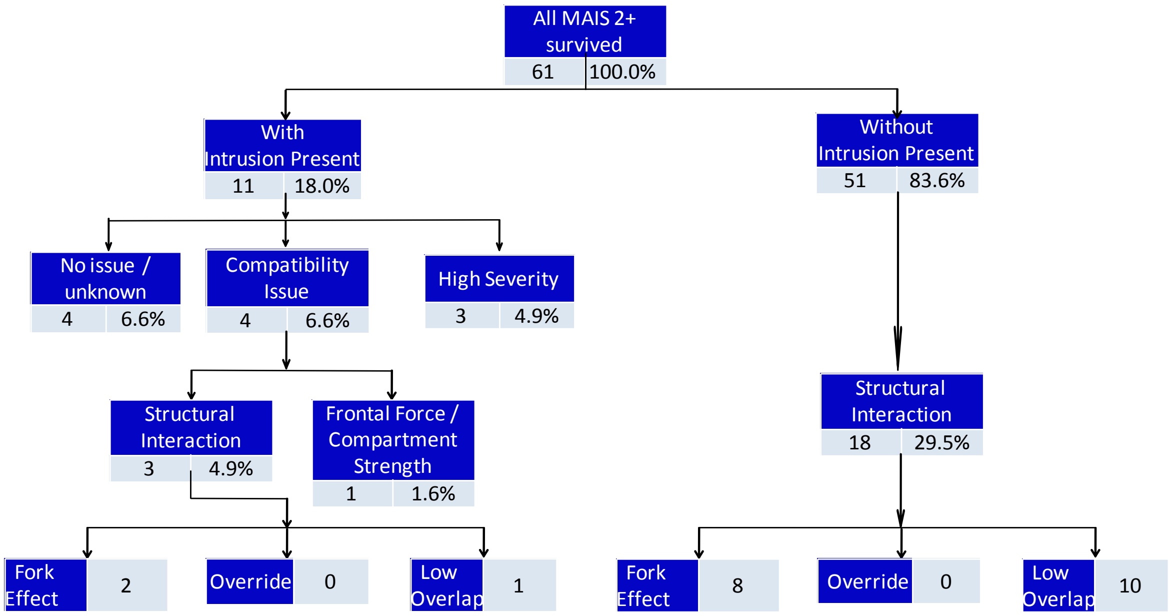


Figure 5.41: Identification of compatibility issues for MAIS 2+ survived car-to-object crashes.

Overall, when intrusion is present about half the cases have compatibility issues, the majority of which are structural interaction. Structural interaction issues were identified in 21 cases (34%) although it is only in 3 of these cases there was intrusion (5%). A large proportion of structural interaction issues related to fork effect are seen for car-to-object impacts. Many of these were related to impacts with narrow objects hitting between the longitudinals.

5.4.4.1 Case Studies Examples

This section provides a few examples of case studies in which compatibility issues were identified for MAIS 2+ survived occupants.

V1 - 2005 Ford Fiesta	V2 - 2006 Mazda 3
	
1105 kg kerb mass 100% overlap, CDC 12:00 50 km/h ETS No intrusions (0)	1265 kg kerb mass 67% overlap, **CDC 01:00** 47 km/h ETS 14 cm Facia intrusion (o/s) 10 cm Knee intrusion (o/s) 9 cm Footwell intrusion (o/s) Driver (Male, 47) MAIS 2, Contact with intrusion

Figure 5.42: Over/underriding Mazda 3 overrides Ford Fiesta.

V1 Renault Clio 2004	V2 Fiat Punto 2007
	
945 kg kerb mass 56% overlap, CDC 12:00 45 km/h ETS 2 cm Facia intrusion (n/s) 1 cm Knee intrusion (n/s) 3 cm Footwell intrusion (n/s) Driver (Female, 41) MAIS 2, Contact with no intrusion	1025 kg kerb mass 57% overlap, CDC 12:00 33 km/h ETS No intrusion (0)

Figure 5.43: Fork-effect, intrusion less than 10 cm. Renault Clio vs Fiat Punto.

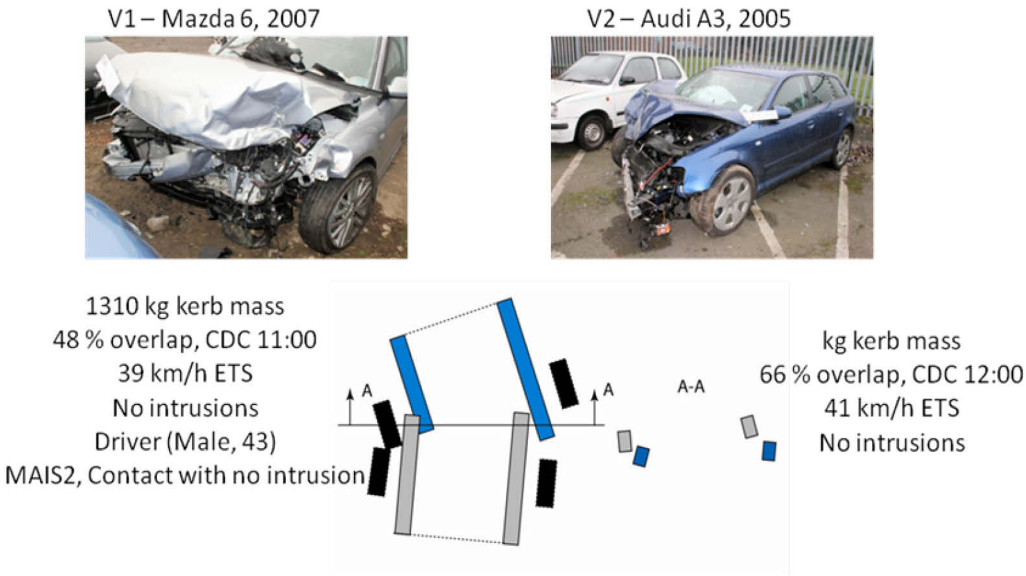


Figure 5.44: Over/underriding with fork effect (classified as overriding because this judged more severe) Mazda 6 vs Audi A3.

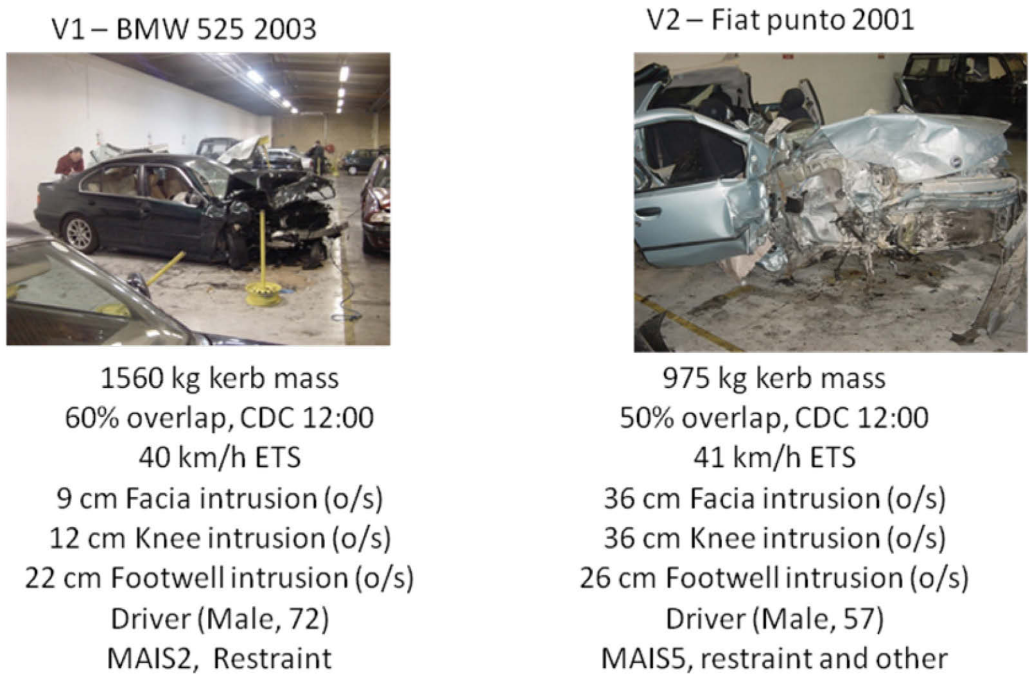


Figure 5.45: Frontal force / compartment strength (BMW 525 vs Fiat Punto), much greater intrusion in Punto.

V1 – Vauxall Vectra 2003

1450 kg kerb mass
34% overlap, CDC 12:00
27 km/h ETS
2 cm Facia intrusion (o/s)
5 cm Knee intrusion (o/s)
0 cm Footwell intrusion (o/s)
Driver (Female, 49)
MAIS2, restraint

V2 – Ford Fiesta 2006

1143 kg kerb mass
34% overlap, CDC 12:00
38 km/h ETS
2 cm Facia intrusion (o/s)
12 cm Knee intrusion (o/s)
6 cm Footwell intrusion (o/s)
Driver (Male, 66)
MAIS1

Figure 5.46: Frontal force / compartment strength (Vectra vs Fiesta), much greater intrusion in Fiesta.

5.4.5 Conclusions CCIS Detailed Case Analysis

- Poor structural interaction has been observed to be a problem in the current vehicle fleet. The dominant structural interaction problems in car-to-car impacts are over/underriding of car fronts and low overlap. However, fork effect is seen more in car-to-object impacts because of impacts with narrow objects.
  - Structural interaction problems identified in 40% of fatal and 36% of MAIS 2+ injured cases. However, only in 25% of fatal and 12% of MAIS 2+ cases there was intrusion present and thus it can be said definitely that improved structural interaction would have improved the safety performance of the car[4].
- Frontal force and/or compartment strength mismatch issues between cars in the current fleet appear[5] to be less of an issue than poor structural interaction.
  - For all accidents, force and/or compartment strength mismatch problems identified for 8% of fatal and 2% MAIS 2+ survived occupants. However, it should be noted that force and/or compartment strength mismatch problems can only be identified for accidents in which there is compartment intrusion into the vehicle.
  - For car-to-car impacts force and/or compartment strength mismatch problems identified for 9% of fatal and 3% MAIS 2+ survived occupants

[4] It should be noted that in 23% of the fatal cases the accident severity was so high that it was not possible to determine whether or not a compatibility issue had occurred.
[5] Note: structural interaction problems could be masking frontal force mismatch problems

6 GERMAN ACCIDENT ANALYSIS

6.1 Data Selection

6.1.1 Approach

The German data sample analysed in FIMCAR included all significant frontal collisions with passenger cars involved that were recorded and reconstructed within GIDAS until the end of year 2009. Statistical analyses were conducted using the statistical analysis software R (version 2.10.1). To consider vehicle compliance with Regulation 94, only passenger cars were included with the first registration in year 2000 or later. In GIDAS, this date is recorded for each vehicle involved with the help of its official vehicle registration certificate. No further check for the R94 compliance has been done. Furthermore, the accident analyses focused on the injuries of drivers and front seat passengers with a minimum age of 12 years; hence all rear seat occupants are excluded. Accidents of all injury severities were regarded whereby vehicles sustained damage mainly at the front (zone 1 of VDI2, see Glossary) and the principal direction of force came of 11, 12 or 1 o'clock (VDI1, see Glossary). To avoid false conclusions, multiple collisions and rollover accidents were excluded consequently from this analysis.

The initial high level analysis (Section 6.2) provides general information and distributions on OCCUPANT and VEHICLE level with regard to gender, injury severity, seating position, age and collision partner groups. Following this, detailed analysis of injuries (Section 6.3) is provided. The collision events are further analysed in Section 6.4 in terms of speed, intrusions, overlap, vehicle mass dependencies, injury mechanisms and acceleration loading. Finally, section 6.5 contains conclusions related to the identified compatibility issues, the nature of injuries and determined significant injury mechanisms. The GIDAS variables VDI 1, 2 and 3 (vehicle deformation indices, see 6.1.3) are used to conduct this analysis and are introduced within the appropriated sections.

6.1.2 Initial GIDAS Dataset

The GIDAS dataset contained all significant frontal collisions with passenger cars with dates of their first registration younger than year 2000. Please see Section 6.1.1 for the entire data query. Two main datasets could be provided. The first one regarded the OCCUPANT LEVEL information and included all involved people (n = 2604). The second one focused on the VEHICLE LEVEL and comprised each vehicle involved in the crashes.

Four main groups were created to separate the results into crashes related to their collision partners and are shown in Table 7.

Table 7: Groups of collision partners.

Abbreviation	Description
CAR_CAR	Passenger car vs. passenger car All vehicles with a car body.
CAR_HGV	Passenger car vs. heavy good vehicle Included are trucks and buses.
CAR_OBJ	Passenger car vs. object Non-vehicles, in particular roadside elements such as trees and pillars.
CAR_OTH	Passenger car vs. other All remaining vehicles, in particular bicycles and powered two-wheelers.

The OCCUPANT LEVEL information of all crashes in the initial dataset is shown in Table 8 whereby absolute numbers and percentages are given. The injured occupants were subdivided into slightly injured people with MAIS 1 and seriously injured people (MAIS 2+) including fatalities. Furthermore, uninjured people (MAIS 0) and people with unknown degree of injury severity (MAIS 9) were reported. This whole dataset (n=2,604) contained 16 fatalities which likely can be assigned to the group of seriously injured people and were extracted separately per collision partner group. In total, 2,604 occupants are considered with quite different injury severity distributions within the collision partner groups.

Table 8: Initial dataset GIDAS analysis (distribution into injury severity)

	Serious (MAIS 2+)		Slight (MAIS 1)	Uninjured (MAIS 0)	Unknown (MAIS 9)	Total		Fatalities
	n	%	n	n	n	n	%	n
CAR_CAR	92	54	499	724	25	1340	51	6
CAR_HGV	20	12	49	21	13	103	4	3
CAR_OBJ	57	33	142	276	14	489	19	7
CAR_OTH	2	1	11	657	2	672	26	0
Total	171	100	701	1678	54	2604	100	16

6.1.3 Explanation of GIDAS Variable Vehicle Deformation Index

The variable Vehicle Deformation Index (VDI) was used for most of the analysis of the accidents in the GIDAS sample. The VDI is similar to the Collision Deformation Characteristics (CDC). The VDI describes in 7 parts (VDI1 – VDI7) the principle direction of force, the general location of the deformation, the horizontal and vertical distribution of the deformation, a brief description of the contact and the degree of deformation. Within this report VDI1, VDI2 and VDI3 were used. The VDI is similar to the Collision Deformation Characteristics (CDC). The VDI describes in 7 parts (VDI1 – VDI7) the principle direction of force, the general location of the deformation, the horizontal and vertical distribution of the deformation, a brief description of the contact and the degree of deformation. Within this report VDI1, VDI2 and VDI3 were used.

VDI1 describes the Principle Direction of Force (PDOF) using a clock direction. Within the GIDAS sample PDOF is normally calculated, in other data sets it is mostly estimated. VDI1 directions 11, 12 and 1 were considered to be frontal impact accidents these correspond to an angle of -45° to +45°.

VDI2 describes which part of the car is deformed. For this study only accidents with the vehicle front being deformed were included.

VDI3 describes the horizontal distribution of the deformation. Figure 6.1 shows the classification used for frontal impacts.

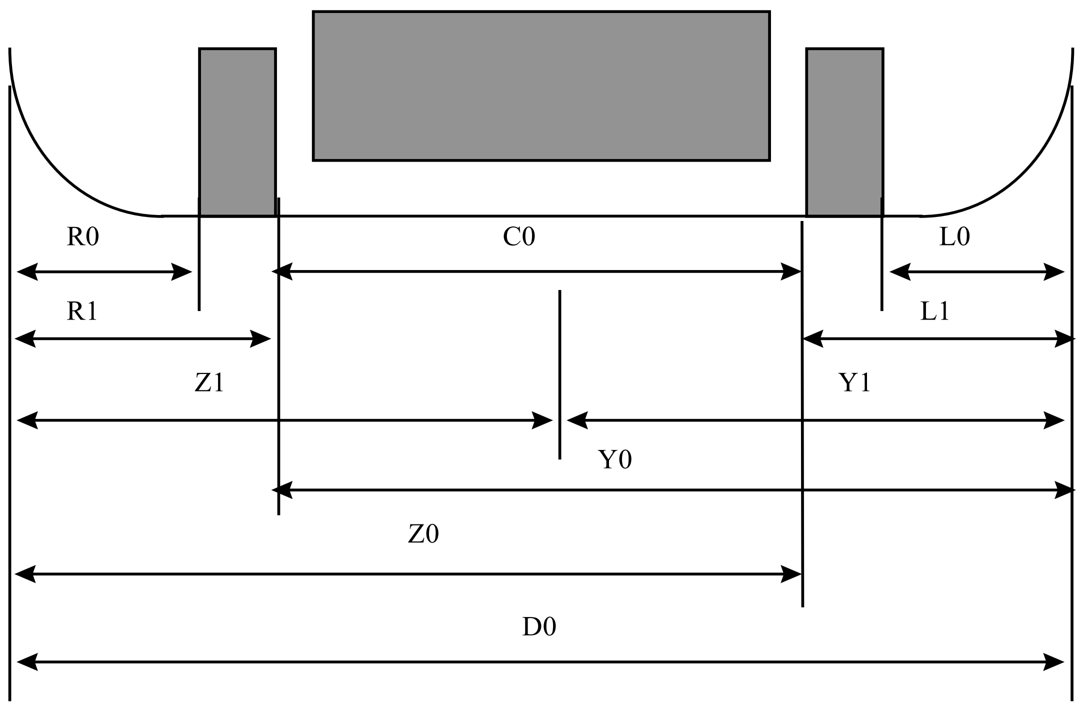


Figure 6.1: VDI3 classification for frontal impact accidents.

6.2 General Overview GIDAS Sample

This section gives some sample checks that have been done in order to provide a general overview of the generated dataset. The overall MAIS distribution of all involved people in the crashes is shown in Figure 6.2. Subdivided into the collision partner groups, most frequent events could be identified in car-to-car crashes followed by car crashes against objects and others.

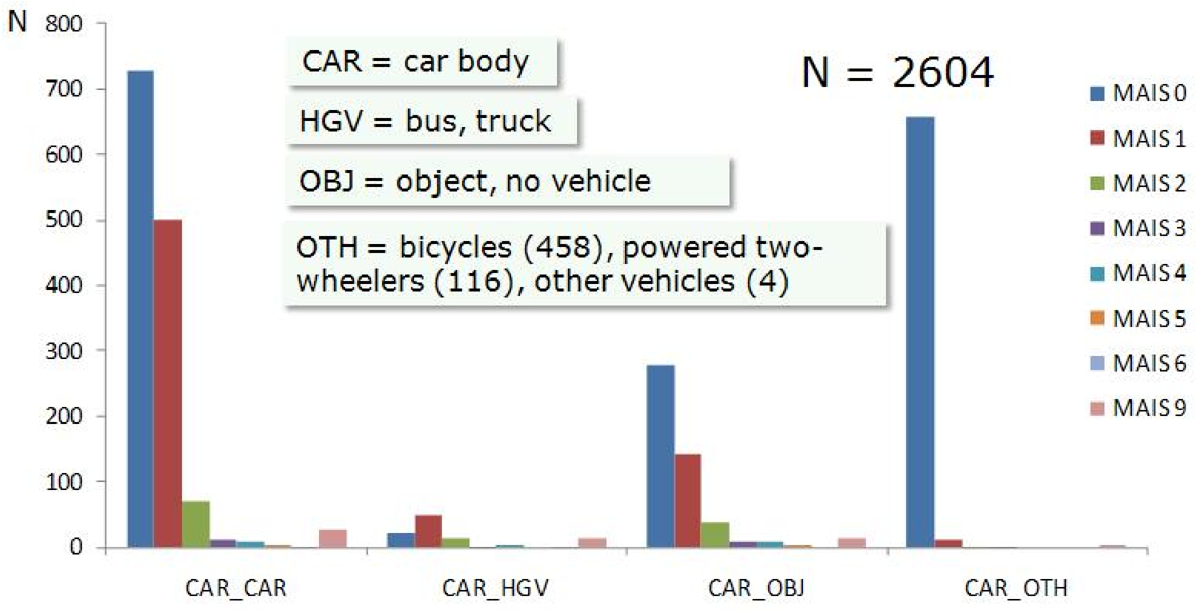


Figure 6.2: MAIS distribution on OCCUPANT LEVEL.

The absolute occupant numbers primarily show the huge amount of relevant crashes between two passenger cars. Involved people were mostly uninjured or suffered injuries of MAIS 1 or 2. The information in Figure 6.2 implies a higher injury severity risk in crashes of cars against heavy good vehicles and objects than for the other groups. Almost no injuries occurred to passenger car occupants whilst hitting “other” collision objects.

Figure 6.3 shows the occupant age distribution subdivided into the four collision partner groups. Again, the total number of involved people was 2,604 (OCCUPANT LEVEL) and the assigned age ranges show different distributions for the different collision partners. No further analysis was done for the national representativeness of these figures to driver and front seat passenger age distributions in Germany. The total age group distribution reflects the high accident number of crashes between two cars. Compared to other collision types, there were large differences in the age distribution identified in crashes against objects for which younger people were more frequently involved.

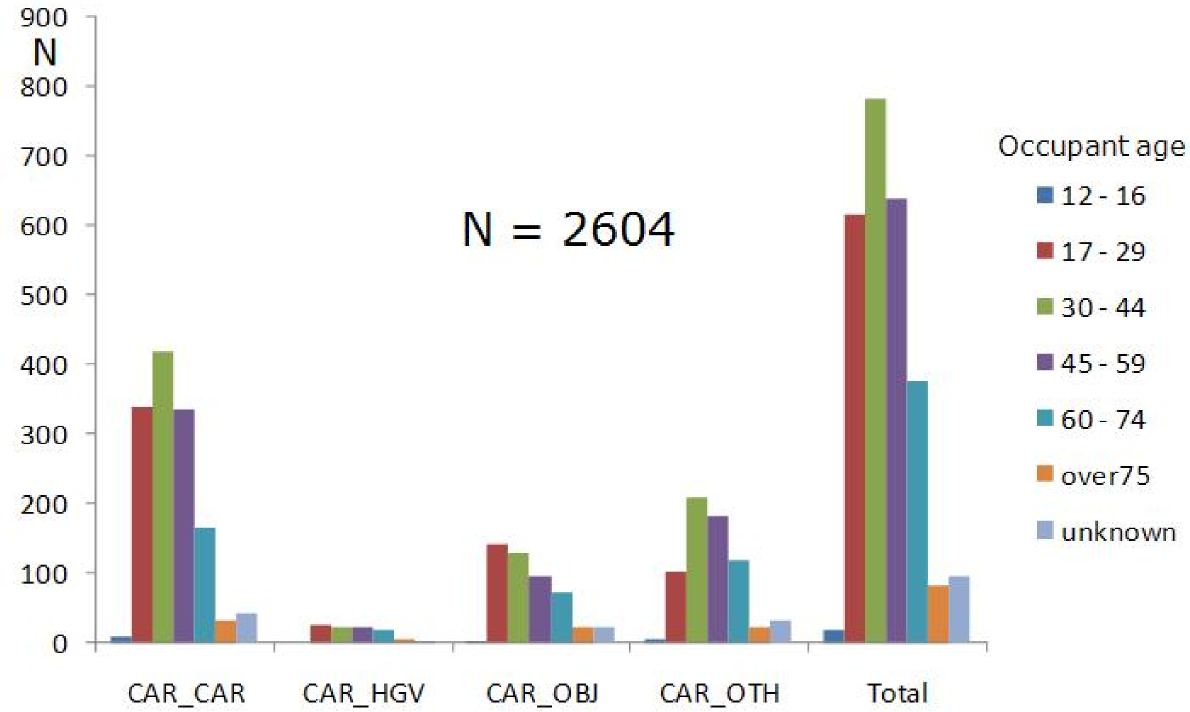


Figure 6.3: Occupant age distribution.

Looking at the gender on OCCUPANT LEVEL of all crashes 38% of the involved people were females. Furthermore, Figure 6.4 demonstrates nearly the same distribution rate within each collision partner groups (38% of female in CAR_CAR, 37% of female in CAR_OBJ).

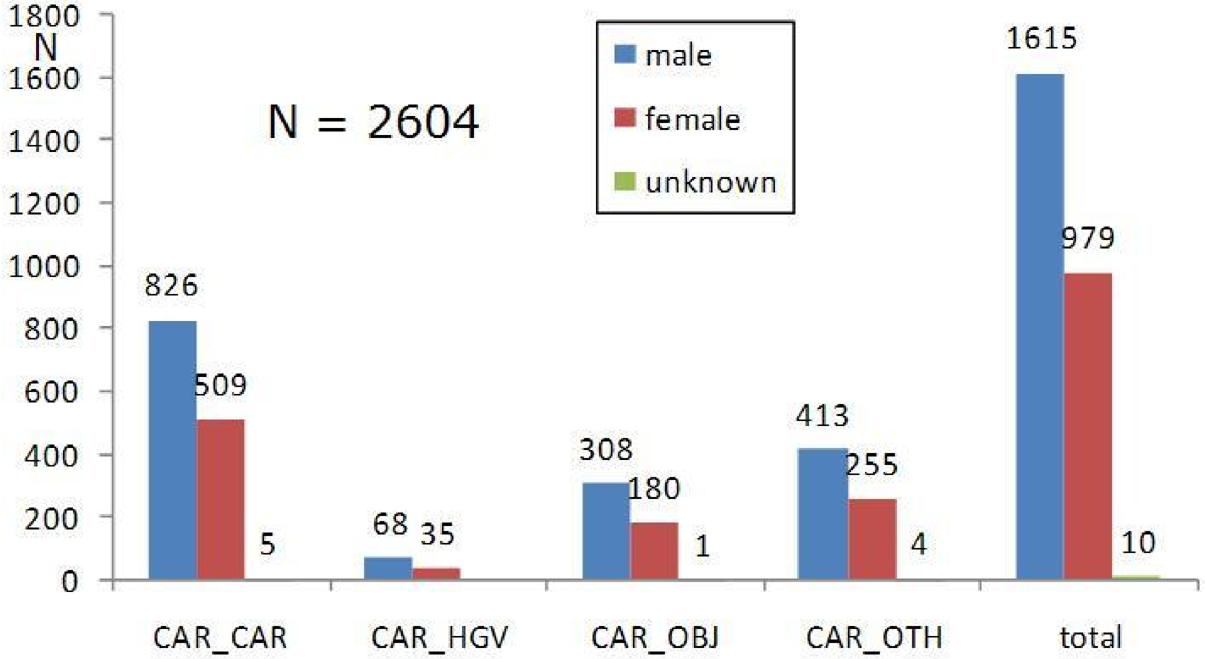


Figure 6.4: Gender distribution of crash involved people.

With a focus on the ratio of occupant's gender and the MAIS, Figure 6.5 shows the distribution of males and females related to their seating position. To ensure the quality and correctness of statements the sample was restricted to people whose seatbelt usage was positively assigned.

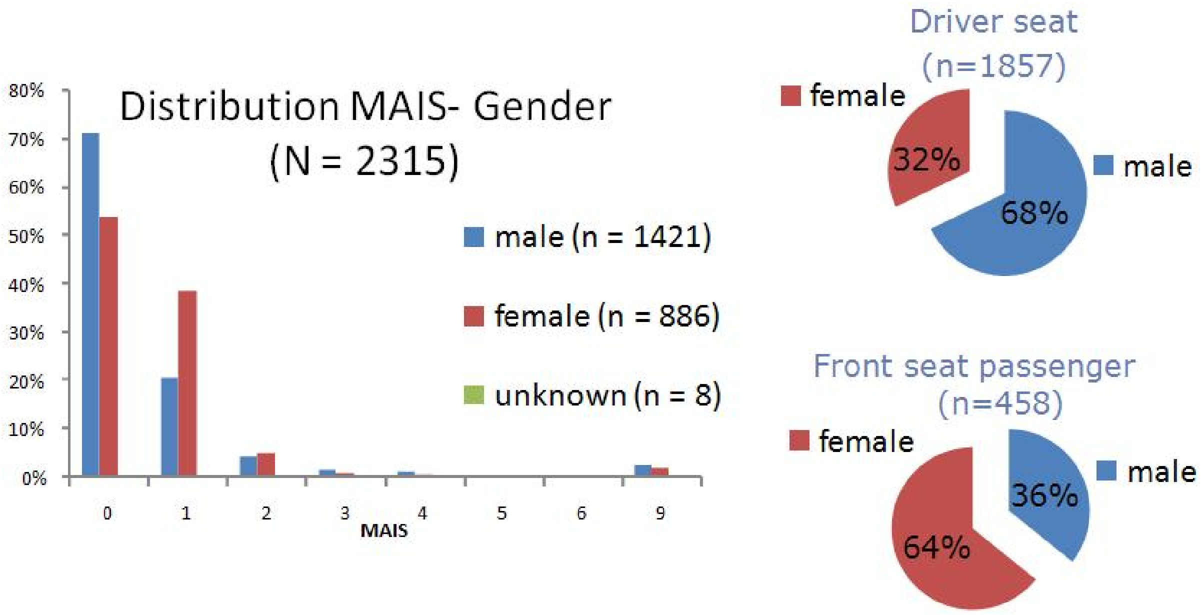


Figure 6.5: MAIS – gender distribution of belted occupants.

The MAIS – gender distribution classifies all men and women (each gender 100%), with their overall MAIS. Male occupants seemed to be more frequently uninjured (MAIS 0) than female ones. Most MAIS 1 and MAIS 2 injuries could be assigned to women whilst male occupants sustained slightly more frequent injuries of MAIS 3 or MAIS 4. To bring these facts into relation to the likely contributing seating position, two diagrams were added on the right side of the figure. Regarding the seats, approximately two-thirds of all drivers were male and again approximately two-thirds of the front seat passengers were female. Additionally, the total numbers of the occupied driver seats (n=1,857) and the front seats (n=458) indicated that about 1,400 occupants travelled alone or with rear seat occupants. Further studies, such as matched-pair-analysis, could show relations between these seating positions, frequencies of use by gender and the related injury severity but were omitted here.

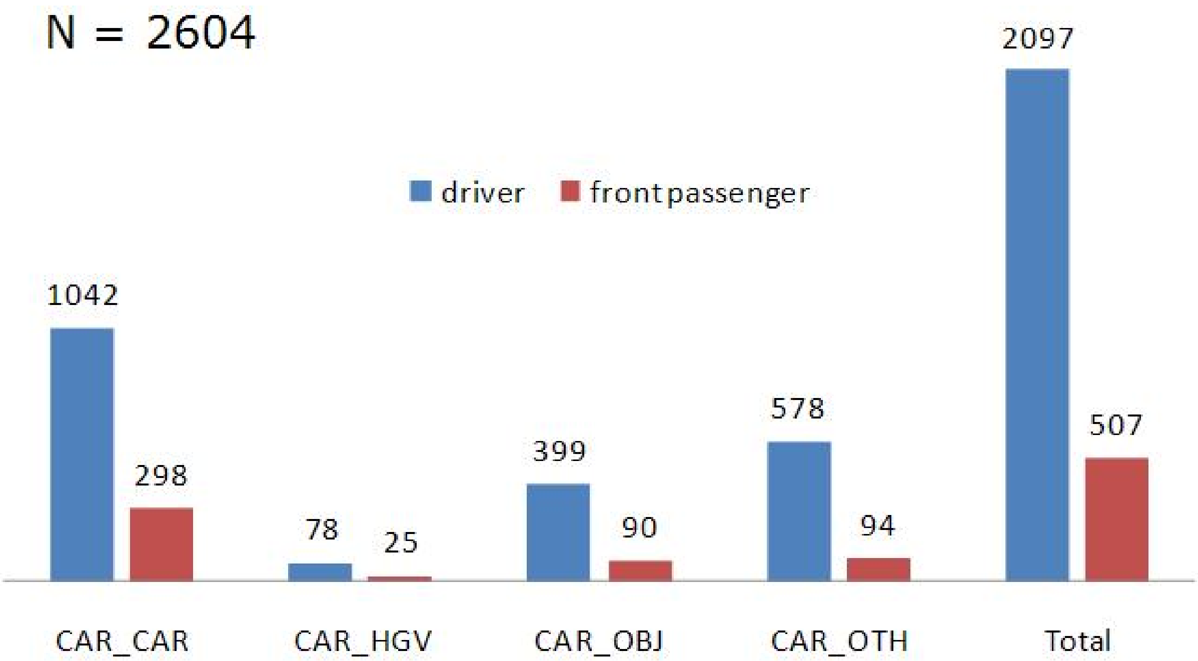


Figure 6.6: Distribution of drivers and front seat passengers in collision partner groups.

To give a generalised view on the distribution of the occupied seat, Figure 6.6 comprises all people in the dataset and shows the total numbers subdivided into the collision partner groups.

In total, nearly 20% of people were front seat passengers. In the group CAR_CAR 22% of the involved people could be assigned to be front passengers, 18% in the group CAR_OBJ and 14% in the group CAR_OTH. The ratio of drivers and front seat passengers in the group CAR_HGV (24%) might be a result of the low number of accidents in this group and could be misleading.

The pie diagram in Figure 6.7 shows the principal directions of forces (PDOF, called VDI1 in the diagram) among the initially determined directions 11, 12 or 1 o‘clock. Half of all crashes occurred in frontal longitudinal direction and nearly a quarter of all crashes were assigned to the frontal left as well as to the frontal right direction.

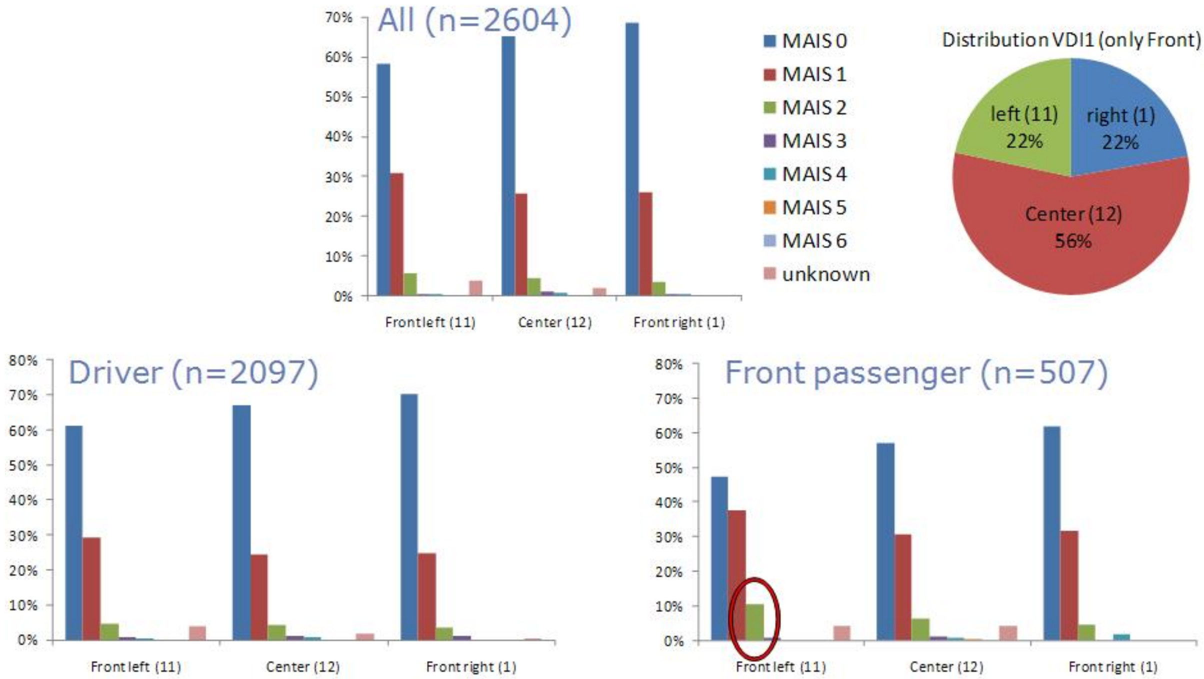


Figure 6.7: MAIS – VDI1 (principal direction of force).

The bar charts in Figure 6.7 point out the MAIS values of all considered occupants related to the principal direction of forces whereby each direction is 100% in itself. The overall view shows more seriously injured persons with the PDOF coming from front left than from centre or front right. In general, drivers and front seat passengers suffered similarly from the direction of force but there was also a small tendency to sustain more severe injuries as a front passenger compared to drivers when comparing the MAIS 0 - 2 bars. In particular, the red circled MAIS 2 bar of front passengers indicates a higher injury severity for forces coming from front left than from other directions or the driver position that might be caused by slipping out of the seatbelt. To explain this trend closer, injury mechanisms would have to be identified through further investigation at the individual injury level that could not be done within this analysis.

6.3 Injury Analysis

The share of all occupants within the collision partner groups is shown as percentages in Figure 6.8 (each group is 100%). Slight and severe injuries were very unlikely for car occupants in the group passenger cars against others. Contrarily, the highest probability to get severely injured was in car crashes against heavy good vehicles. When comparing the groups CAR_CAR and CAR_OBJ, more slight injuries (MAIS 1) occurred to occupants in crashes against passenger cars and more severe injuries (MAIS 2 and 3) occurred in crashes with objects.

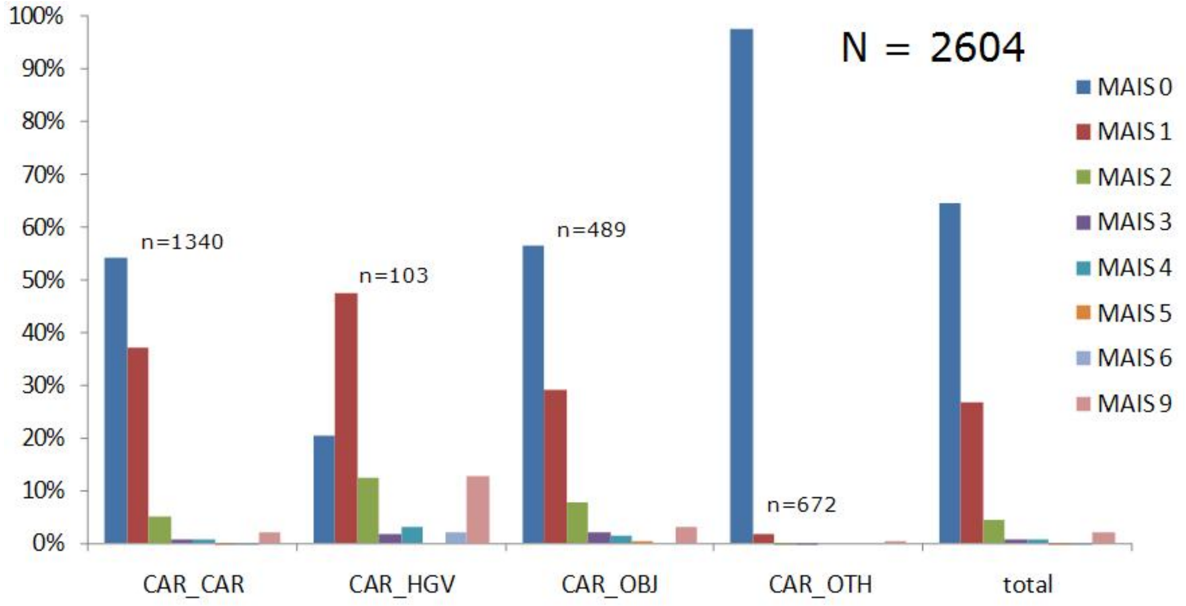


Figure 6.8: MAIS distribution by percentage of all occupants.

To analyse the injury mechanisms in more detail it's necessary to have a look at the body regions concerned. Therefore, the highest AIS values of predetermined regions (head, neck, arms, thorax, abdomen, pelvis and legs) were compiled in Figure 6.9 at the OCCUPANT LEVEL for all collision partner groups. To address the severely injured people, the sample was reduced to belted occupants with a minimum value of MAIS 2 and maximum MAIS 4. People with unknown overall MAIS and fatalities are excluded.

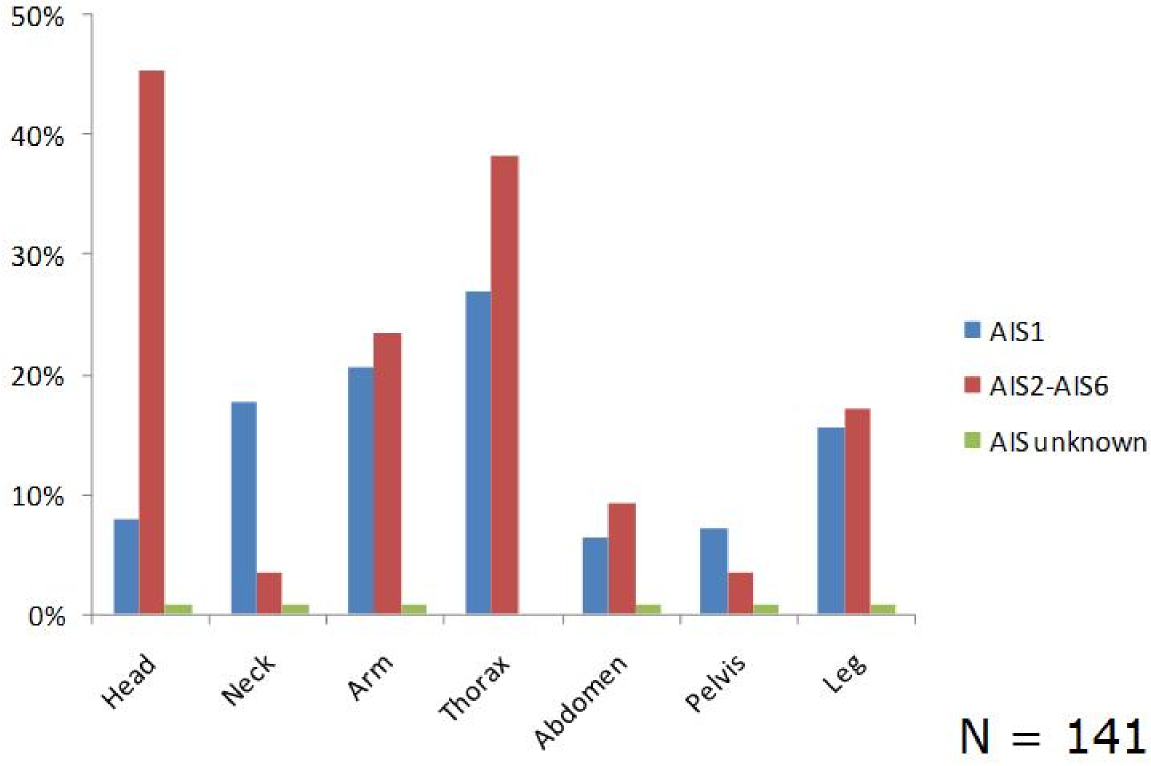


Figure 6.9: AIS distribution by body regions for all groups.

The percentages were derived separately for each body region considering all occupants (100%) in this reduced data sample (n = 141) with MAIS 2+ injured people. The remaining percentages per body region were assigned to AIS 1 or uninjured, respectively. It can be seen that highest injury rates (AIS 2+) were located in the head region, followed by thorax. Regarding AIS 1+ injuries and comparing all body regions thorax injuries could be identified as most frequently (approx. two-thirds of observed people suffered from thorax injuries).

Using the same data query as above but focusing on the collision partner group passenger car against passenger car (car-to-car) Figure 6.10 demonstrates differing distributions compared to Figure 6.9. Again, the body regions thorax and head showed highest injury rates (AIS 2+) compared to all regions but severe head injuries decreased significantly and the thorax is seen to be the most frequent severely injured body region.

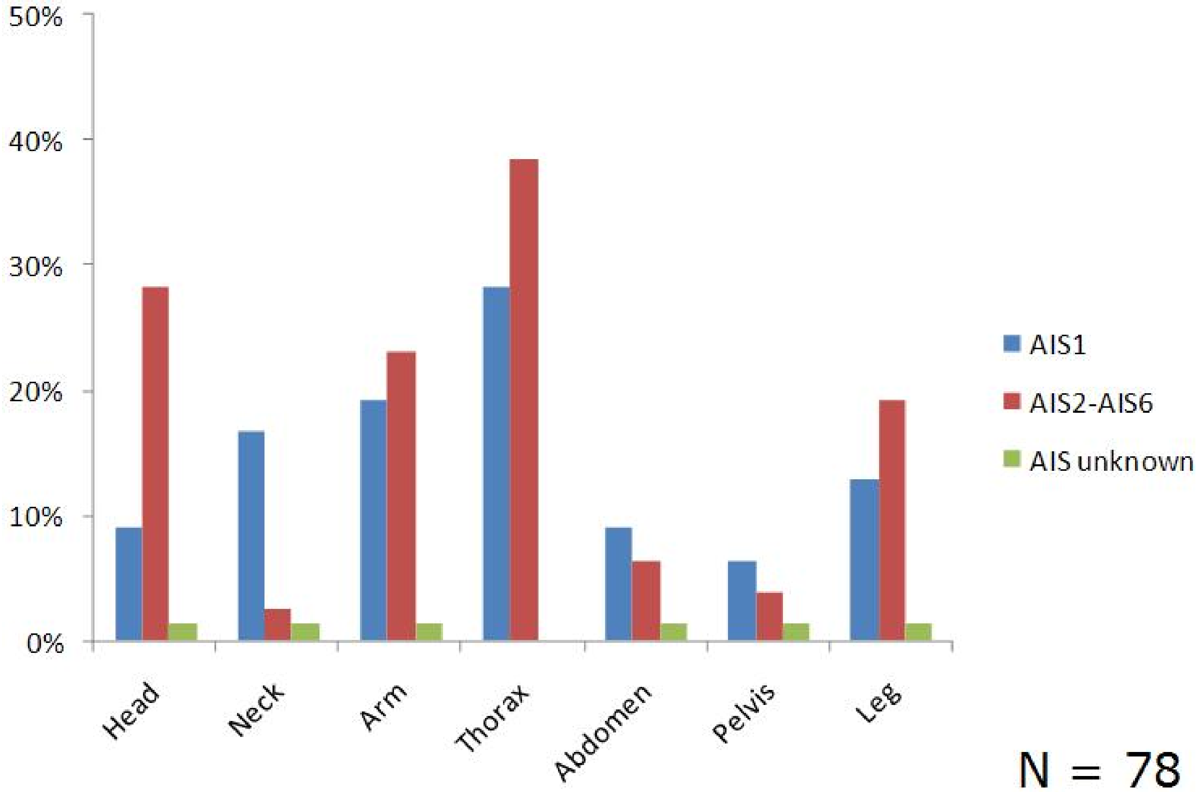


Figure 6.10: AIS distribution by body regions exclusively for group CAR_CAR.

6.4 Collision Analysis

6.4.1 EES

The Energy Equivalent Speed (EES) is a theoretical value that describes the amount of energy a vehicle absorbed in an accident. EES is similar to the collision speed when crashing with large overlap into a rigid obstacle. This value is used in Figure 6.11 to compare the different collision partner groups with each other at the VEHICLE LEVEL (n = 2097). Comparing the sizes of bars per group (each is 100%) showed significant differences between collision severities with the collision partners.

Crashes of passenger cars against others could be classified as a low EES collision (1 - 19 km/h), in contrast to collisions between cars and heavy good vehicles with most frequent values in a range of 10 - 39 km/h in about 75% of the cases. When crashing with an object, approximately one-third of the vehicles had an EES lower than 10 km/h and further one-third was analysed in a range of 10 - 39 km/h. In addition, CAR_OBJ and CAR_OTH were groups with each about 30% of unknown EES values.

When looking at crashes between two cars again approximately 75% of the vehicles had an EES in the range of 10 - 39 km/h and two-thirds of all reviewed crashes showed EES values between 10 - 29 km/h.

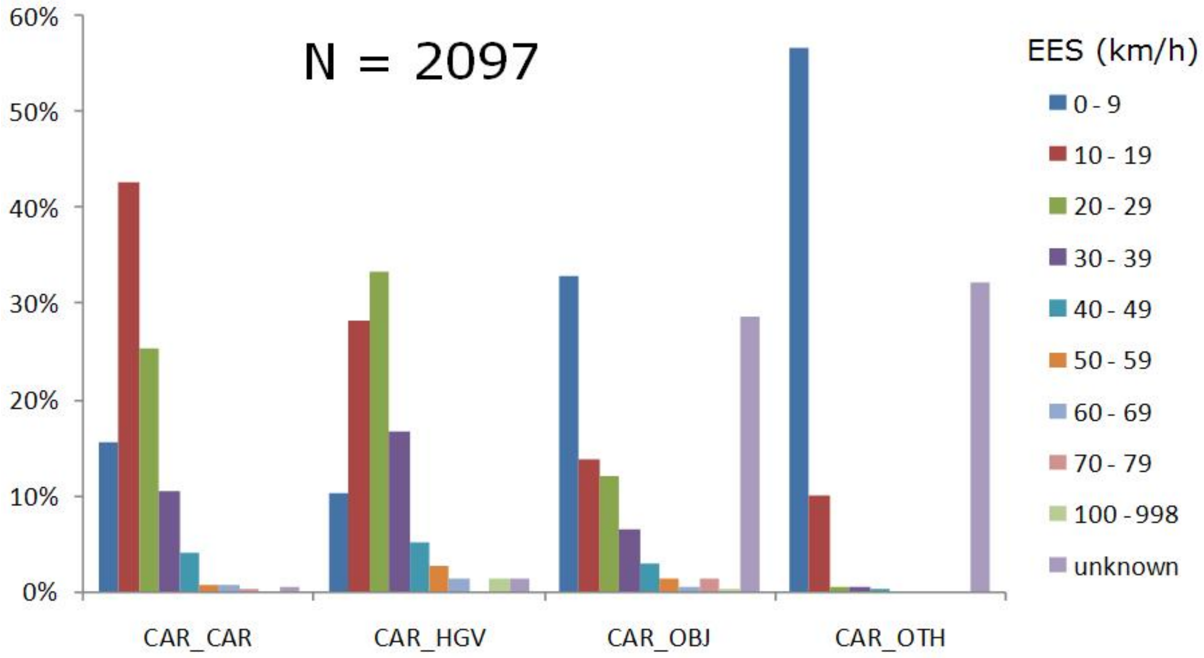


Figure 6.11: EES distribution on VEHICLE LEVEL.

The EES distribution for all vehicles is shown in Table 9 and divided into different EES intervals.

Table 9: EES (km/h) share of all vehicles (n = 2097) in the data set

km/h	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	>100	Unknown
n	629	579	342	151	57	15	9	7	2	306

To address the severely injured people, the sample was reduced to vehicles with belted occupants who survived and suffered from a MAIS 2+ injuries. People with unknown overall MAIS and fatalities had been excluded. Figure 6.12 contains this data at the VEHICLE LEVEL (n = 101) whereby each collision partner group is 100%. Due to the small number of cases within the groups CAR_HGV and CAR_OTH, the focus of this chart is on crashes CAR_CAR, CAR_OBJ and TOTAL. About 70% of all severe frontal crashes in this dataset occurred in an EES range of 10-39 km/h and in general, EES values in all collision partner groups increased compared to Figure 6.11. Approximately 75% of crashes between two passenger cars (red circled area) occurred at EES values of 10 - 39 km/h (red circle in Figure 6.11) and a further 12% in values of 40 - 49 km/h but only 6% of all vehicles showed EES values around the Euro NCAP test severity.

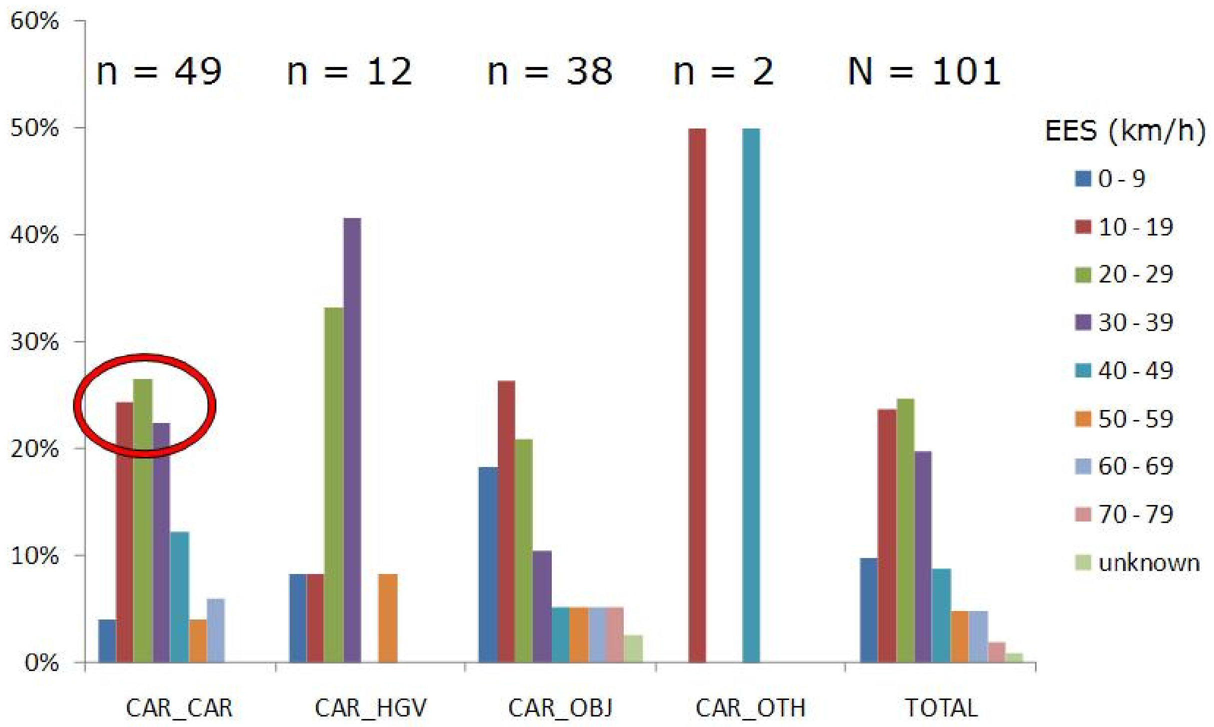


Figure 6.12: EES distribution on severely injured people (MAIS 2+).

6.4.2 Investigation of Intrusions

This section investigates in detail the compartment intrusions to the car. For GIDAS, analysis intrusion is considered to be present if visible loss of stability of relevant parts of the cabin was recognised or a door opening reduction (DOR) of more than 10 cm was recorded.

Table 10 gives an overview about the share of involved vehicles (n = 2,097) classified by the collision partner groups. Nearly half of all vehicles could be listed as frontal crashes between two passenger cars.

Table 10: Numbers of involved vehicles in the entire data set

Number of vehicles	CAR_CAR	CAR_HGV	CAR_OBJ	CAR_OTH
n = 2097	1043	78	398	578

Figure 6.13 compares the observed stability losses of a-pillars and the bulkheads on both left and right sides of the vehicles. For each combination, the crash partner groups were set to 100% to highlight differences. The charts demonstrate the overall rare occurrence of significant deformations. Crashes between passenger cars and heavy good vehicles were the most severe followed by crashes against objects. In less than 2% of all CAR_CAR crashes in this dataset the a-pillars showed stability losses on the left or right side. Furthermore, in CAR_CAR collisions there were a few more cases with stability loss on the left side compared to the right side in contrast to CAR_OBJ collisions where this issue was shifted to the right side.

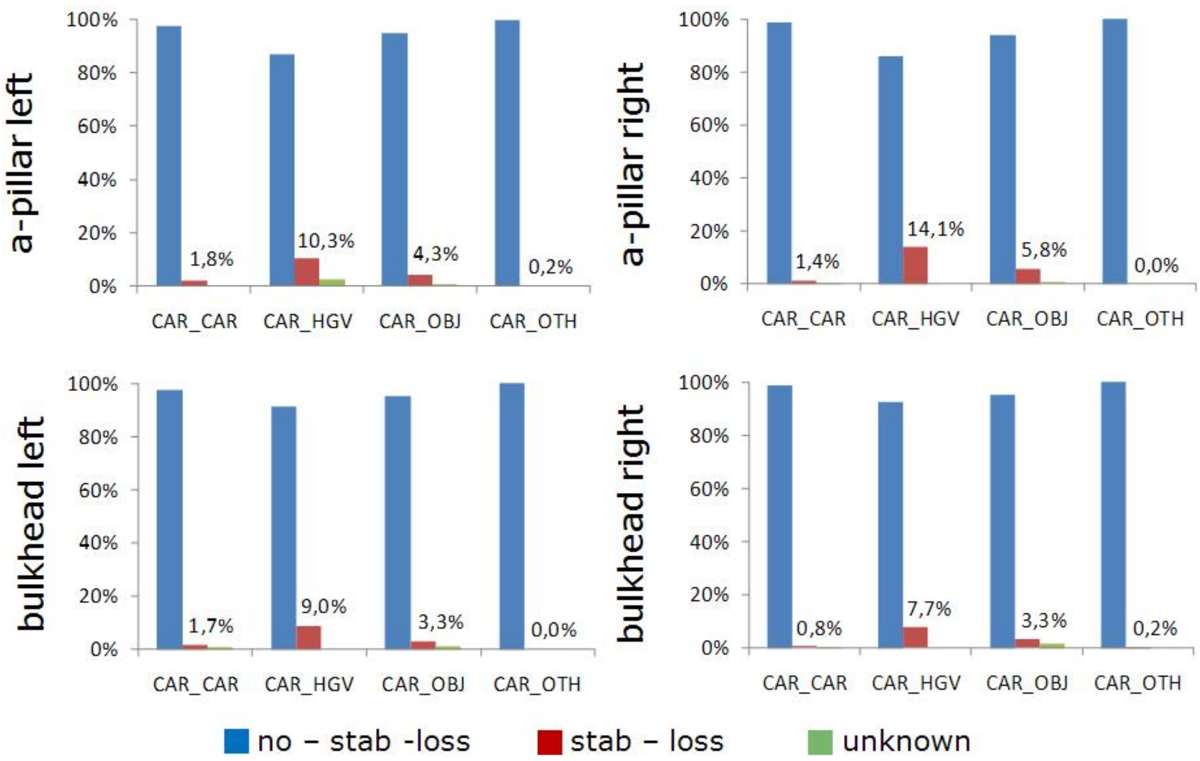


Figure 6.13: Stability losses of pillars and bulkheads for all involved vehicles

Considering further significant occupant compartment parts Figure 6.14 focuses on VEHICLE LEVEL on stability losses of a-pillars, bulkheads and the dashboard on both left and right side of all vehicles (n = 2097).

Crashes between passenger cars and heavy good vehicles led to most severe outcomes to the compartment. Stability losses of the a-pillar of cars occurred in about 12% of all crashes of type CAR_HGV, in about 5% of type CAR_OBJ, in 2% of type CAR_CAR (marked by red circle) and almost never in crashes of type CAR_OTH. All the data presented in Figure 6.13 report the rates a component exhibited instability. Considering that different combinations of instability can occur (a-pillar, bulkhead, DOR) on each side (left and right), one can assume that the occupant compartment was compromised in more cases than indicated by one bar in Figure 6.13. This maximum rate of compartment instability occurred for impacts with HGVs and was relatively rare in car-to-car crashes.

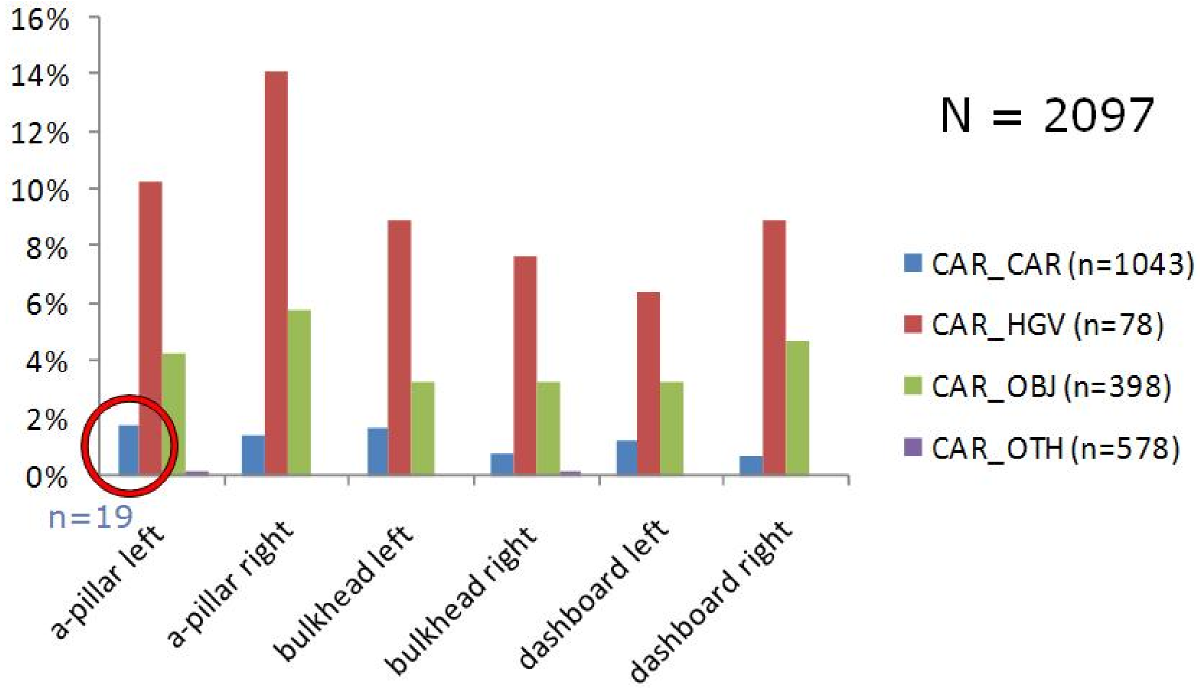


Figure 6.14: Stability losses of significant compartment parts.

Creating a new sample to address the severely injured people was realised by reducing the selection of vehicles to only belted drivers and front passengers who suffered from a MAIS 2+ injury. People with unknown MAIS were excluded. Figure 6.15 contains this data at the VEHICLE LEVEL (n = 105) whereby each collision partner group is 100% per compartment component. Paying attention to the decreasing total numbers leads the focus of this chart to CAR_CAR and CAR_OBJ cases, although crashes of passenger cars against heavy good vehicles led to most severe damages to the compartment. Stability losses of one a-pillar of cars occurred here in about 20% of type CAR_OBJ, in 8% of type CAR_CAR (marked by red circle) and almost never in crashes of type CAR_OTH. Left side compartment parts collapsed more frequently in crashes CAR_CAR than on the right side.

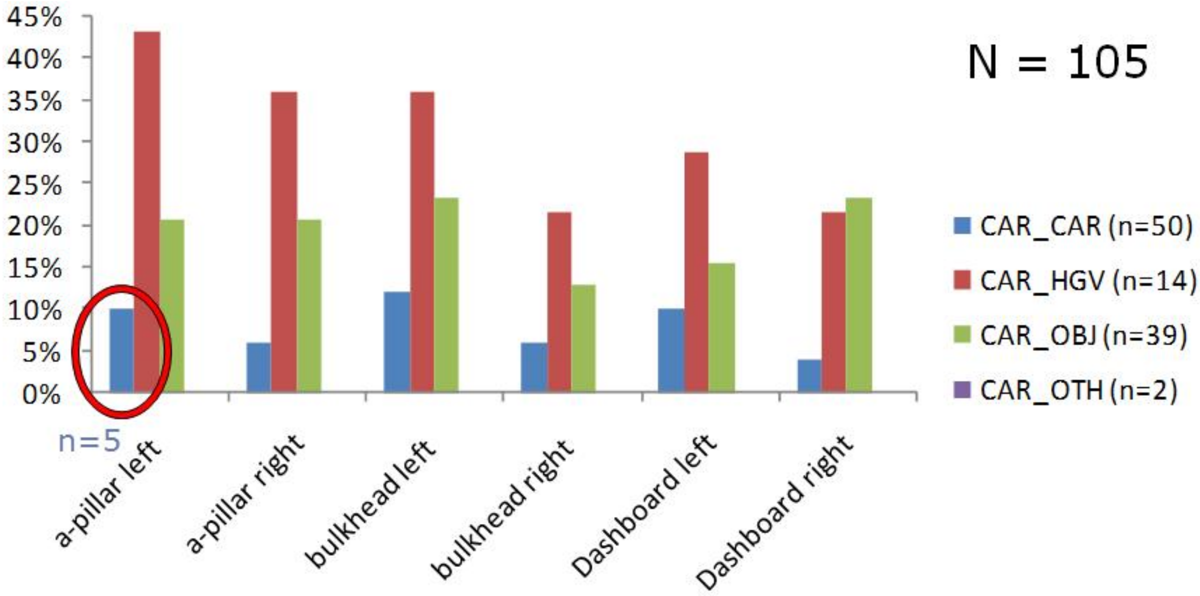


Figure 6.15: Stability losses in crashes involving occupants with MAIS 2+.

The red circled bars in Figure 6.14 and Figure 6.15 show the relatively low proportions of cabin stability losses in crashes between two cars compared to other collision partner groups.

Searching for another value in GIDAS to analyse severe damage to the occupant compartment led to the Door Opening Reduction (DOR) data which is shown in Figure 6.16. The upper bar chart includes the entire data set on VEHICLE LEVEL (n = 2,097) and gives an impression about the dimensions of gathered deformation data at the accident scene. In total, in up to 10% of all involved vehicles door opening reductions could be observed whereby a tendency of more frequently damages to the left side could be noted. Heavy DOR with 10 cm and more occurred in 1 - 2% to the vehicles.

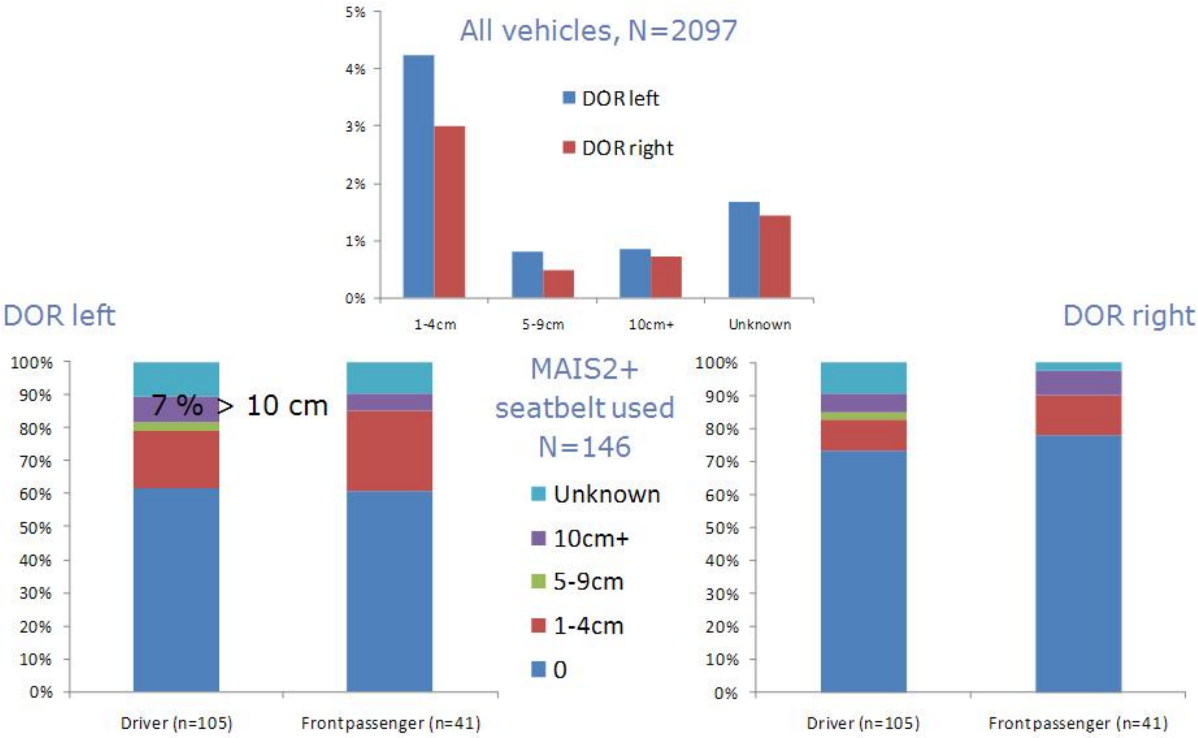


Figure 6.16: Door opening reduction (DOR) for VEHICLE LEVEL (top) and OCCUPANT LEVEL (bottom).

Switching to the OCCUPANT LEVEL and focusing on belted MAIS 2+ occupants led to a total number of n = 146 and to slight differences between DOR on the left and the right side. This is shown in Figure 6.16 as well (two charts below). About 7% of the drivers plus about 5% of the front seat passengers had been severely injured in conjunction with significant door opening reductions of at least 10 cm on the near-side seating position. 60% of accidents with MAIS 2+ casualties have not shown any DOR on the left side, whereas 70% of accidents with MAIS 2+ casualties did not show any DOR on the right side, for both drivers and front passengers.

When analysing the charts and the accompanying statements one has to consider that these analyses focus on frontal collisions with directly opposing force directions. Hence, very often damage occurred to the left and right vehicle sides at the same time. Checks whether one vehicle has damage on both sides have not been conducted.

6.4.3 Frontal Overlap

Frontal overlap in this analysis means the amount of directly damaged (deformed) impact structure overlapping with the collision partner. The value is expressed as a percentage of the vehicle’s width and is split into 25% steps. For example, 20% of overlap by the collision opponent could mean either 20% of the car front is damaged from one edge or some area (20% of the car width) in the central car front has been damaged and the car wings/fenders are undeformed. Looking at the entire data set (VEHICLE LEVEL, n = 2097) some significant differences could be observed, Figure 6.17. The distributions of overlap were very similar between CAR_CAR and CAR_HGV crashes, in contrast to the shares of crashes CAR_OBJ and CAR_OTH. Nearly half of all passenger cars in crashes between two cars showed frontal overlaps of 75 - 100% and two-thirds of all vehicles had overlaps of at least 50%. Most frontal collisions (about 65%) between cars and objects (e.g. narrow objects such as trees) ended up in small overlaps of 1 - 24%. Of course these facts are directly related to the geometry and mass of the collision partners.

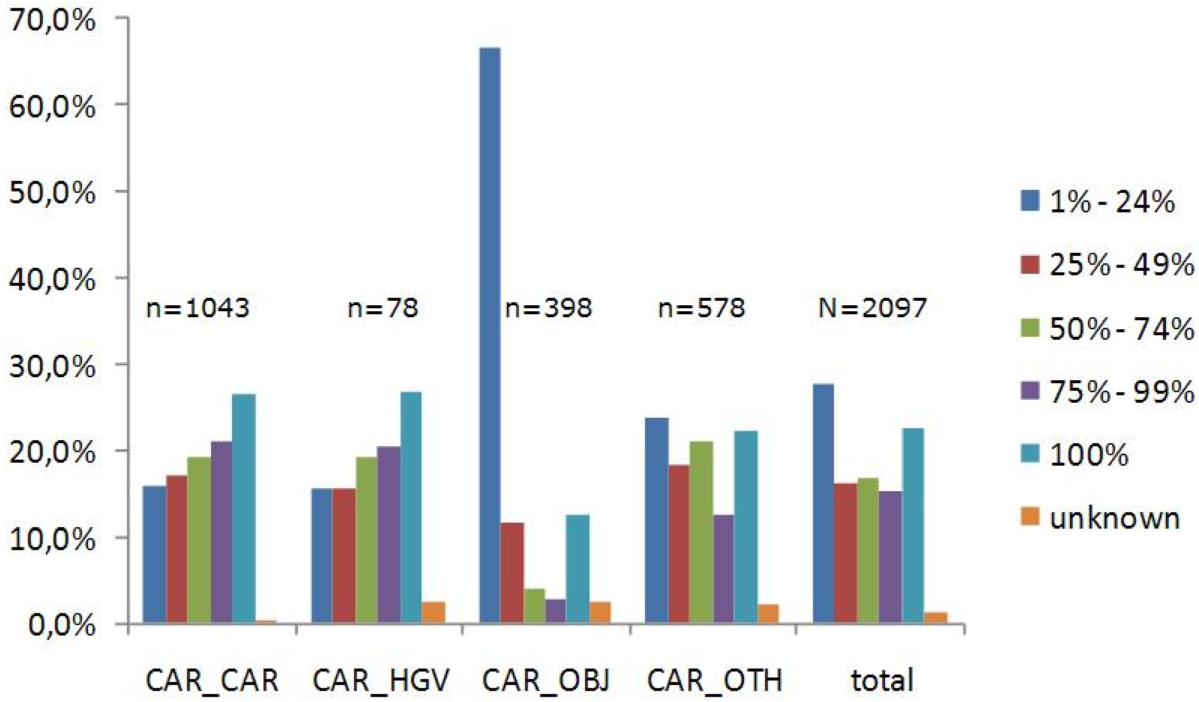


Figure 6.17: Frontal overlap.

Distributions of the injury severities (each category is 100%) against the frontal overlap on OCCUPANT LEVEL (n = 780) are shown in Figure 6.18. The chart considers all collision partner groups; seat belted injured people who survived with a known MAIS were classified into the three categories MAIS 1, MAIS 2+ survived and fatal. The analysis of Figure 6.18 does not list statements concerning fatalities because there are 'only' nine fatalities shared over four overlap steps. Comparable portions between MAIS 1 and MAIS 2+ injured persons could be found over all overlap steps as well as distinctive peaks for low (1 - 24%) and full overlaps (75 - 100%). About 40 - 45% of all injured people suffered from frontal overlaps in the range of 75 -1 00%. The marked red line is a trend line of the MAIS 2+ survived group throughout all overlap steps. In this dataset no MAIS 2+ survived person sustained a MAIS value of 5 or 6.

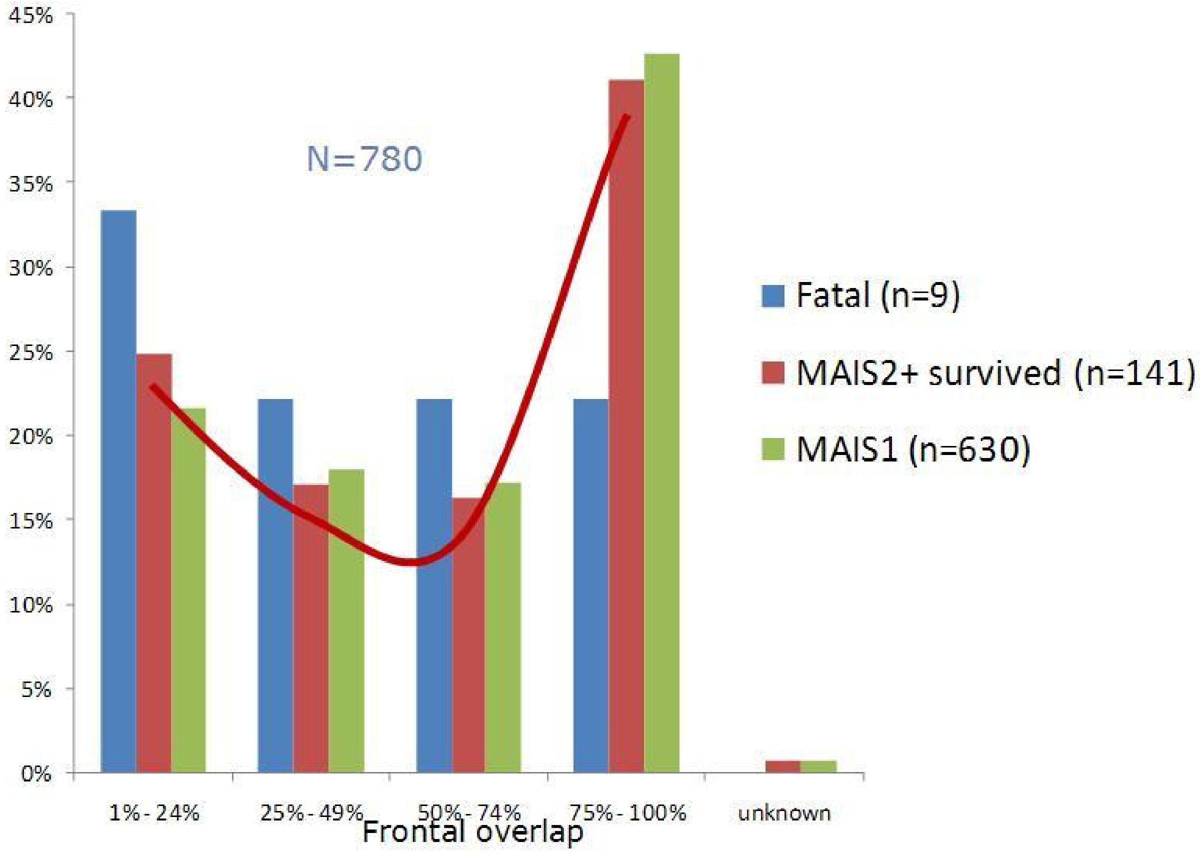


Figure 6.18: Distribution of injury severity against frontal overlap.

Furthermore, Figure 6.19 restricts this dataset to the collision group passenger car against passenger car (n = 534). Two-thirds of all involved injured people occurred at an overlap >50% and nearly half of them at a frontal overlap >75% but only about 20% of these injuries were related to low overlaps (1 - 24%).

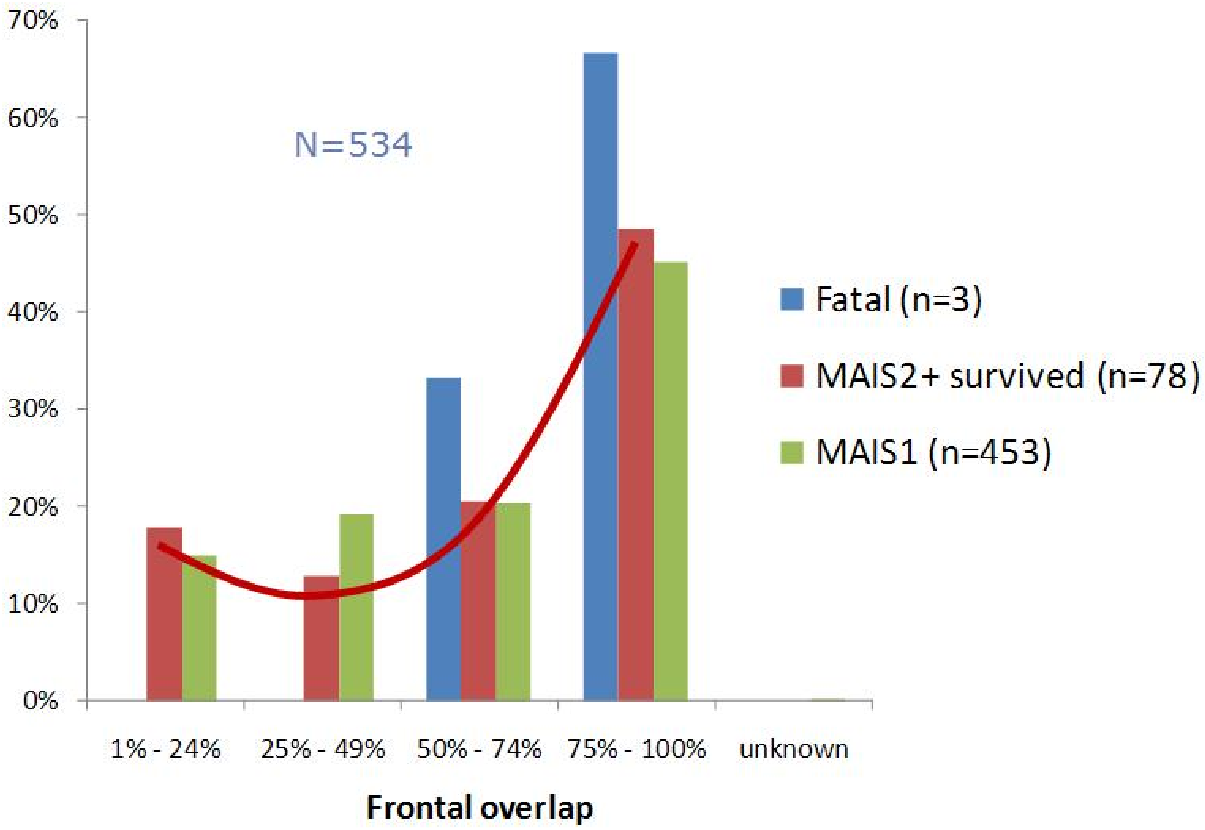


Figure 6.19: Distribution of injury severity against frontal overlap for CAR_CAR.

To give further core statements it would be necessary to consider the frequencies of these frontal overlap steps and to combine them with the information about the injury severities.

Table 11 reveals the shifting of the proportions of the MAIS 2+ injured people (survived, seatbelt used) against the frontal overlap (OCCUPANT LEVEL). Again the trend could be seen that narrow objects (up to a frontal overlap of 24%) were more frequent over all MAIS 2+ cases than for crashes between two passenger cars. In the latter group full frontal overlap crashes were observed more often. In other words, car-to-car crashes often showed less severe issues with low frontal overlap than car crashes with other collision partners such as tree objects.

Table 11: Frontal overlap for known injured, survived people (MAIS 2+), seatbelt used

Frontal overlap	**1%-24%**	**25%-49%**	**50%-74%**	**75%-100%**
MAIS 2+ (all groups) n = 140	25%	17%	16%	41%
MAIS 2+ (car vs. car) n = 78	18%	13%	20%	49%

6.4.4 Horizontal Location of the Deformation

The VDI3 (Vehicle deformation index 3) codes the specific horizontal location of the damage for all four sides of a vehicle. It is possible to code the damage of the whole front, side or rear just as smaller parts, e.g. from the car wing to the longitudinal beam or the centre part between both longitudinal beams.

In order to evaluate whether or not the impact occurred at the corners or in the centre of the car VDI3 can be analysed. This analysis is especially important for the small overlap cases, where important differences between CCIS and GIDAS were observed. Taking the entire dataset and focussing on the cases that have VDI3 coded as well as on the accidents with at least one MAIS 2+ survived, injured, and belted person led to n = 101 remaining passenger cars (VEHICLE LEVEL). Figure 6.20 shows the VDI3 distributions for different collision partner groups. Most impacts could be seen for the full front width over the groups which had a range from 37 - 45% there. The remaining proportions revealed deviating trends. These proportions were distributed uniformly regarding all groups (n = 101), showed a trend to the left side for crashes between two passenger cars and were mostly centred for collisions of cars and objects like trees.

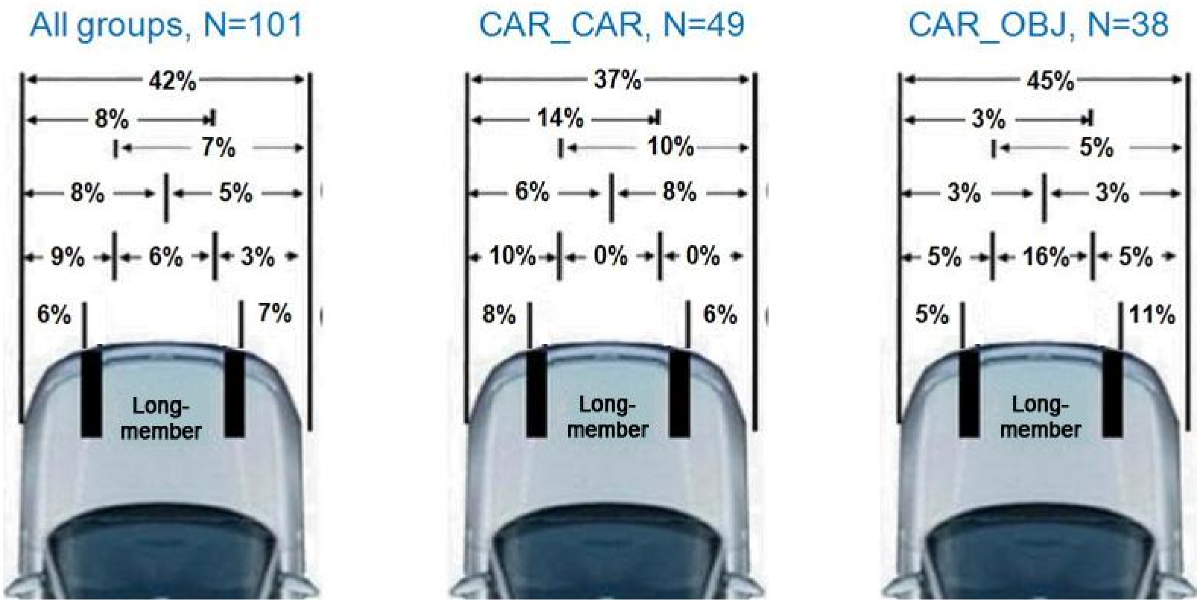


Figure 6.20: VDI3 distributions for all groups, car-to-car and car-object collisions.

By using the VDI3 coding the horizontal frontal car damages could be identified. The ‘Low External Overlap’ is determined as the zones R0, R1, L0 and L1 (see VDI3 in glossary) which represent the areas from the car wings up to the longitudinal beams on the left and the right side of the front. Transferring these cases to the OCCUPANT LEVEL led to the percentages in Table 12. This table shows the numbers of MAIS 2+ casualties for the different collision partner groups as well as the proportions for the low frontal (external) overlaps within each group. Omitting the crashes CAR_OTH (due to its very small number of cases) led into percentages of 20 - 24% for each collision partner group. That means the low external overlap issue was distributed homogeneously within each group CAR_CAR, CAR_HGV and CAR_OBJ on OCCUPANT LEVEL. Furthermore, nearly each fourth observed person suffered from an AIS 2+ injury following a Low External Overlap crash.

Table 12: Low frontal (external) overlap (from car wing to longitudinal beam)

Low External Overlap (VDI3: 20, 40, 21, 41)	All groups n=141	CAR_CAR n=78	CAR_HGV n=15	CAR_OBJ n=46	CAR_OTH n=2
MAIS 2+ casualties	23,4%	24,3%	20,0%	23,9%	0,0%

6.4.5 Mass

One of the most likely contributing factors to severity of crashes is mass of the opposing vehicle/object in a crash. Therefore, Figure 6.21 shows total numbers of the distribution of all involved vehicles opposite to their kerb weight split into 250 kg intervals on the VEHICLE LEVEL. About 80% of these vehicles were in the kerb weight range of 1000 - 1749 kg and approximately 60% between 1000 kg and 1499 kg.

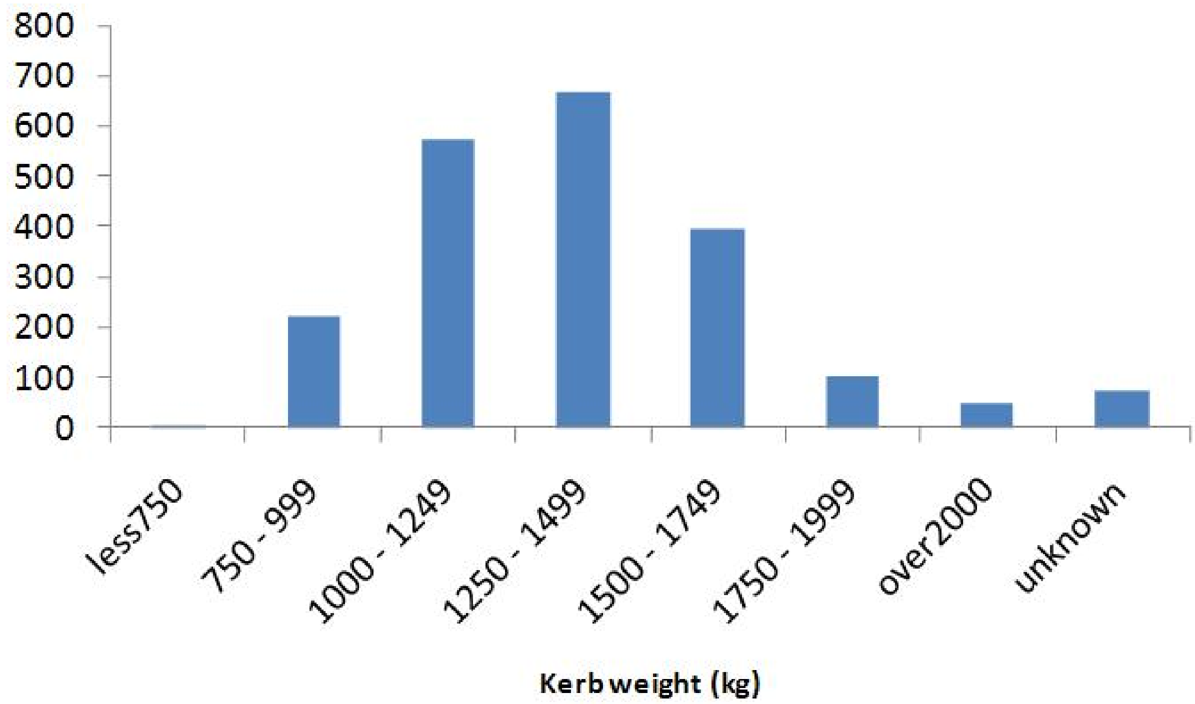


Figure 6.21: Total numbers of vehicles (n = 2097) by kerb weights.

Figure 6.22 presents the linear mass ratio for the reduced sample to crashes between two passenger cars with known injury severities MAIS 2+ and belted occupants on VEHICLE LEVEL (n = 50). This mass ratio was calculated by the division of opponent's and one's kerb weight. That is, when the mass ratio is greater than 1, the opponent car is heavier. Most frequent were crashes with the mass ratios between 0.9 and 1.29 which accounted for approximately half of all cases.

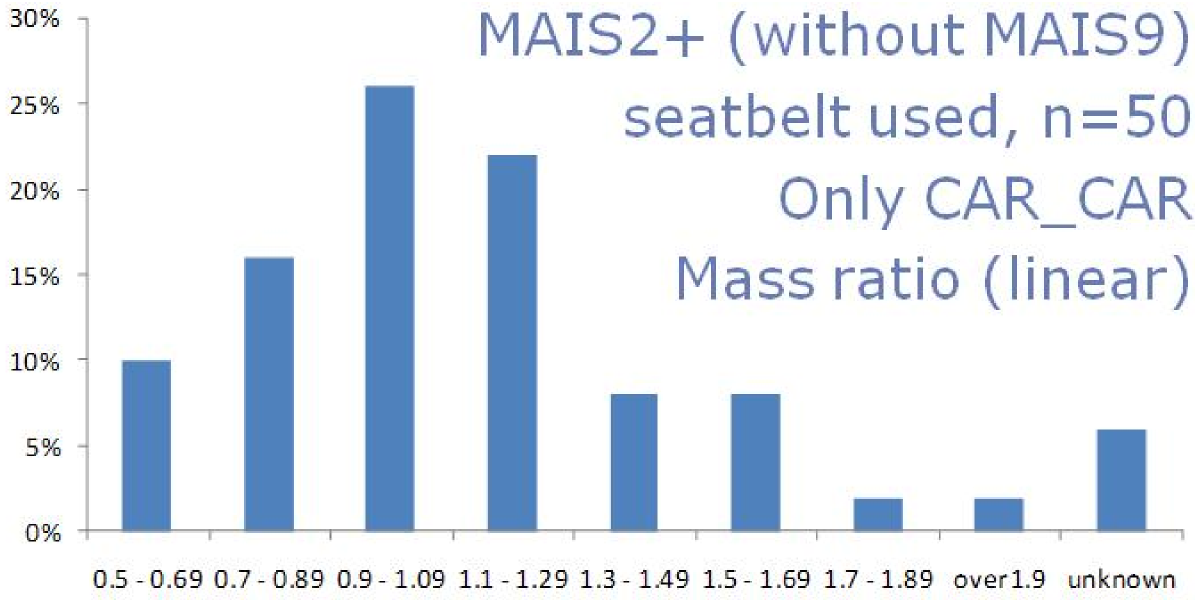


Figure 6.22: Linear mass ratio.

6.4.6 Injury Mechanisms

As a further part of the collision analysis injury mechanisms were identified in the GIDAS sample based on six specific categories that describe possible contact partners which might contribute to severe injuries in time of the crash.

The categories ('Restraint', 'Contact w/o intrusion', 'Contact w intrusion', 'Non-contact', 'Unknown causation of contact', 'Other object') are explained more in detail in Table 13.

Table 13: Explanation of injury mechanisms categories

Category	Explanation and examples
'Restraint'	Restraint system *E.g.: airbags, seat belt (webbing, buckle...), headrest. The categorisation as restraint injury does not imply that there was something wrong with the restraint system or that injury severity would be reduced without the restraint system.*
'Contact No Intrusion'	All parts and items inside the car (no 'Restraint' parts) that are normally fixed. No intrusion to the occupant compartment *E.g.: steering wheel, radio, section of sunroof, air vents, dashboard, pedals, glass between pillars...*
'Contact Intrusion'	All parts and items inside the car (no 'Restraint' parts) that are normally fixed. Intrusion to the occupant compartment
'Non-contact'	Own actions (*e.g. bit tongue*) or body motions, Rescue measures Fire
'Unknown causation'	Unknown
'Other object'	All remaining parts and items inside the car and from outside (no 'Restraint', 'Contact No Intrusion', 'Contact Intrusion' parts). *E.g.: interaction between passengers, ejected, collision partner, crash barrier, road surface, front spoiler...*

A specific analysis is shown in Figure 6.23 on OCCUPANT LEVEL (n = 141) to discover injury causing effects of intruding car parts or items, the restraint system, other objects and other causations within all collision partner groups. This chart considers belted MAIS 2+ survived occupants. Within this sample the single most severe injuries (AIS 2+) by body region were investigated in order to identify their coded main causation and assigned to the six categories. If a person sustained several injuries with the same highest AIS value in the same body region, one injury was chosen by choice. It could be identified that only few injuries were caused by contact with intruding parts (12%), but more than 40% of these injuries were caused by both the restraint system and normally fixed car-internal parts. Of course, in case of unknown causation these numbers could increase slightly.

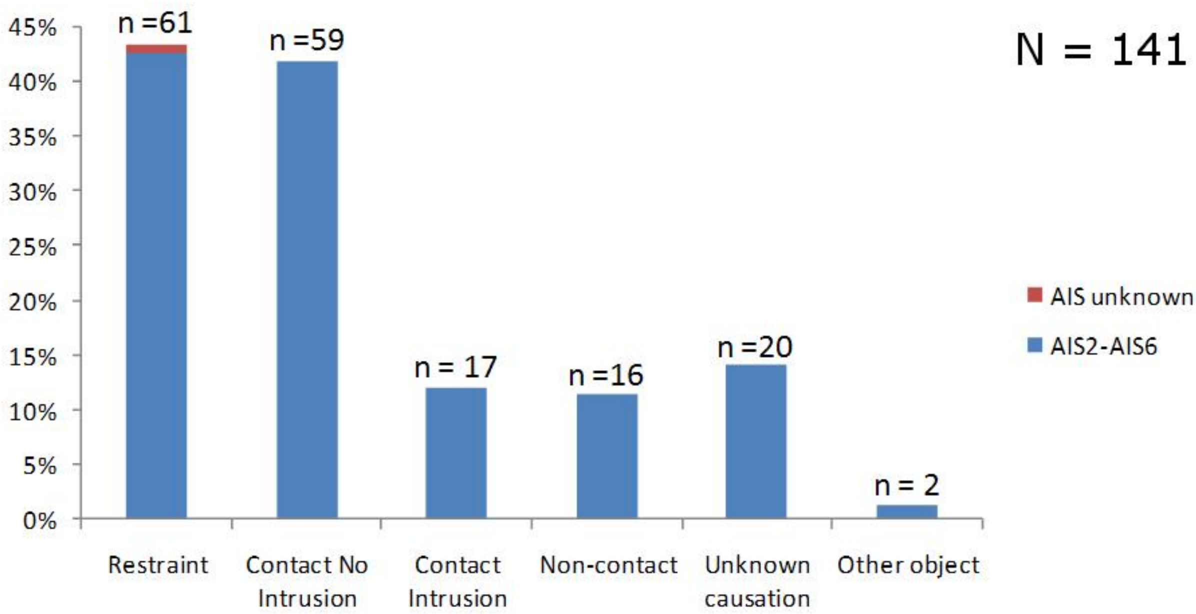


Figure 6.23: Injury mechanisms

The same dataset was used to show the differing proportions (see Figure 6.25) for the frontal overlap reduced by one case due to missing information. Each frontal overlap group is 100% (and hence all times n = 140) which means these groups can be compared with each other. For each of these groups the causations of the injuries are shown in the classification of AIS 2 - AIS 6 in percentage. The remaining percentages (not shown in Figure 6.25) per combination could be assigned to AIS 0 - AIS 1. Only within the combination overlap of '25% - 49%' and injury causation 'Restraint' 4% of the AIS data was unknown and is also not shown in Figure 6.25. It could be seen that the proportions of injuries caused by 'Restraint' increased with higher overlap and that injuries caused by 'Contact intrusion' decreased with higher overlap.

The analysis in section 6.4.4 and in particular the results of Table 12 identified that approximately 23% (n = 33) of the MAIS 2+ casualties (n = 141) could be allocated to crashes with low external overlap. This low number of low external overlap cases (n = 33) is analysed for the injury causation in Figure 6.24. Again, serious injuries (AIS 2 - AIS 6) caused by 'Restraint' could be identified as most frequently occurring injuries.

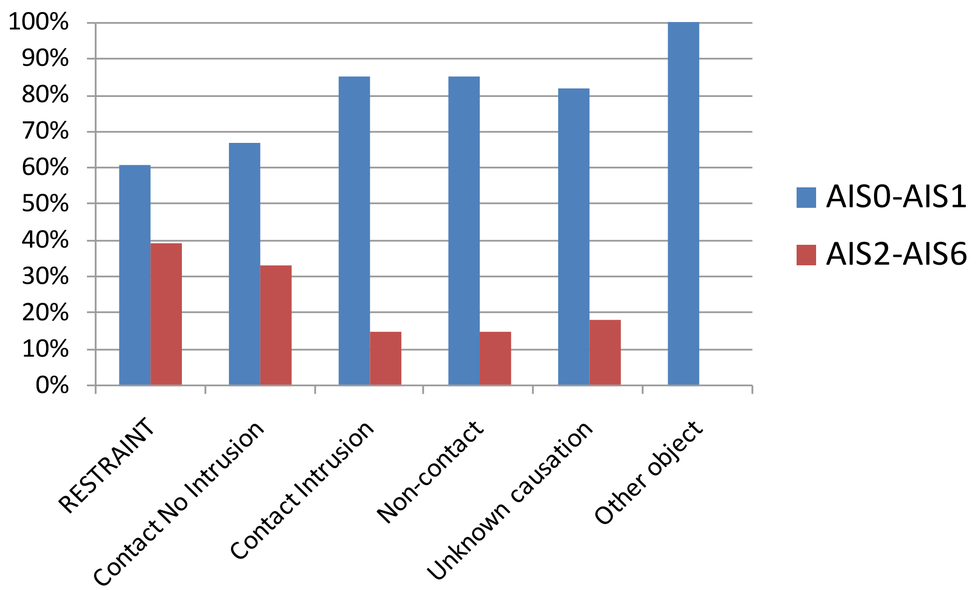


Figure 6.24: Injury causations in low external overlap cases.

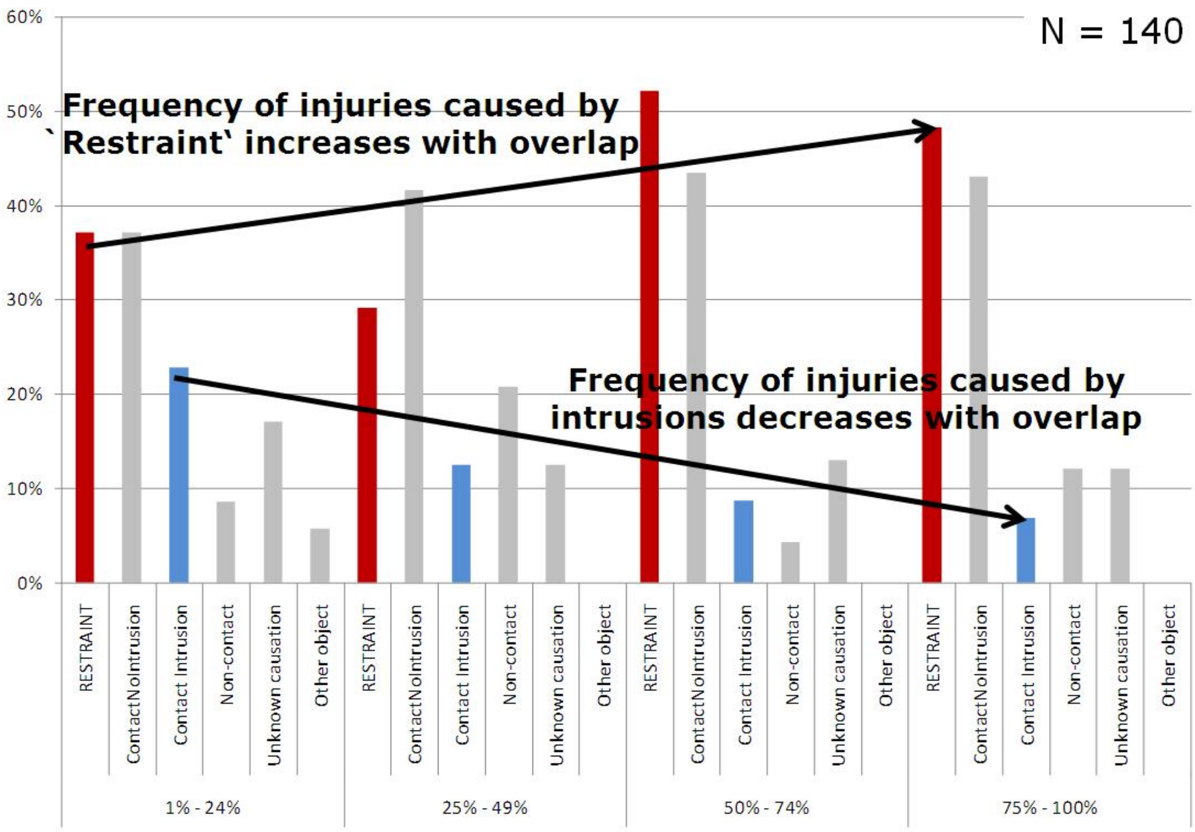


Figure 6.25: Proportions of AIS 2+ injuries by frontal overlap groups for crashes CAR_CAR (each combination of frontal overlap and injury causation group represents 100% - missing percentages are assigned to AIS0, AIS 1 and unknown injury severity).

6.4.7 Acceleration Loading

This section investigates the acceleration loading to the occupants for different core parameters and the restriction to serious injuries (MAIS 2+ injured, survived people) independent on their injury causations as in the previous sections. It is important to mention that due to the created injury causation groups the acceleration issues were exclusively referred to 'Restraint'. The AIS levels shown in this section refer to these acceleration caused injuries. Further injuries or causations were not considered detailed in this section. The following paragraphs are on INJURY LEVEL. If no injury of an occupant was assigned to the 'Restraint' group, AIS 0 was assigned.

6.4.7.1 Frontal Overlap

Focussing on the injured individuals with known frontal overlap (n = 140) led to the distributions demonstrated in Figure 6.26. Each column represents one frontal overlap group that summarise the respective cases to 100%. With the help of this chart serious injuries caused by 'Restraint' could be identified to occur more often in cases of higher overlap (>50%). Again, a frontal overlap of 50% could either be beginning on a side of the car or could be centred in the front or something in between.

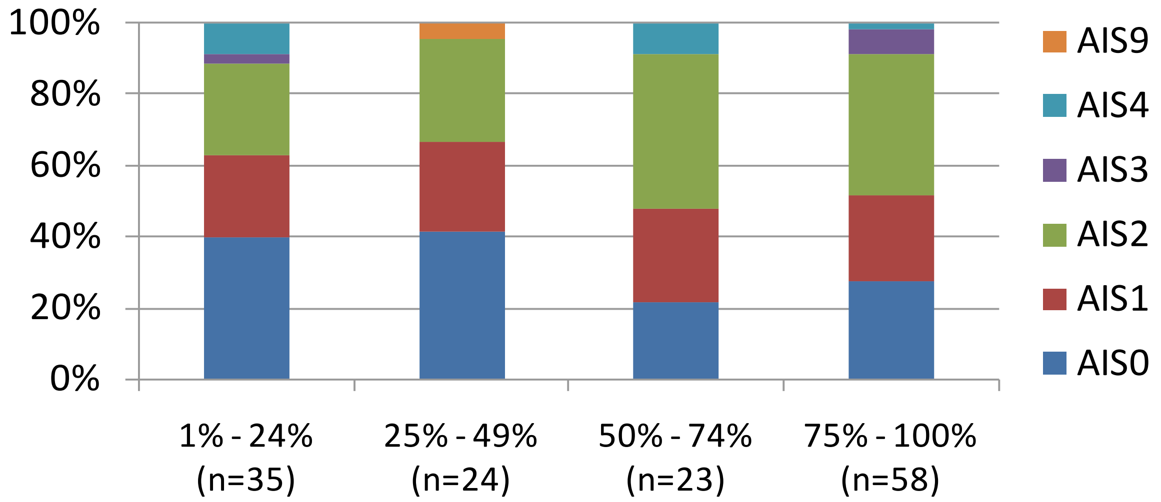


Figure 6.26: Injuries caused by 'restraint' by frontal overlap (AIS 0: other injury causation group).

6.4.7.2 Collision Partner

A further analysis parameter is the kind of collision opponent. Figure 6.27 shows the proportions of the acceleration loading caused injuries by each group (each 100%). Serious injuries (AIS 2+) due to 'Restraint' were most frequent in collisions between two passenger cars and cars against heavy good vehicles.

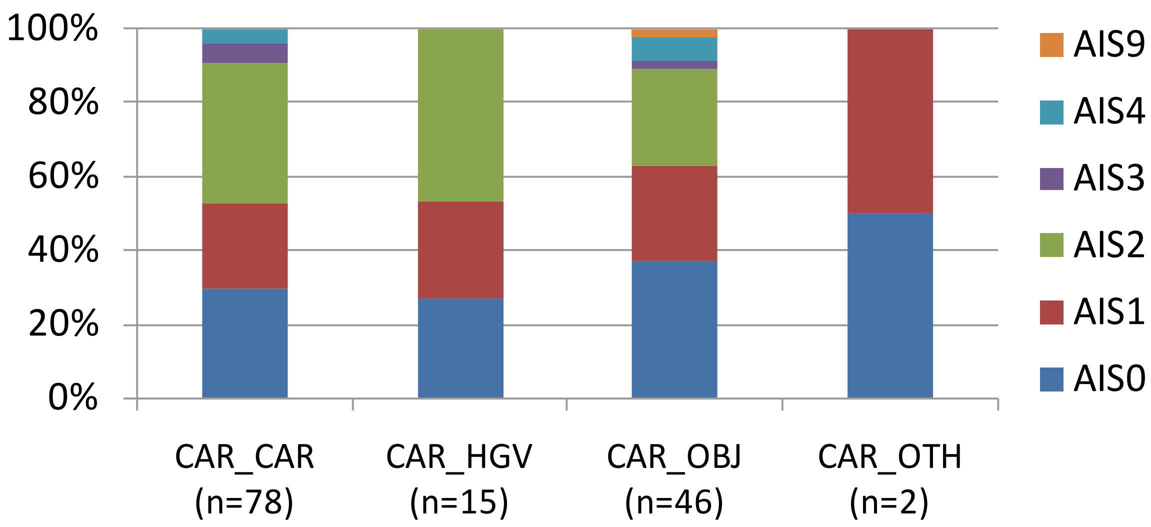


Figure 6.27: Injuries caused by 'restraint' by collision partner groups (n = 141) (AIS 0: other injury causation group).

6.4.7.3 Mass Ratio

The kerb weight ratios of the vehicles are shown in Figure 6.28 whereby each column is 100%. Because of the fact that this value could only be calculated for crashes between one passenger vehicle and another vehicle the total number of used (known) mass ratios was n = 76. Serious injuries due to 'Restraint' were more frequent in cases when the opponent car is heavier.

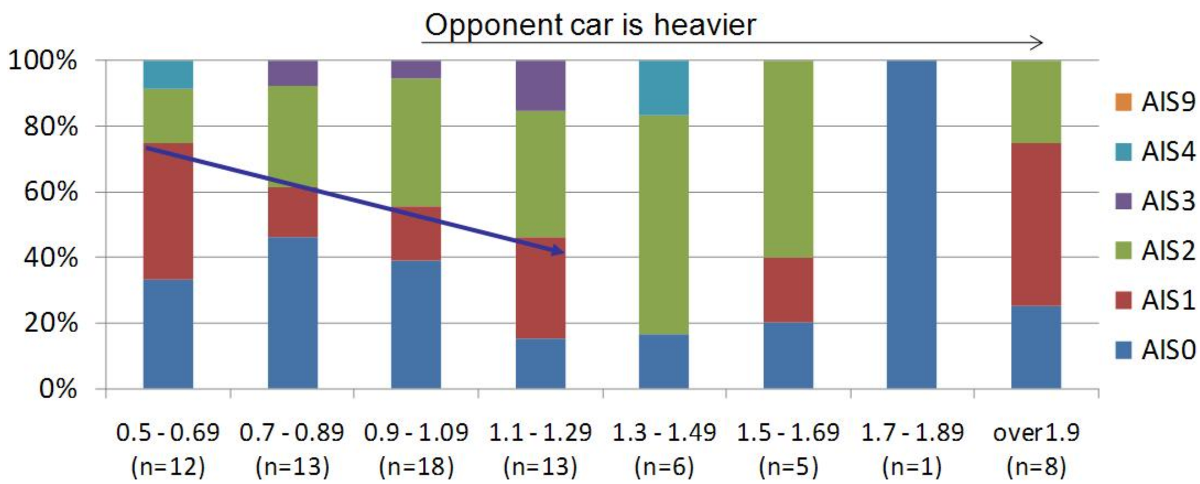


Figure 6.28: Injuries caused by 'restraint' by mass ratios (n = 76) (AIS0: other injury causation group).

6.4.7.4 Age Groups

The age was known of all concerned people (n = 141) and classified into the five groups already used in Chapter 6.2. In this analysis no clear trend could be identified for serious injuries due to 'Restraint' as can be seen in Figure 6.29.

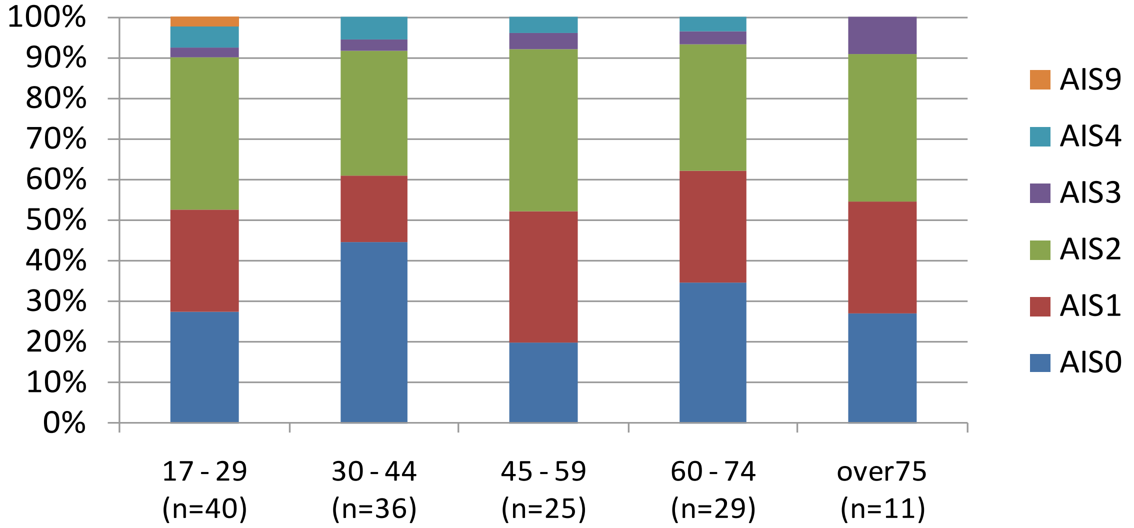


Figure 6.29: Injuries caused by 'restraint' by age groups (n=141) (AIS0: other injury causation group).

6.4.7.5 Gender / Seating Position

As introduced in Section 6.2 the gender might be a meaningful parameter and is shown together with the seating positions in Figure 6.30. In general, serious injuries (AIS 2+) due to 'Restraint' showed higher proportions for women than men. Having a look at their seating position led to the finding that serious injuries due to 'Restraint' are linked with slightly higher proportions for front passengers than drivers. This could also be analysed in combination with the gender but this would decrease the dataset too much and therefore no numbers are presented.

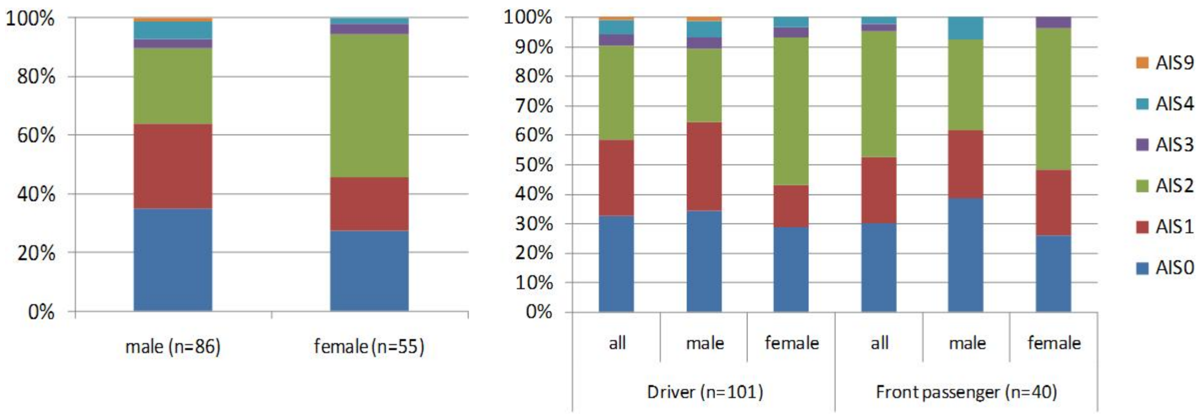


Figure 6.30: Injuries caused by 'restraint' by gender and seating position (AIS 0: other injury causation group).

6.4.7.6 Stature

The same dataset was used to make an analysis about the body stature. The number of cases is reduced to n = 103 (see Figure 6.31) since the information was not always available. Each column represents one stature group (each is 100%). Serious injuries (AIS 2+) due to 'Restraint' revealed higher proportions for smaller people (under 170 cm). In contrast, when 'Restraint' injuries occurred in taller occupants the injuries tended to be more severe.

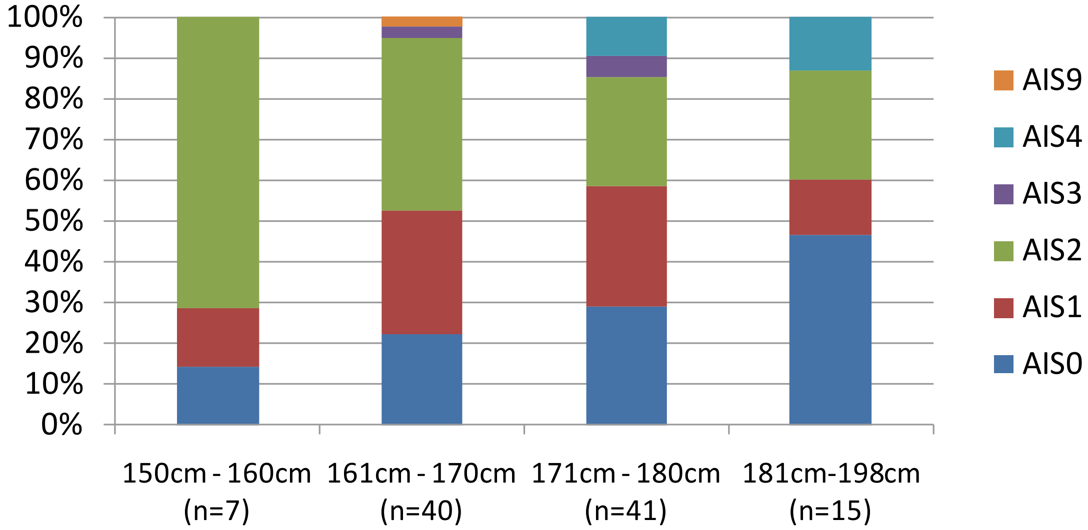


Figure 6.31: Injuries caused by 'restraint' by stature (AIS 0: other injury causation group).

6.4.7.7 Body Weight

Another parameter analysed was the body weight which could be used in n = 104 cases and is shown in Figure 6.32. The weight was classified into 6 categories. No clear trend could be identified for serious injuries due to 'Restraint'.

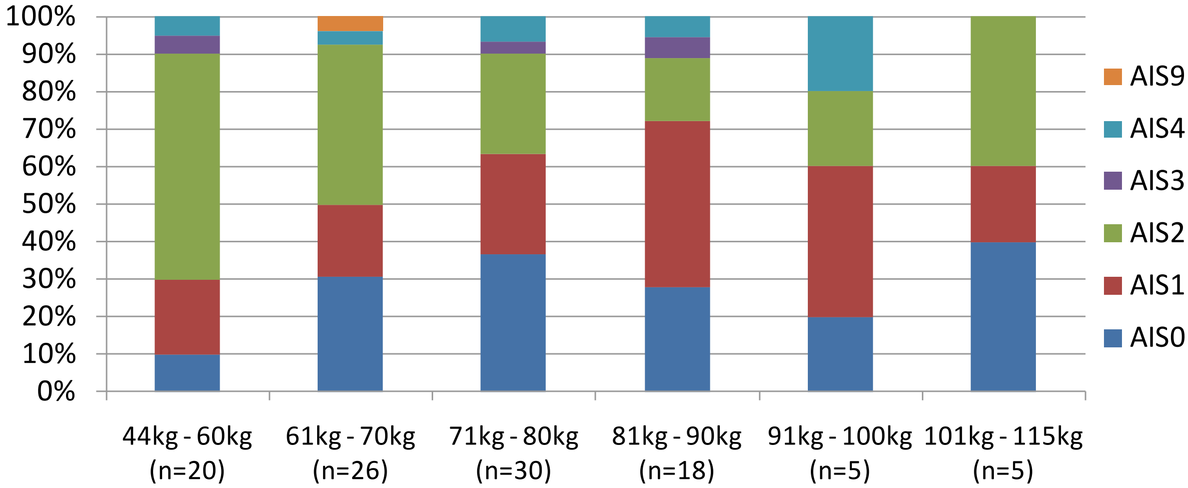


Figure 6.32: Injuries caused by 'restraint' by body weight (AIS 0: other injury causation group).

6.5 Conclusions GIDAS Analysis

The analyses often considered the collision partner groups (see Table 7). Most frequent collisions occurred between two passenger cars (CAR_CAR), followed by crashes of cars with others (CAR_OTH) and objects (CAR_OBJ). In contrast, the highest probability for an occupant to sustain severe injuries or even to die was for passenger car crashes against objects (CAR_OBJ) or heavy good vehicles (CAR_HGV). Most crashes occurred with an EES below 50 km/h.

Stability loss of a-pillar, bulkhead or dashboard could be identified in about 10% of all crashes between passenger cars and heavy good vehicles (CAR_HGV) and 5% in collisions of cars against objects (CAR_OBJ). Regarding all frontal crashes between two passenger cars (CAR_CAR) about 2% showed stability losses, increasing to 10% when focusing on accidents with a high injury severity outcome.

The injury frequencies and probability of occupants rose with high overlap (> 75%) likely due to acceleration and in contrast, by small overlap (< 25%) likely due to intrusion. This higher injury risk in crashes with low and full overlaps could be assigned to all collision groups. Table 14 shows some noticeable issues related to overlap.

Table 14: Noticeable issues on injury frequencies and risks

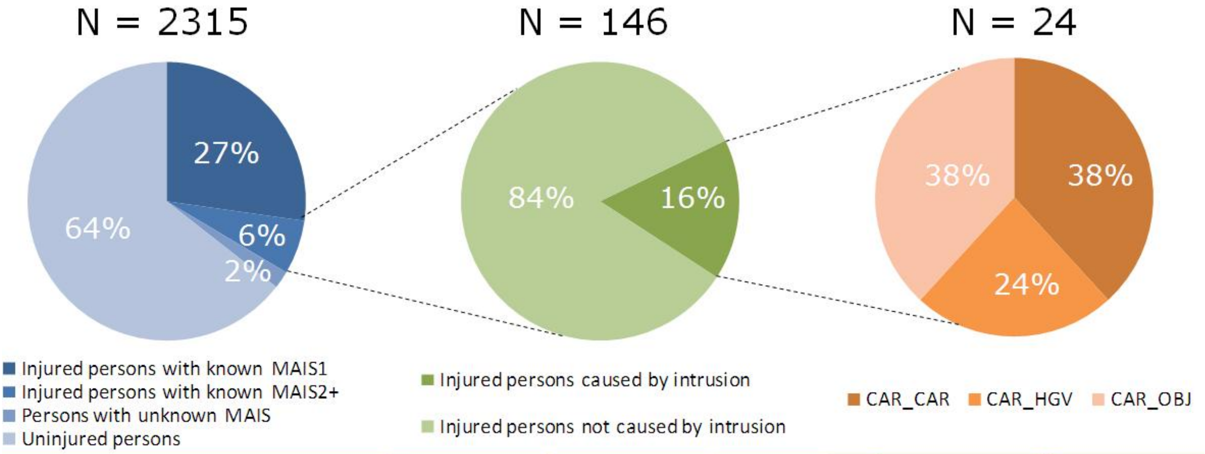
Collision partner group	Noticeable issues
'CAR_CAR'	• High injury risk in crashes with full overlap • Few cases of deformed a-pillars, bulkheads and dashboards
'CAR_OBJ'	• Frequent collisions with low overlap and not activated main load paths • Severe injuries caused by high deceleration (also in collisions without compartment intrusions)

Poor structural interaction was observed in low overlap crashes of passenger cars against another passenger car (CAR_CAR) or against an object (CAR_OBJ), as well as in collisions of a car and a heavy good vehicle (CAR_HGV).

If there was a severe frontal crash, passenger car occupants sustained most frequent injuries on their thorax and head. These injuries were often related to acceleration issues (e.g. restraint systems) and just few to intrusions.

Figure 6.33 shows the GIDAS sample on OCCUPANT LEVEL restricted to belted people (n = 2315). Extracting the injured people with known MAIS 2+ led finally to 146 people. 16% of these MAIS 2+ injured people sustained serious injuries that were mainly caused by intruding parts. The third circle diagram in Figure 6.33 bases on these crashes including injured occupants who sustained injuries caused by intrusion into the car, classified by the collision partner groups (n = 24).

The table within Figure 6.33 represents the first and second circle diagram and shows the percentages of the collision partner groups based on the injured people with known MAIS 2+ injury level.



FREQUENCIES	CAR_CAR	CAR_HGV	CAR_OBJ	CAR_OTH	Total N
Known MAIS2+, seat belted	55%	12%	32%	1%	146
Injured persons caused by intrusion	38%	24%	38%	0	24

Figure 6.33: Overview on seat belted, injured people caused by intrusions.

Furthermore, CAR_CAR crashes showed a higher injury frequency of MAIS 1 compared to collisions of type CAR_OBJ. In contrast injuries with MAIS 2 and MAIS 3 could be more frequently assigned to crashes of type CAR_OBJ than to car-to-car (CAR_CAR).

Additionally, some further occupant characteristics could be identified. Higher injury risks could be detected for female (especially AIS 1 and AIS 2 injuries), for elderly people and for front seat passengers.

Additionally, serious injuries (AIS 2+) due to acceleration loading (here restricted to causation group 'Restraint') could be identified with higher proportions in:

- Crashes with higher frontal overlap (>50%),
- Collisions CAR_CAR and CAR_HGV,
- Cases when the opponent vehicle is heavier and in
- Cases of smaller people.

7 EUROPEAN ACCIDENT ANALYSIS

The original analysis of frontal impacts in the PENDANT was restricted by decisions taken by the consortium in the first months of the project. Although PENDANT contains about 150 frontal impacts, very few of them comply with the selection criteria of UNECE R94 compliant vehicles. As a result there were only 5 cases that were possible for detailed analysis. Of these, some cases were already included in the CCIS analysis. However, the overall analysis of PENDANT database gives additional input to FIMCAR and is summarised below.

The PENDANT database was quickly analysed to provide impact data that was not dependent on the vehicle age. The following analyses do not account for impact severity or injury outcomes and provide a reference for all types of frontal impacts.

The overlap of frontal impacts (all impact types) was reviewed to provide information important for the test configuration. In Figure 7.1, the PENDANT researchers reported that about 50% of frontal impacts had an overlap of 50% or less.

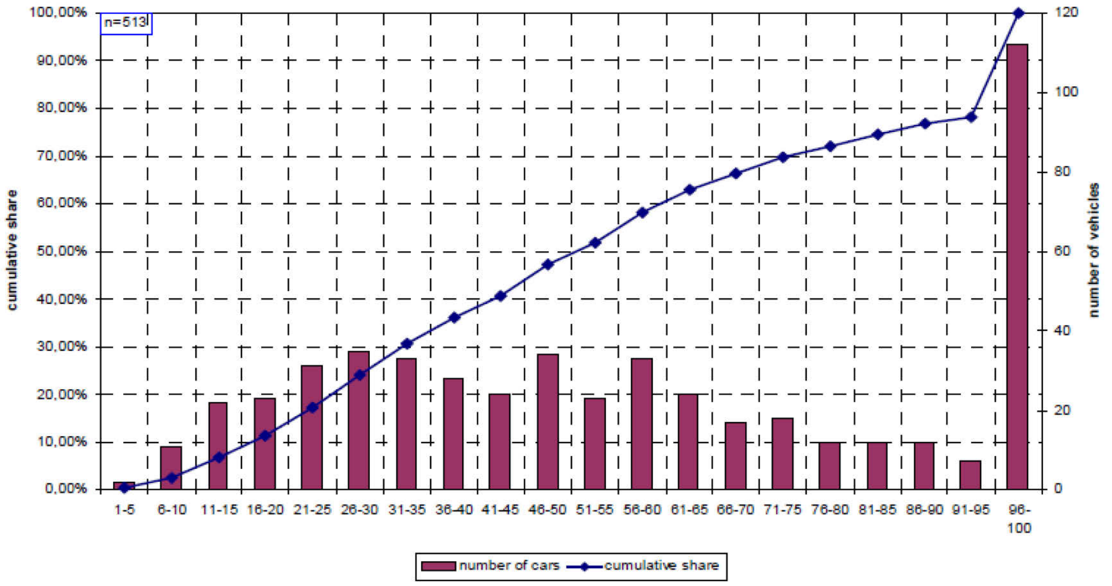


Figure 7.1: Vehicle overlap as reported by PENDANT consortium.

Further analyses of the car-to-car frontal impacts that were present together with their accident reconstructions results were conducted within FIMCAR. This provided a dataset of 166 vehicles spanning all model years.

Figure 7.2 shows how frontal crashes can be grouped into PDOF and impact severity using calculated delta-v. The figure shows that impacts with low delta-v (< 30 km/h) are most often angled impacts (11 o'clock) higher delta-v collisions are most frequently straight-on frontal impacts.

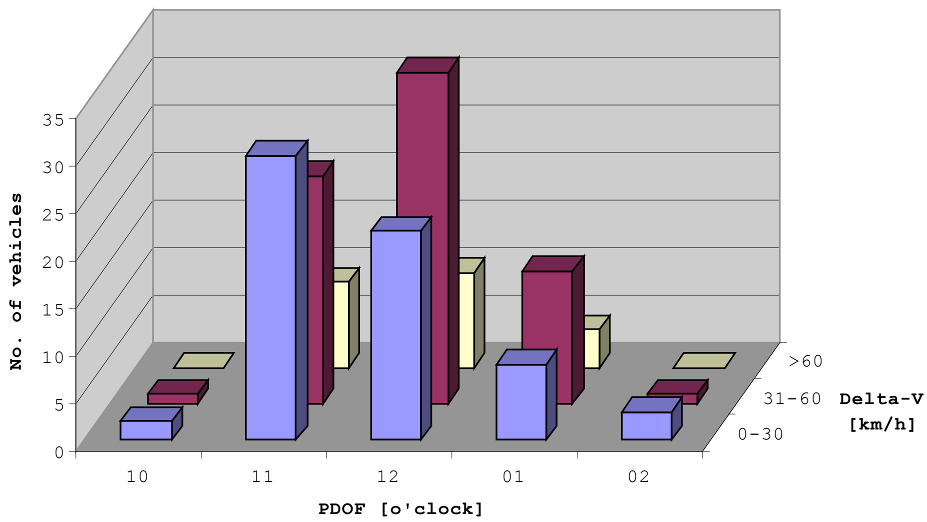


Figure 7.2: Principal direction of force in different delta-v intervals (n = 166). Compensated for right hand driven cars.

Figure 7.3 shows how often a certain horizontal overlap occur for different delta-v intervals. Because of the reasonable symmetry in the front structure of cars, left and right are combined for the different horizontal locations in terms of driver side impacts.

In general one can see that the horizontal location of the impact and the PDOF share similar characteristics. More central impacts and straight-on (12 o'clock) impacts are common for higher severities (delta-v > 60 km/h). At lower speeds, the distribution of horizontal location is more to the left and is consistent with the large number of 11 o'clock impact directions. This is an expected result for left turning conflicts.

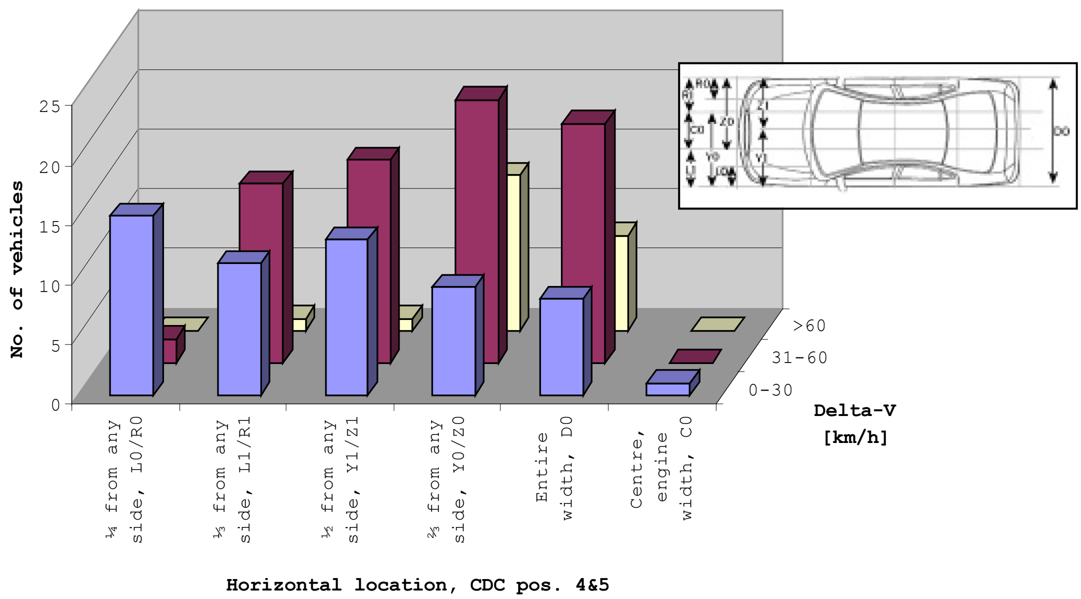


Figure 7.3: Horizontal location of direct contact for different delta-v intervals (n = 156). Only impacts with CDC3="front".

8 DISCUSSION

As detailed in Section 4, the accident sampling procedures for the GB CCIS and German GIDAS databases are different. The CCIS sampling procedure is biased towards accidents containing fatal and seriously injured (MAIS 2+ survived) occupants whereas the GIDAS procedure samples accidents involving personal injury to be representative of the national data. The result of this is that the CCIS database contains a greater number of accidents with fatal and seriously injured occupants relevant to this study than the GIDAS database (Table 15).

Table 15: Size of CCIS and GIDAS data samples for study. Note: selection criteria: Regulation 94 compliant (or equivalent) car involved in frontal impact.

Database	Fatal	MAIS 2+ survived (Seriously injured)	MAIS 1 (Slightly injured)
CCIS	83	466	1236
GIDAS	16	156	701

Hence, the approach followed for the study was to focus on the analysis of the CCIS database because the results were more statistically significant due to the larger number of relevant cases. Following this, where possible, a comparison of the results of the CCIS and GIDAS analyses was made to check the relevance of the conclusions of the CCIS analysis (effectively for GB) to Germany and identify any differences.

The following key similarities / differences were found:

- Characteristics of data set

  Injury distribution by overlap

  Both the CCIS and GIDAS data show that a high proportion of fatal and MAIS 2+ survived occupants were in crashes with a high frontal overlap (> 75%) (Figure 8.1). However, the GIDAS data for all impacts also shows a slighter higher proportion of fatal and MAIS 2+ survived in lower overlap impacts (< 25%) whereas the CCIS data does not. It is believed that the main reason for this difference is that the GIDAS data includes impacts with narrow objects (e.g. trees and poles), of which there are many in Germany, in the '1 - 24%' overlap category. In contrast the CCIS data includes impacts with narrow objects, of which there are not so many in GB, in a '0' overlap category. Comparison of the injury distribution by overlap for GIDAS car-to-car impacts (Figure 8.2) shows a more similar distribution to the complete CCIS data set.

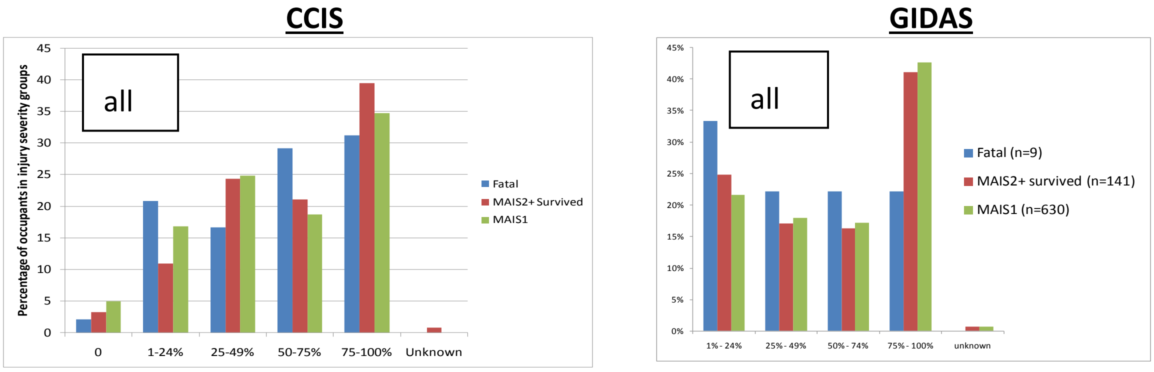


Figure 8.1: Comparison of injury distribution by overlap (belted occupants) for CCIS (left) and GIDAS (right) accident data samples.

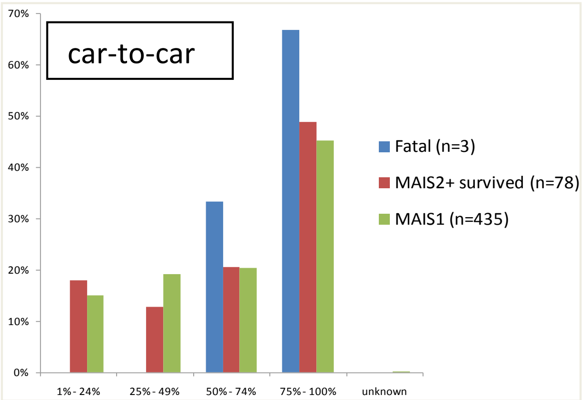
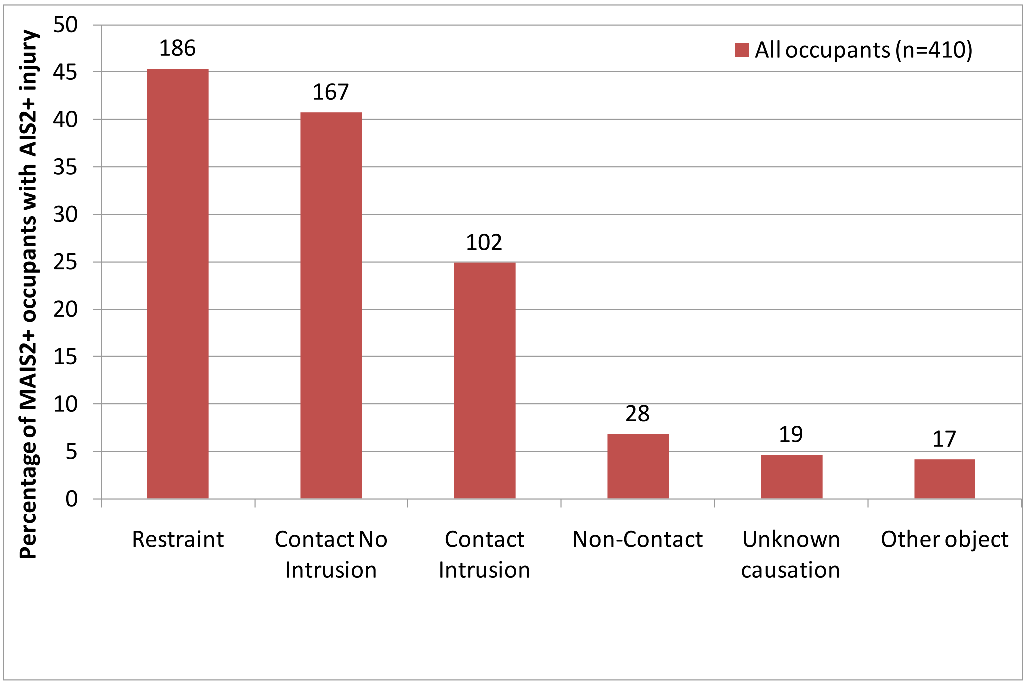


Figure 8.2: Injury distribution by overlap (belted occupants in car-to-car accidents) for GIDAS accident data sample.

- Compartment strength - intrusion
  <u>Injury causation</u>

  For MAIS 2+ injured occupants the proportion of occupants with AIS 2+ injuries caused by contact with intrusion is greater for the CCIS analyses than for the GIDAS analyses (CCIS 25%, GIDAS 12%) (Figure 8.3). Although both studies give different results (which could be caused by the different way of coding of intrusion) both datasets indicate that the compartment strength issue is important in terms of MAIS 2+ injured occupants.



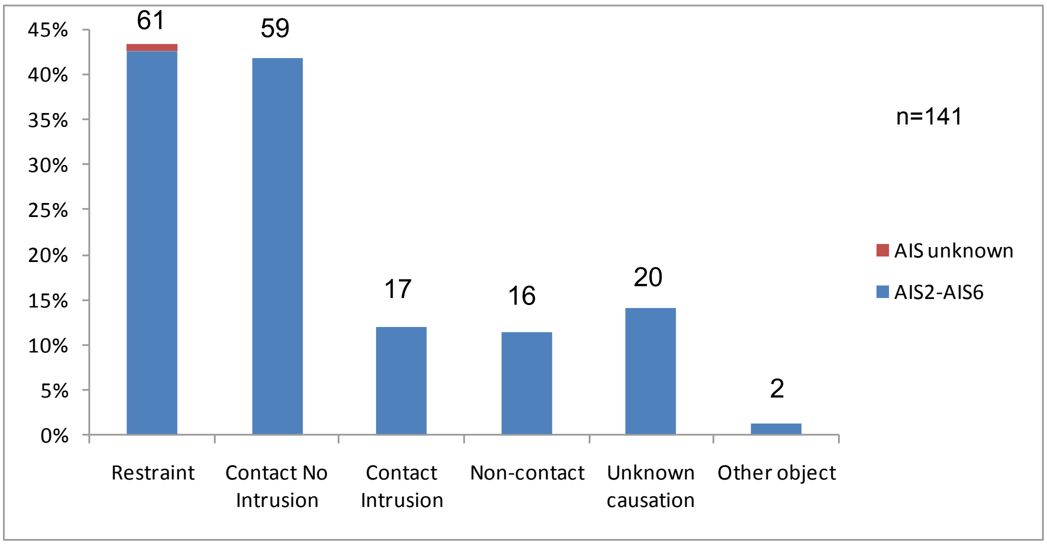


Figure 8.3: Comparison of injury causation for MAIS 2+ injured casualties for CCIS (top) and GIDAS (bottom) accident data samples.

- Injury patterns

  Injury distribution by body region

  For MAIS 2+ injured occupants, for both the CCIS and GIDAS analyses, the thorax is the most frequently injured body region at the AIS 2+ level. However, for the GIDAS analysis the head is almost at the same level as the thorax whereas for the CCIS analysis it is substantially lower. It has not been possible to determine a reason for this difference. AIS 2+ injuries are also frequently sustained to the legs and arms.

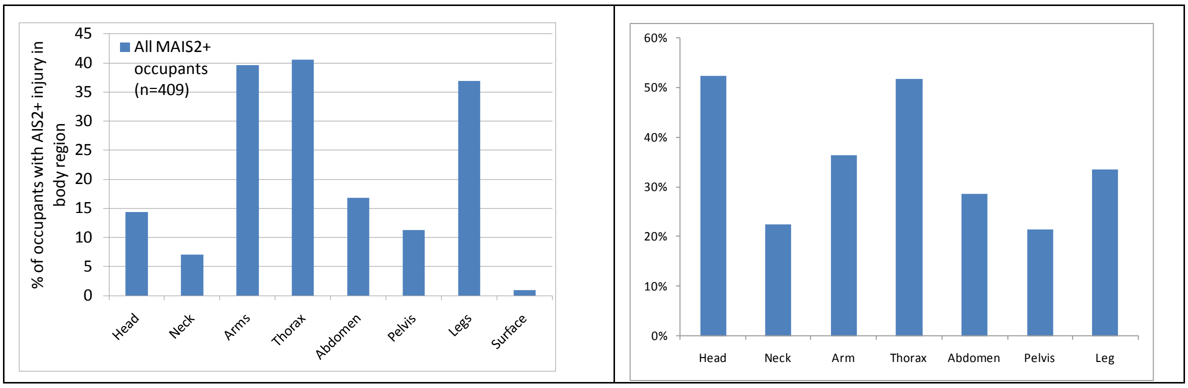


Figure 8.4: Comparison of AIS 2+ body injury distribution for MAIS 2+ injured occupants for CCIS (left) and GIDAS (right) analyses.

9 SUMMARY OF CONCLUSIONS

The main data sources for this report were the CCIS and Stats 19 databases from Great Britain and the GIDAS database from Germany. The different sampling and reporting schemes for the detailed databases (CCIS & GIDAS) sometimes do not allow for direct comparisons of the results. However the databases are complementary – CCIS captures more severe collisions highlighting structure and injury issues while GIDAS provides detailed data for a broader range of crash severities. The following results represent the critical points for further development of test procedures in FIMCAR.

9.1 Compatibility Issues

Poor structural interaction has been observed to be a problem in the current vehicle fleet. The dominant structural interaction problems in car-to-car impacts are over/underriding of car fronts and low overlap. However, fork effect is seen more in car-to-object impacts because of impacts with narrow objects.

In CCIS structural interaction problems were identified in 40% of fatal and 36% of MAIS 2+ injured cases. However, it is only in cases where there was intrusion present (25% of fatal and 12% of MAIS 2+ cases) that it can be said definitely that improved structural interaction would have improved the safety performance of the car. This is because in cases with intrusion improved structural interaction will increase the energy absorption capability of the car's front-end and thus reduce the intrusion. This, in turn, will help decrease the casualty's injuries caused by contact with intrusion. In cases without intrusion improved structural interaction will change the shape of the compartment deceleration pulse which may or may not help decrease the casualty's injuries depending on the response of the restraint system.

In GIDAS poor structural interaction could mostly be observed in low overlap crashes against objects / cars and in collisions with HGV.

It should be noted that in 23% of the CCIS fatal cases the accident severity was so high that it was not possible to determine whether or not a compatibility issue had occurred.

Frontal force and/or compartment strength mismatch issues between cars in the current fleet appear[6] to be less of an issue than poor structural interaction.

In CCIS, for all accidents, force and/or compartment strength mismatch problems were identified for 8% of fatal and 2% MAIS 2+ survived occupants in CCIS. However, it should be noted that force and/or compartment strength mismatch problems can only be objectively identified for accidents in which there is compartment intrusion into the vehicle.

For car-to-car impacts force and/or compartment strength mismatch problems identified for 9% of fatal and 3% MAIS 2+ survived occupants.

Compartment strength of vehicles is still an issue in the current vehicle fleet.

- Occupants with injuries caused by contact with intrusion CCIS 25%, GIDAS 12% of MAIS 2+ injured occupants.

[6] Note: structural interaction problems could be masking frontal force mismatch problems

  - When an occupant sustains an injury caused by 'contact with intrusion' in the majority of cases it is the most severe injury, often a leg or thorax injury but sometimes a head or arm injury.
- In a matched pair analysis of car-to-car impacts from CCIS, a relationship was found between mass ratio and driver injury severity, namely the higher the mass ratio the higher the driver injury severity. However, no such relationship was found between mass ratio and intrusion. The implications of this are that intrusion (and hence compartment strength) is not the major contributory factor to more severe injuries in the lighter car in a car-to-car impact. However, it should be noted that the data sample used for this analysis was relatively small and hence confidence in this result is limited. In addition the result may have been confounded by the age of the vehicle (newer vehicles generally have better compartment integrity) and the age of the occupant.
- Compartment strength is a particular problem in collisions with HGVs and objects, with these collisions having a high proportion of fatal and MAIS 2+ injuries
  - In CCIS, 31% of car-HGV cases resulted in intrusion in the car, compared to 25% for car-to-car cases
  - In GIDAS, 20% of car-HGV cases had MAIS 2+ injury severity for the car occupant, compared with 7% for car-to-car cases

9.2 Injury patterns

- AIS 2+ injuries to the thorax are the most prevalent. AIS 2+ injuries are also frequently sustained by the head, legs and arms.
  - Over 80% of fatally injured occupants and 35% of MAIS 2+ survived occupants sustained AIS 2+ thorax injuries in CCIS
- AIS 2+ injuries resulting related to the restraint system (i.e. those caused by loading of the occupant by the seatbelt or airbag to decelerate him and prevent greater injury by contact with other car interior structures) are present in a significant proportion of frontal crashes, regardless of whether intrusion was present or not.
  - Over 40% MAIS 2+ occupants sustained AIS 2+ injury attributed to restraint loading in both CCIS and GIDAS datasets.
- Analysis of injury mechanisms in CCIS found that 45% of MAIS 2+ injured occupants had an AIS 2+ injury related to the 'restraint system', 40% had an AIS 2+ injury caused by 'contact with no intrusion' and 25% had an AIS 2+ injury caused by 'contact with intrusion' In the majority of cases these injuries were the most serious injuries that the occupant had.
  - When the most severe injury was related to the 'restraint system' the injury was mainly to the thorax (62%) with some to the arms (21%) (clavicle fractures).
  - When the most severe injury was related to the 'contact no intrusion' the injury was mainly to the legs (42%) with some to the arms (30%) (clavicle fractures) and thorax (12%).
  - When the most severe injury was related to the 'contact with intrusion' the injury was mainly to the legs (46%) and thorax (30%).
- For accidents for which there is intrusion, for MAIS 2+ injured occupants AIS 2+ injuries to the legs are the most prevalent

    - Where intrusion was present about 70% MAIS 2+ occupants sustained AIS 2+ leg injuries in CCIS
    - Note: about 40% sustained AIS 2+ thorax injuries
- AIS 2+ injuries resulting from contact with the intrusion occur in a large proportion of cases where compartment intrusion is present
    - 65% of MAIS 2+ occupants in cars with intrusion sustained AIS 2+ injury attributed to contact with intrusion (CCIS)
- High proportion of fatal and MAIS 2+ injuries in cases with high overlap (>75%)
    - In GIDAS, 41% of MAIS 2+ survived were in high overlap cases
    - In CCIS, 40% of MAIS 2+ survived and 31% of fatal occupants were in crashes with high overlap
- GIDAS analysis showed that the proportion of MAIS 2+ injuries due to acceleration loading (i.e. injuries related to the restraint system caused by loading of the occupant by the seatbelt or airbag to decelerate him and prevent greater injuries by contact with other car interior structures) increased for higher overlap cases, whilst proportion of MAIS 2+ injuries due to contact with intrusion increased for lower overlap cases
    - In GIDAS 25% of MAIS 2+ survived were in low overlap cases indicating possible issues with low overlap and/or narrow object impacts. However, much lower percentages were seen in car-to-car impacts and CCIS data.
- Greater proportion of fatal and MAIS 2+ injuries for elderly occupants compared with other age groups
    - In CCIS dataset, occupants over 60 years old represent 18% of injured occupants, however account for 52% of fatalities and 25% of MAIS 2+ survived occupants
- In GIDAS, serious injuries (AIS 2+) due to acceleration loading (restraints) could be identified to occur more often for women than men and are linked with slightly higher proportions for front passengers than drivers.

10 ACKNOWLEDGEMENTS

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11 REFERENCES

[Baghat 2009] Baghat, A.; Francis, L.; Kilbay, P.; Noble, B.; Tranter, M.; Wilson, D.; Waite, C.; Xu, Y.: "*Reported Road Casualties Great Britain: 2008 Annual Report".* https://www.gov.uk/government/organisations/department-for-transport 2009.

[Carroll 2009/1] Carroll, J.; Cuerden, R.; Richards, D.; Smith, S.; Cookson, R.; Hynd, D.; Adolph, T.; Eggers, A.; Pastor, C.; Chauvel, C.; Labrousse, M.: "*Matrix of serious thorax injuries by occupant characteristics, impact conditions and restraint type and identification of the important injury mechanisms to be considered in THORAX and THOMO; Consisting of one main summary report and three annexes".* http://www.biomechanics-coordination.eu/downloadables/Deliverables/COVER-D05-Annex%20I%20TRL-FINAL-Matrix%20of%20serious%20thorax%20injuries-24March2010.pdf. Paper Number: 218740 2009.

[Carroll 2009/2] Carroll, J.; Adolph, T.; Eggers, A.; Hynd, D.; Trosseille, X.; Smith, S.: "*A comparison between crash test results and real-world accident outcomes in terms of injury mechanisms and occupant characteristics".* http://www.thorax-project.eu/downloadables/Public%20Deliverables/THORAX%20-%20D1.1%20-%20FINAL-Differences%20between%20accidents%20and%20crash%20test%20results-11-11-2009.pdf. Paper Number: 218516 2009.

[Chauvel 2009] Chauvel, C.: "*French accident data Self-Protection and Partner-Protection involving new vehicles".* GRSP Informal Group on Frontal Impact. 2009 2009. http://www.unece.org/fileadmin/DAM/trans/doc/2009/wp29grsp/FI-05-03e.pdf.

[Cover Project 2013] Cover Project. *Coordination of Vehicle and Road Safety Initiatives* 2013. http://www.biomechanics-coordination.eu/.

[Edwards 2007] Edwards, M.; Coo, P. de; van der Zweep, C.; Thomson, R.; Damm, R.; Tiphaine, M.; Delannoy, P.; Davis, H.; Wrige, A.; Malczyk, A.; Jongerius, C.; Stubenböck, H.; Knight, I.; Sjoberg, M.; Ait-Salem Duque, O.; Hashemi, R.: "*Improvement of Vehicle Crash Compatibility through the Development of Crash Test Procedures (VC-Compat - Final Technical Report)".* http://ec.europa.eu 2007.

[European Commission 2013] European Commission. *CARE- European Road Accident Database* 2013. http://ec.europa.eu/transport/road_safety/observatory/statistics/care_en.htm.

[Faerber 2007] Faerber, E.; Damm, R.: "*EEVC Approach to the Improvement of Crash Compatibility between Passenger Cars".* 19th Enhanced Safety Vehicle Conference 2005. Paper Number: 05-0155-0 2007. http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0155-O.pdf.

[Lenard 2006] Lenard, J: "*2nd International Conference on ESAR „Expert Symposium on Accident Research".* http://bast.opus.hbz-nrw.de/volltexte/2011/294/pdf/F61.pdf. Paper Number: F61 2006.

[Otte 2003] Otte, D.; Brunner, H.; Krettek, C.; Zwipp, H.: "*Scientific Approach and Methodology of a New In-depth Investigation Study in Germany so called GIDAS".* 18th Enhanced Safety Vehicle Conference 2003. http://www-nrd.nhtsa.dot.gov/pdf/esv/esv18/CD/Files/18ESV-000161.pdf.

[Pastor 2009/1] Pastor, C.: "*Frontal Impact Protection - German Accident Data Analysis".* GRSP Informal Group on Frontal Impact. Geneva. 2009. Paper Number: FI-05-02 2009. http://www.unece.org/fileadmin/DAM/trans/doc/2009/wp29grsp/FI-05-02e.pdf.

[Pastor 2009/2] Pastor, C.: "*Frontal Impact Protection - German Accident Data Analysis II".* GRSP Informal Group on Frontal Impact. Geneva. 2009. Paper Number: FI-07-02 2009. http://www.unece.org/fileadmin/DAM/trans/doc/2010/wp29grsp/FI-07-02e.pdf.

[Richards 2001] Richards, D.; Edwards, M.; Cookson, R.: "*Technical assistance and economic analysis in the field of legislation pertinent to the issue of automotive safety: provision of information and services on the subject of accident analysis for the development of legislation on frontal impact protection".* http://ec.europa.eu. Paper Number: ENTR/05/17.01 2001.

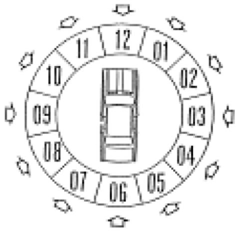
[Thorax Project 2013] Thorax Project. *Thoracic injury assessment for improved vehicle safety* 2013. http://www.thorax-project.eu/.

[Vallet 1999] Vallet, G.; Laumon, B.; Martin, J. L.; Lejeune, P.; Thomas, P.; Ross, R.; Koßmann, I.; Otte, D.; Sexton, B.: "*STAIRS - Standardisation of Accident and Injury Registration Systems".* http://ec.europa.eu. Paper Number: FR 1 1999.

12 GLOSSARY

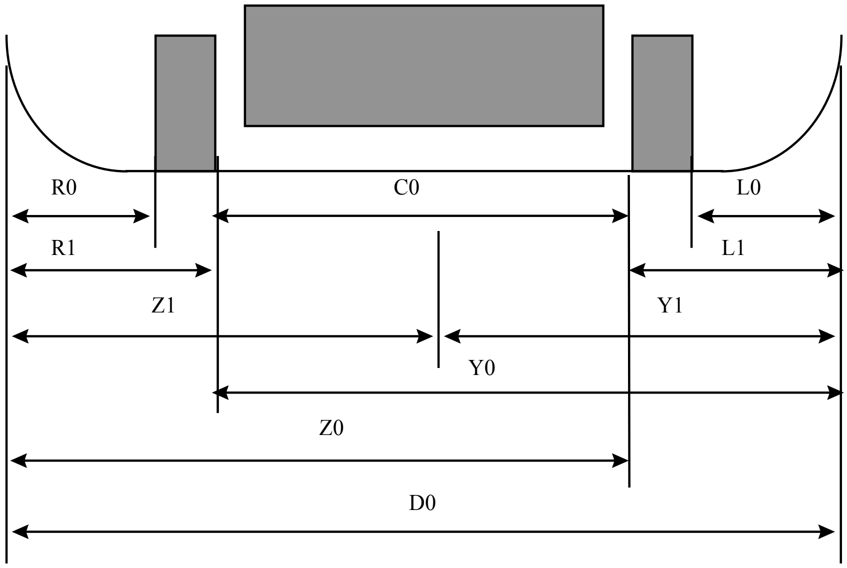
AIS:	Abbreviated Injury Severity Scale, describing the mortality rate of an injury ranging from 0 (not injured) to 6 (medical treatment today impossible), AIS 1 injuries and sometimes also AIS 2 injuries are reported to be superficial; Injuries above a certain level are often described as AIS X+ (e.g., AIS 2+ meaning injuries with severity levels 2, 3, 4, 5 and 6). In the databases AIS 9 is often coded for unknown severity level
CDC:	Collision Deformation Classification, VDI (see below) is derived from CDC
Deceleration injuries:	injuries related to the restraint system caused by loading of the occupant by the seatbelt or airbag to decelerate him and prevent greater injuries by contact with other car interior structures. Deceleration injuries are sometimes referred to as 'restraint' or 'restraint related' injuries.
delta-v:	velocity change following a collision
DRV:	Driver
EES:	Energy Equivalent Speed describing the deformation energy by a velocity that would create this deformation with $E_{def} = ½\ m\ EES^2$
ETS:	Estimated Test Speed; test speed of the vehicle against a rigid fixed barrier that would cause the same deformation. Note: similar to EES.
HGV:	Heavy Goods Vehicle / large truck (within GIDAS study also including coaches and busses
MAIS:	Maximum AIS coded, i.e. the most severe injury
Mass ratio:	relationship between the mass of two vehicles with mass ratio larger than one meaning the opponent vehicle is heavier than the case vehicle
FSP:	Front Seat Passenger
FPS:	Front Passenger Seat
PDOF:	principle direction of force, see also VDI1
PSV:	Public Service Vehicle (busses and coaches)
VDI:	Vehicle Deformation Index; is used in GIDAS in order to code the deformation of a vehicle in a seven figure code. The first two digit figure (VDI1) describes the principle direction of force, the second figure (VDI2) is a one digit code describing which part of the vehicle (front, right side, roof, …) is deformed and the third part (VDI3) describes the horizontal distribution of the deformation. The other parts are not of relevance for this study
VDI1:	The first part of the vehicle deformation index describes the principle direction of force in a clock wise system. For example 12 o'clock means

accidents with a principle direction of force between -15° and +15° from the front, see also Figure below.



VDI2: The second part of the vehicle deformation index indicates which part of the vehicle is mainly damaged (e.g., front, right side, rear, …)

VDI3: The third part of the vehicle deformation index describes the horizontal distribution of the main deformation. VDI2 is defined differently for the different zones according to VDI2. However, within the scope of FIMCAR only deformations to the car front are of interest. The different zones for the horizontal distribution are shown in the Figure below.



APPENDIX A: REPRESENTATIVENESS OF CCIS DATA SET

It is known that there are some differences in the characteristics of the GB CCIS in-depth accident data and the national accident data. These are caused by the accident sampling procedure for CCIS which is biased to fatal and serious accidents and to new cars.

The characteristics of the CCIS data set used for the compatibility analysis and an equivalent STATS19 data set were compared to quantify any biases in the CCIS data set. This was necessary to help ensure that the results of the compatibility analysis performed were interpreted correctly.

The CCIS data sample selection criteria were:

- Occupant in car or car derived van
- Car involved in 'significant' frontal impact without significant rollover
- Car registered in year 2000 onwards and ECE Regulation 94 compliant

The STATS19 data set used data from accidents which occurred in 2008 and was adjusted to represent a fleet that comprised entirely of R94 compliant vehicles using the scaling factors derived by D Richards *et al*. 2010 shown in Table A-1.

Table A-1: Adjustment to 2008 STATS19 data based on the entire fleet being compliant with ECE Regulation 94

Vehicle hit	Fatal	Serious	Slight
Adjustment to 2008 figures	98%	90%	101%

The results were:

- Little / no difference was found in the proportions of fatal and serious injured occupants in the data sets when just fatal and seriously injured occupants were considered.

Table A-2: Comparison of distribution of fatal and seriously injured occupants in STATS19 and CCIS data sets.

	Fatal	Serious
STATS19	10.2%	89.8%
CCIS	11.6%	88.4%

- A higher proportion of HGV/bus impacts and a lower proportion of narrow object impacts was seen in the CCIS data set compared to the STATS19 national accident data set.

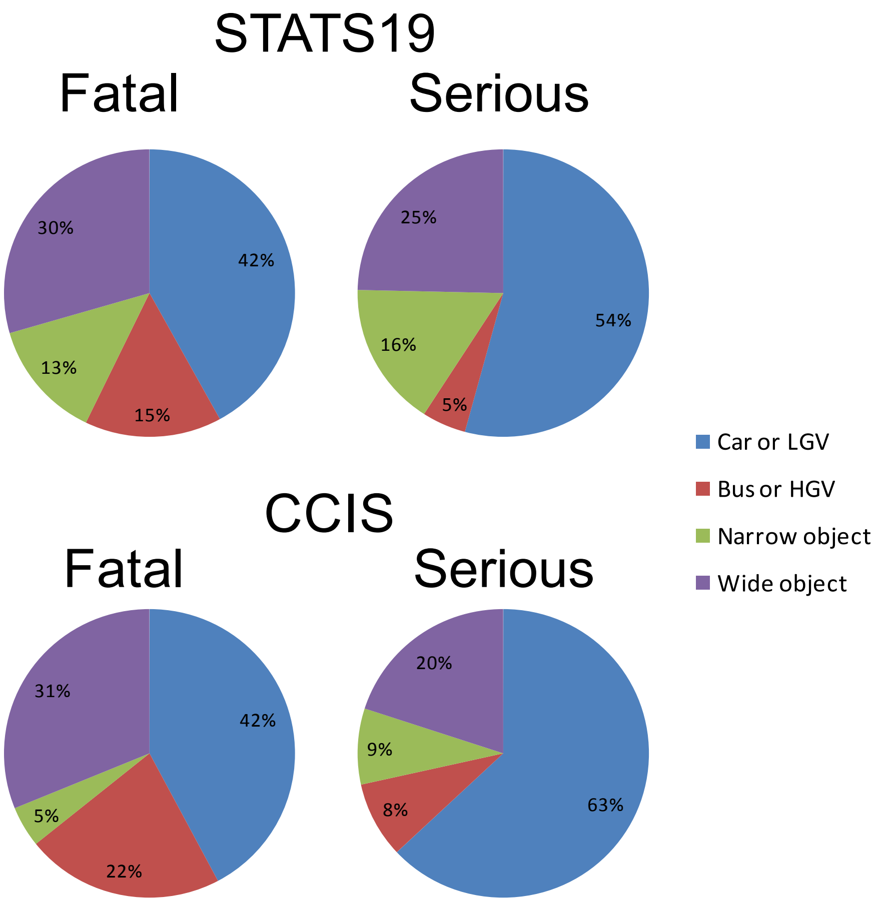


Figure A.1: Distribution of impact type for Regulation 94 compliant vehicles in STATS19 and CCIS

- A greater proportion of the occupants in CCIS are elderly (aged 66 or older), and a smaller proportion are aged 12-25 years.

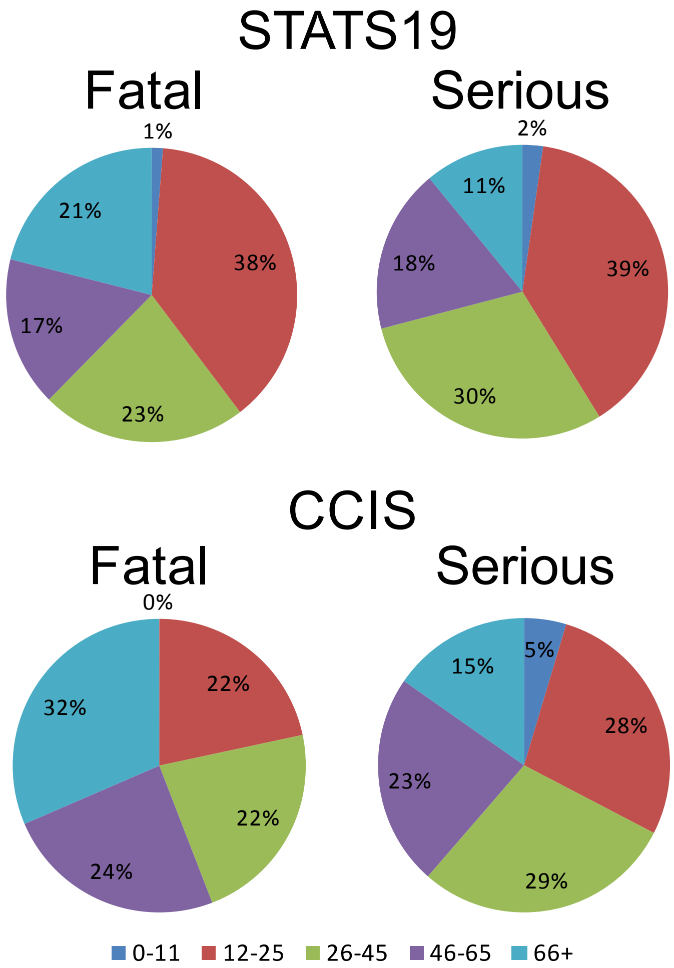


Figure A.2: Distribution of casualty age for Regulation 94 compliant vehicles in STATS19 and CCIS

In summary, it was found that the CCIS data set has a higher proportion of HGV/bus impacts, a lower proportion of narrow object impacts and a bias towards older occupants.