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# ASSESSMENT OF INJURY SEVERITY OF NEARSIDE OCCUPANTS IN POLE IMPACTS TO SIDE OF PASSENGER CARS IN EUROPEAN TRAFFIC ACCIDENTS – ANALYSIS OF GERMAN AND UK IN-DEPTH DATA

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## ABSTRACT

The national accident statistics demonstrate that the situation of passenger car side impacts is dominated by car to car accidents. Car side to pole impacts are relatively infrequent events. However the importance of car side to pole impacts is significantly increasing with fatal and seriously injured occupants. For the present study the German in-depth database GIDAS (German In-Depth-Accident Study) and the UK database CCIS (Co-operative Crash Injury Study) were used. Two approaches were undertaken to better understand the scenario of car to pole impacts. The first part is a statistical analysis of passenger car side to pole impacts to describe the characteristics and their importance relevant to other types of impact and to get further knowledge about the main factors influencing the accident outcome. The second part contains a case by case review on passenger cars first registered 1998 onwards to further investigate this type of impact including regression analysis to assess the relationship between injury severity and pole impact relevant factors.

## 1. DATABASES

National accident statistics are not detailed enough to get information on the characteristics of impact types therefore two in-depth databases were used, the German In-Depth Accident Study (GIDAS, Germany) and the Co-operative Crash Injury Study (CCIS, UK).

### GIDAS

GIDAS (German In-Depth Accident Study) is a joint project of the Federal Highway Research Institute (BASt) Germany and the German Association for Research in Automobile Technology (FAT). It

started in 1999 in the two research areas Dresden and Hanover based on the established research activities of the Medical University Hannover (Otte, 1990). About 2,000 accidents involving all kinds of traffic participants are recorded each year in a statistical random procedure resulting in a representative sample of the national German accident statistic (Pfeiffer, 2006). The teams consisting of technical and medical students investigate the data at the accident scene and the hospitals. Each case is encoded in the database with about 3,000 variables. The database contains detailed information about: environment (meteorological influences, street condition, traffic control), vehicle (deformations, technical characteristics, safety measures), person (first aid measures, therapy, rehabilitation) and injury (severity, description, causation). On the basis of full-scaled sketches of the accident scene and the vehicle deformations every accident is reconstructed.

### CCIS

The objective of CCIS (Co-operative Crash Injury Study) is to investigate and correlate car crash data, with a view to increase the understanding of human injury mechanisms, and the effectiveness of car secondary safety systems. The study provides the mechanism to monitor in-depth crash performance of car structures, occupant protection systems and the benefits of countermeasures now becoming available. CCIS is a collaborative project. The UK Department for Transport, several motor vehicle manufacturers and a vehicle component supplier jointly fund the programme of research. Currently, information on approximately 1300 vehicles is gathered each year for inclusion into the database. It is possible to weight the CCIS data in order to address the sampling bias towards serious injury; however this study uses unweighted data. Data col-

lection consist of sampling criteria, i.e. passenger cars 7 years old or younger at the time of accident, injury occurred to an occupant in the car and the vehicle was towed from the accident scene.

In detail the following basic query criteria/parameter were examined for the present study:

Basic inquiries applied to GIDAS 07/2007 and CCIS 2007 (combined phase 6y, 7o and 8c)
<b>Passenger cars</b>
<ul style="list-style-type: none"> <li>○ Impacts to vulnerable road users were excluded from GIDAS (not necessary in CCIS dataset)</li> <li>○ All vehicles 1998 onwards which had only one impact to the side (single side impacts)</li> <li>○ Cars with rollover before or after the side impact where excluded.</li> </ul>
<b>Pole impacts</b>
<ul style="list-style-type: none"> <li>○ Cars with single impact to pole (tree, lamp post, traffic light post...)</li> <li>○ Resulting injury severity and individual injuries for belted occupants only</li> </ul>

## 2. INTRODUCTION

The national accident statistics demonstrate that the situation of passenger car side impacts is dominated by car to car accidents. Car side to pole impacts are relatively infrequent events. However the importance of car side to pole impacts is significantly increasing with fatal and seriously injured occupants. Pole impacts, especially lateral, comprise one of the most aggressive impact environments for automobile structures. Due to the close proximity of occupants to the side structure, these pole impacts represent a more severe crash exposure than comparable impacts to other structures for instance to the front of a car (Varat et al 1999). Especially if the pole impact is directly to the compartment area the risk to receive severe injuries is high. A study of Zaouk et al (2001) postulated by using NASS and FARS data for 1988 to 1997 with respect to side impacts, that direct impacts of narrow objects with the occupant compartment have a high portion of MAIS3+injuries.

A considerable step in the improvement of side impact protection for passenger cars has already been done. With additional and improved structures in the doors and/or pillars of a vehicle and with the industry wide introduction of various types of side airbags, occupant protection has reached a high level.

The regulatory frameworks for these developments are the FMVSS 214 (Kahane, 1999) on the US side and the ECE 95 (Economic Commission for Europe) in Europe. In addition consumer testing by US-NCAP and EU-NCAP established also side impact testing protocols not only for the car-to-car side impact but also for pole impacts. The latter are the focus for the current study, which was part of

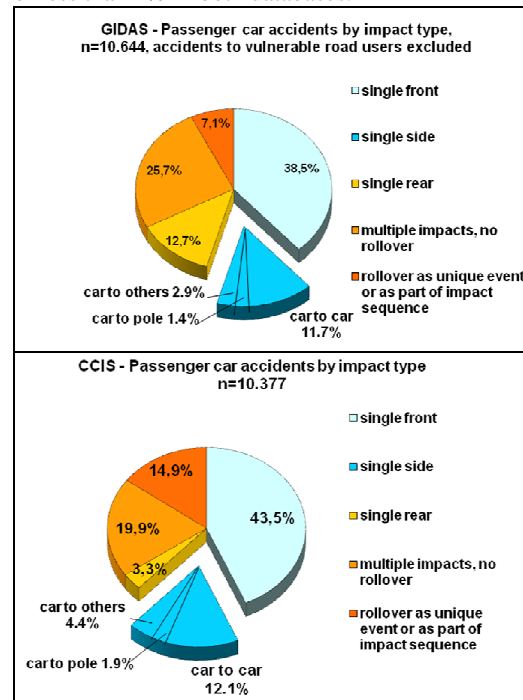
the work of the European Enhanced Vehicle Safety (EEVC) working group 21 (Accident Studies) for the EEVC WG13 (Side Impact) to develop recommendations for future regulatory side impact test procedures. The working group 21 was founded for compiling experiences and scientific results from existing in-depth-investigations of European research teams supporting the different activities of EEVC.

Two approaches were undertaken within this study to better understand the characteristics of car to pole impacts. The first part is a statistical analysis of pole impacts to describe the characteristics and their importance relevant to other types of impact and to get further knowledge about the main factors influencing the accident outcome. The second part contains a case by case review on cars registered 1998 onwards only, to further investigate car side to pole impacts focussing on factors that influence the injury severity and finding injury mechanisms of struck side occupants.

## 3. STATISTICAL ANALYSIS OF SIDE TO POLE IMPACTS

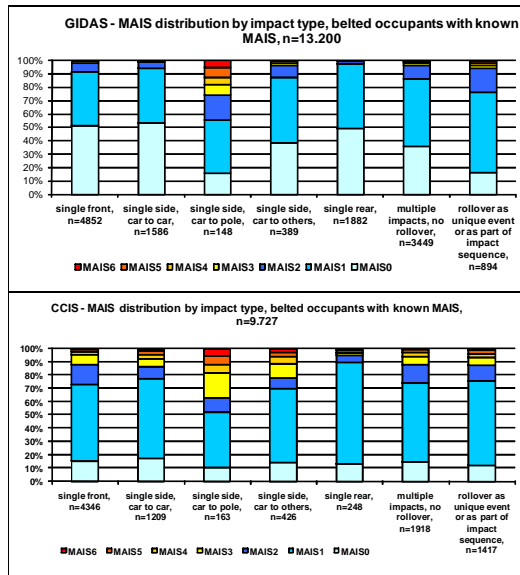
### 3.1. Relevance of Side to pole impacts

Beside the frontal impact the side impact is the most common impact type. In GIDAS 16% of the passenger cars have single side impacts in CCIS 18.4% (fig. 1). The passenger car side impacts are dominated by car-to-car impacts. Car side to pole impacts are relatively infrequent events with a share of less than 2% in both databases.



**Figure 1:** Passenger Car Accidents by Impact Type

However the importance of car side to pole impacts is significantly increasing with fatal and seriously injured occupants. Single side to pole impacts have the highest proportion of MAIS3+ injured occupants compared to the other accident types (fig. 2). The obvious difference in the injury severity distribution between GIDAS and CCIS with a higher share of MAIS3+ injured occupants is caused by the difference in sample criteria of the studies.

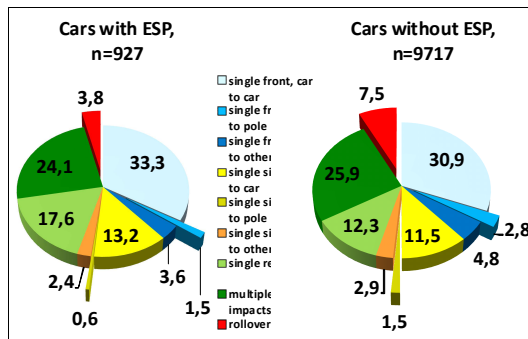


**Figure 2:** MAIS Distribution by Impact Type, Belted Occupants only

### 3.2 Effect of ESC on the Occurrence of Car Side to Pole Impacts

To further demonstrate the effectiveness of ESC in reducing car to pole impacts GIDAS data were analysed.

1.5%/2.8% of the cars (in GIDAS) without ESC have single side/front to pole impacts, for cars with ESC these shares are with 0.6%/1.5% less than half. The share of accidents with rollover is halved as well from 7.5% to 3.8%.



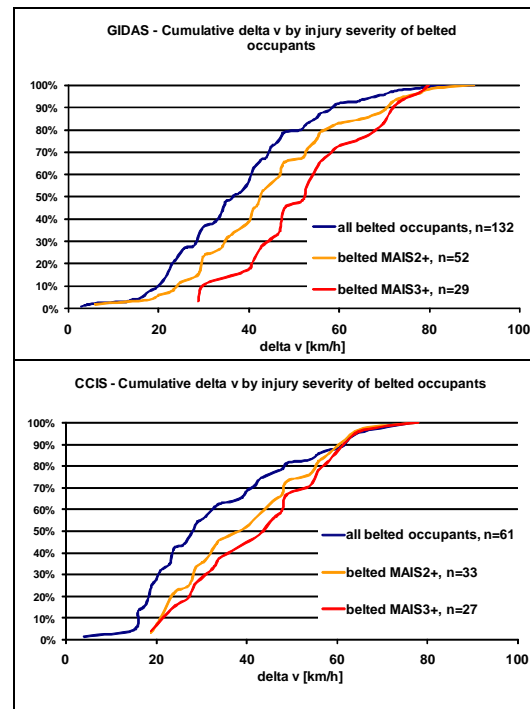
**Figure 3:** Passenger Car Accidents by Impact Type with and without ESC; accidents to vulnerable road users are excluded (GIDAS)

Especially the share of accidents with rollover and pole impacts is definitely lower for cars equipped with ESC compared to cars without ESC. This would indicate for an effectiveness rate of 40 to 54% for ESC equipped cars against pole impact risk.

### 3.3 Characteristics of the Impact

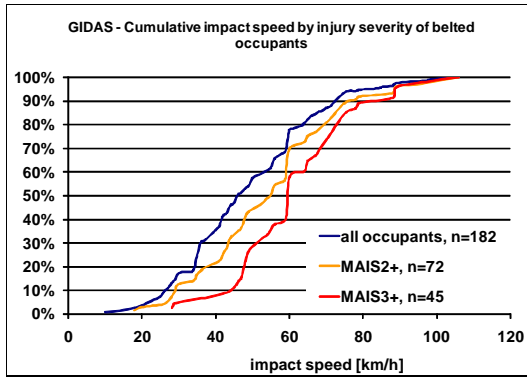
#### Delta v and Impact Speed

To differentiate the impact severity relative to the injury severity the delta v was analysed on the occupant level. In GIDAS 50% of the occupants in single side to pole impacts receive a delta v less than 35 km/h, in CCIS this 50% rate is reached at 29 km/h (fig. 4). This difference is even more remarkable because in contrast the share of MAIS3+ injured occupants in single side to pole impacts is in CCIS with 37.5% clearly higher than in GIDAS 26.4%.



**Figure 4:** Cumulative Delta v Distribution for Different MAIS Classes in Pole Impacts, Belted Occupants only

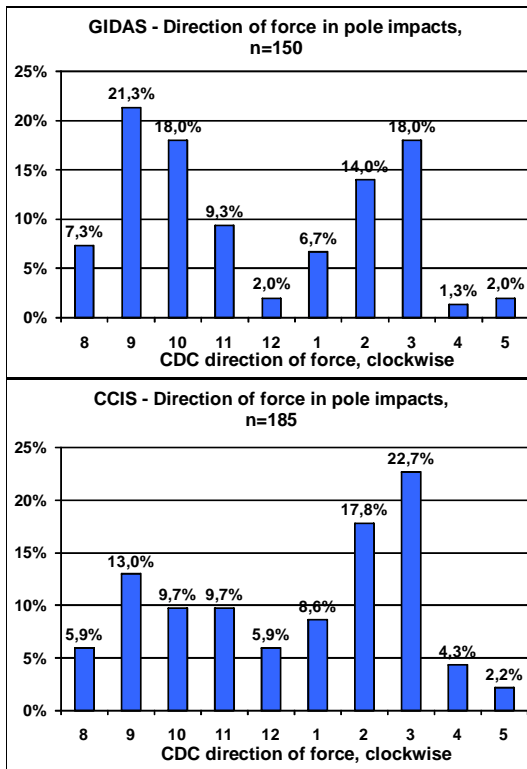
The GIDAS database provides also the possibility to analyse the impact speed of the passenger car, due to the full reconstruction of the accident. 50% of all occupants had a side to pole impact with an impact speed below 46 km/h (fig. 5).



**Figure 5:** Cumulative impact speed distribution by MAIS classes in single side to pole impacts, belted occupants only

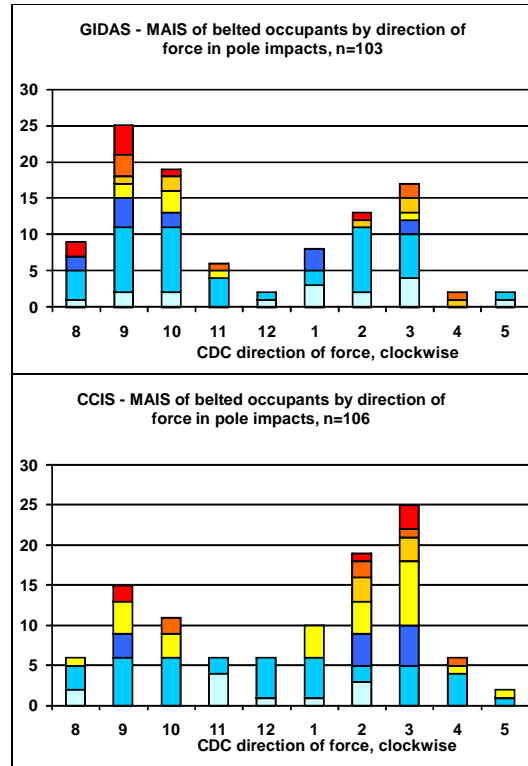
### Impact Force Angle

The CDC direction of principle force with its clockwise differentiation of directions was used to analyse the impact force angle. The most frequent direction of impact force with 40% is perpendicular or  $90^\circ \pm 15^\circ$  (3 and 9 o'clock) in both databases (fig. 6), with the majority of impacts to the drivers side (left in GIDAS and right in CCIS).



**Figure 6:** CDC Direction of Force in Single Side to Pole Impacts

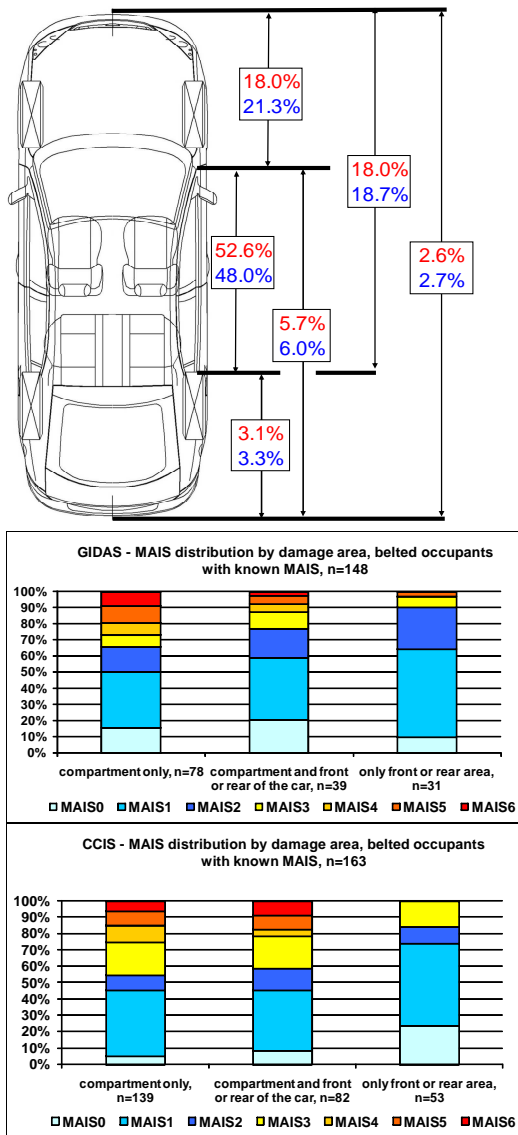
The majority of the MAIS3+ injured occupants have also been found in perpendicular  $\pm 15^\circ$  impacts biased to the driver's side (fig. 7).



**Figure 7** MAIS Distribution by Direction of Force, Belted Occupants only

### Damage Area

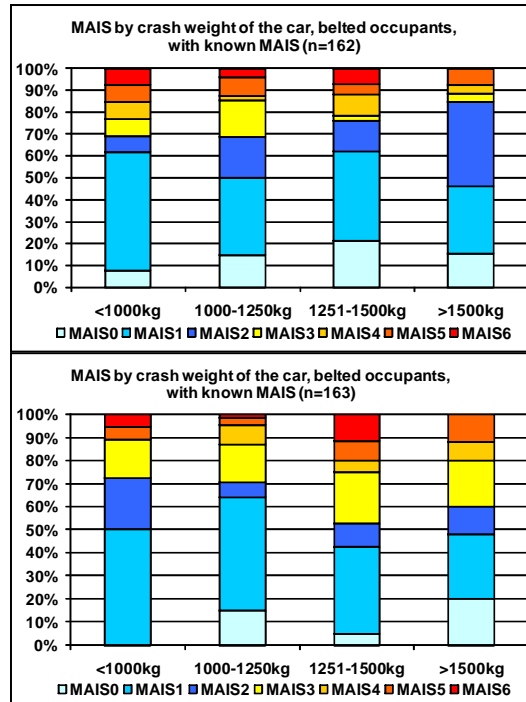
The by far highest proportion (50%) of all pole impacted passenger cars show damage exclusively in the passenger compartment (fig. 8). Pole impacts affecting the area in front of the A-pillar occur second most (around 20%), impacts behind the C-pillar occur rarely (around 3%). Severe and especially fatal injuries only occur when the passenger compartment is affected (fig. 9).



**Figure 8** Damage Area in Pole Impacts and MAIS distribution by damage area

### Crash weight of the car

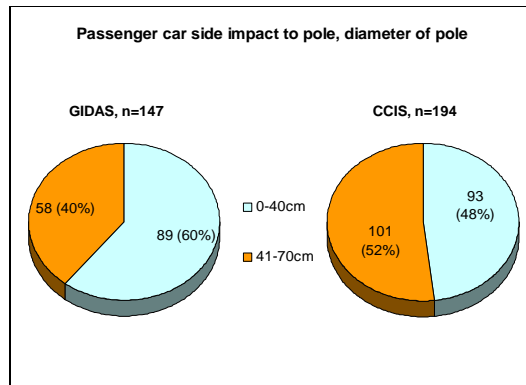
In the GIDAS data there seems to be a correlation between MAIS and crash weight of the car, but the numbers of cars in the individual weight groups are very small. In CCIS there is no correlation visible. Finally it can be stated that in side impacts to pole the crash weight of the car has no, or only minor influence on the injury severity (fig. 9).

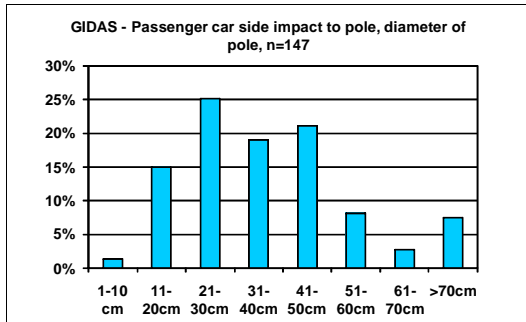


**Figure 9** MAIS by Crash Weight of the Car

### Pole Diameter

In the GIDAS database 60% of the impacted poles have a diameter less than 40 cm. In CCIS nearly one half of the single side to pole impacts happen to poles of this size. GIDAS provides also more detailed information on the distribution of pole diameters. Biggest group with more than 25% are the poles with diameter between 21 and 30 cm.



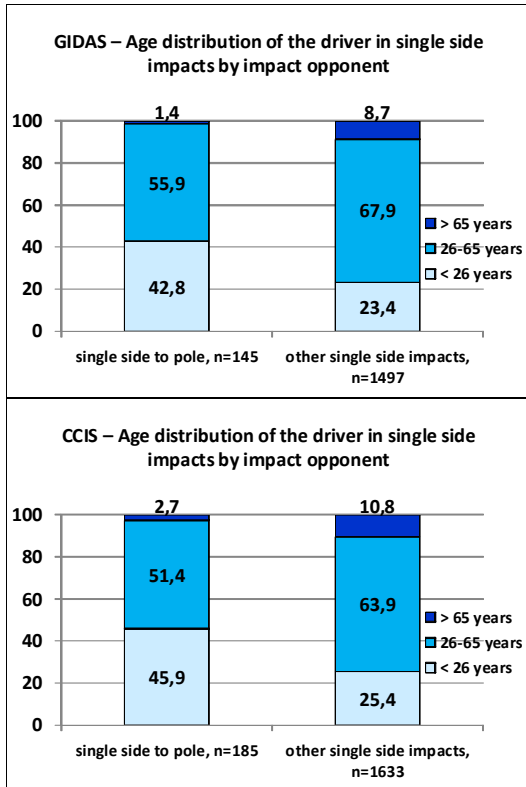


**Figure 9** Diameter of Pole in Car to Pole Impacts

### 3.4 Occupant Parameters

#### Age

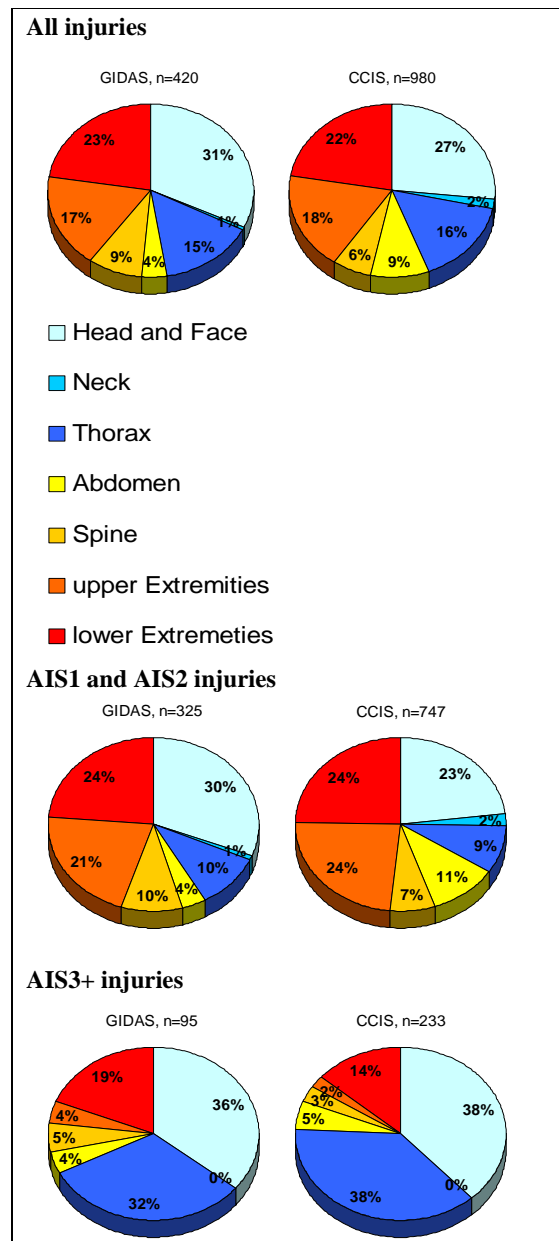
The share of young drivers is significantly higher in car to pole impacts compared to all other side impacts. Clearly more than 40% of all drivers in pole impacts are younger than 26 years. In other side impact configurations this share is around 25% (fig. 10). Side to pole impacts are generally single vehicle accidents. Other studies show that especially in this type of accident young drivers are overrepresented [STBA 2006].



**Figure 10** Driver Age Distribution in Side Impacts and Pole Impacts of Cars

### Injuries per Body Region in Pole Impacts

Looking at all injuries, occupants received in car side to pole impacts the head, the thorax and the extremities account for more than 80% of the injuries (fig. 14). Slight injuries are dominated by the head and the extremities. The combined share is about 75%. For AIS3+ injuries the share of injuries to the thorax rises to 32% in GIDAS and 38% in CCIS. The share of abdominal injuries is 4% in GIDAS for slight and severe injuries. In CCIS abdominal injuries have a share of 11% for AIS1&2 and 5% for AIS3+ injuries.



**Figure 12** Injury Distribution per Body Region in Pole Impacts

#### 4. CASE BY CASE ANALYSIS

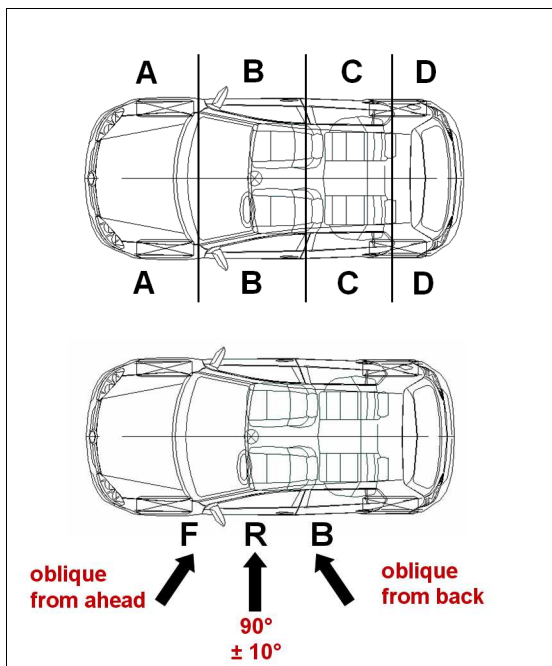
Complementary to the statistical analysis on all car side to pole impacts a case-by-case analysis was carried out. It is focussed on a detailed in-depth-investigation by using the original accident files, the accident images, injuries and its causation factors and the vehicle deformation pattern.

##### Data sample for case by case analysis

The data set on side to pole impacted cars is based on the data that was used for statistical analysis. In addition the case by case analysis is focussed on struck side occupants in cars registered 1998 onwards resulting in a sub sample with **n=26 cases out of the GIDAS data base and n=97 cases out of CCIS.**

##### Methodology of case by case analysis

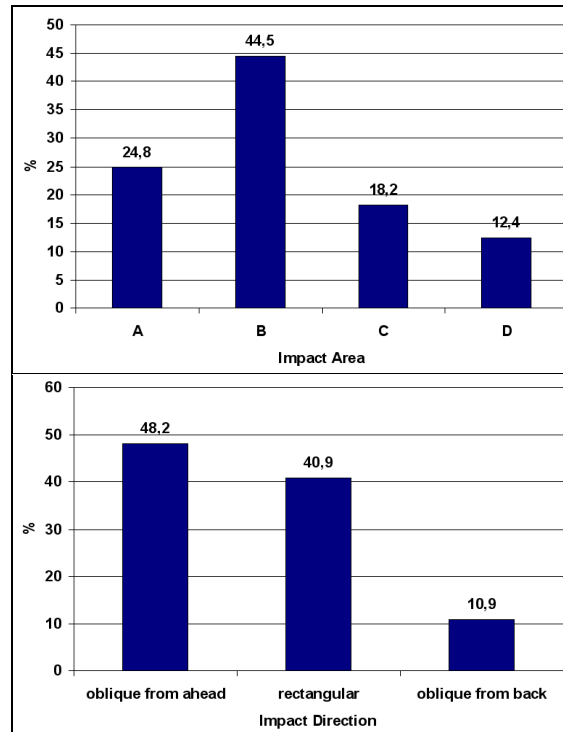
For the analysis the car exterior is classified into a matrix system A, B, C, and D (fig. 13). The area A describes the area in front of the A-pillar, B describes the area between A- and B-pillar, C the area between B- and C-pillar and D the area in the rear of the car. The principle direction of force (fig. 13) was classified into rectangular (R) and oblique from the front (F) and oblique from the rear (B).



**Figure 13:** Definition of the 4 impact areas and principle direction of force

The frequency for these different classifications in side to pole impacts is given in the figures below (fig. 14). The most frequent impact area is the B-area with 44.5%. The most frequent impact direction is in oblique direction from the front in nearly

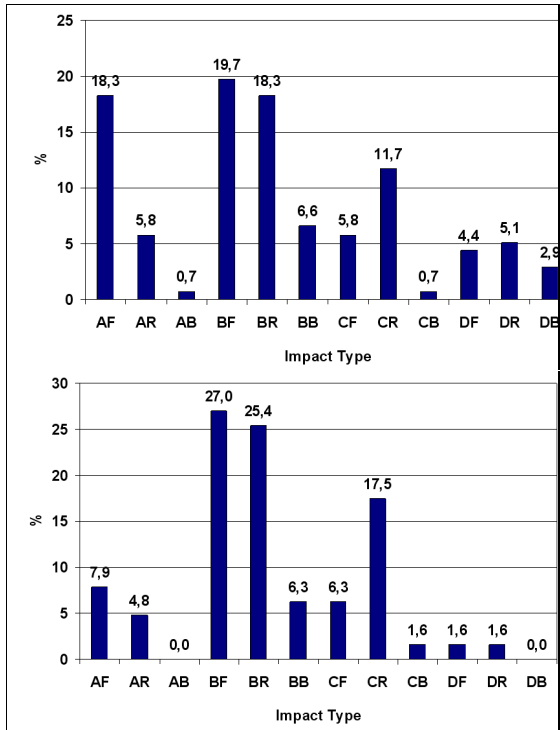
the half of all cases (48.2%). A rectangular impact  $\pm 10$  degree can be seen in 40.9%. Impacts from the rear direction occur rarely (10.9%).



**Figure 14:** Frequencies of impact area and impact direction

The most frequent combinations of impact areas and directions are AF, BF, BR and CR (fig. 19), together they cover 68% of all situations. Around 19% of all impacts occur in the area between A- and B-pillar with force direction from front respectively perpendicular direction. Focussing on seriously injured struck side occupants (MAIS3+) more than the half had an impact from the frontal or perpendicular direction to the B area. Impacts to the front or the rear of the car occur rarely.





**Figure 19:** All struck side occupants (upper chart) and MAIS 3+ struck side occupants (lower chart), Combinations of impact area and direction

### Statistical Analysis of Car-Side-Pole-Impacts within the Case by Case Analysis

#### Ordinal logistic regression

To identify the relevant factors for the MAIS of the struck side occupants an ordinal logistic regression was carried out. As potential factors/variables the delta v, year of first registration, impulse angle, depth of deformation, country, diameter of pole and damage location were used.

In Table 1 the p-values for the Chi square test are given for the correlation of the variables and MAIS, respectively MAIS in individual body regions. According to this delta v has significant influence on the overall MAIS, on the injury severity in head and abdomen. The depth of deformation has significant influence on the injury outcome of the extremities, and the damage area on MAIS and the injury severity in thorax and lower extremities. The impulse angle has only significant influence on MAIS, the pole diameter only to the head injury severity and country only to the injury severity of the lower extremities. Having only cars registered 1998 onwards presented in this sample; this variable has no significant influence on the injury severity levels.

Variable	Degree of Freedom	MAIS	Head AIS	Thorax AIS	Abdomen AIS	Upper Ex-tremities AIS	Lower Ex-tremities AIS
Delta-v	1	0.0002	0.2836	0.0011	0.0022	0.0590	0.0547
Year of first Registration	1	0.2024	0.5139	0.3297	0.2341	0.5039	0.1382
Impulse Angle	1	0.0242	0.5742	0.2418	0.8825	0.0858	0.6958
Depth of Deformation	1	0.2716	0.5308	0.1071	0.5839	0.0462	0.0213
Country	2	0.3494	0.6573	0.8830	0.3151	0.1845	0.0122
Pole Diameter	1	0.9178	0.0286	0.6395	0.4471	0.6758	0.6684
Damage Area	4	0.0221	-	0.0341	0.1619	0.2379	0.0010

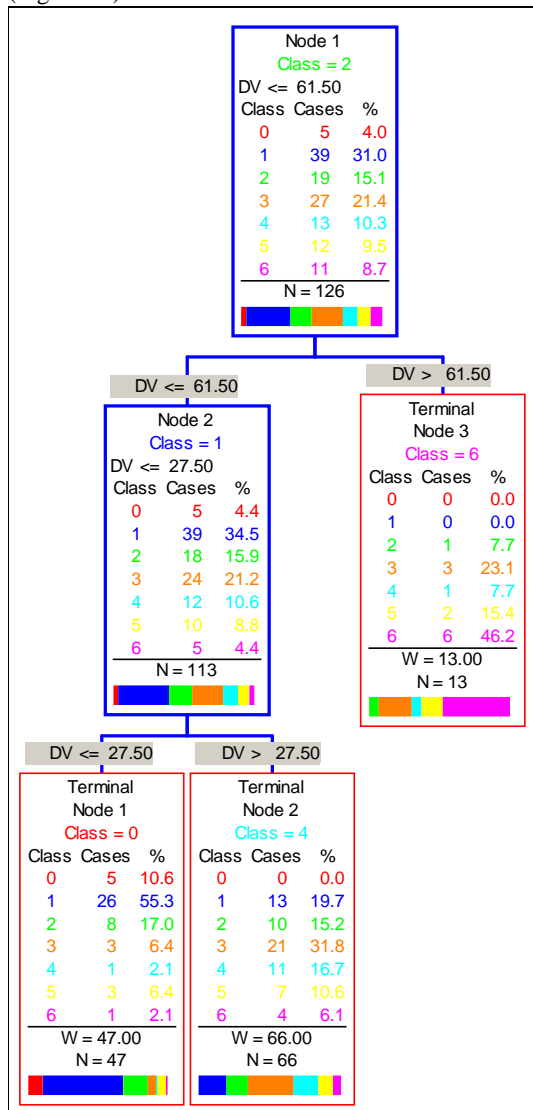
**Table 1:** p-values for the ordinal logistic regression analysis, correlation of given variables and injury severity of struck side occupants.

#### CART-analysis

To get more information on the influence of delta-v on the injury outcome a Tree- or CART-Analysis was carried out. It gives more information on the thresholds of a variable (delta v) where changes in the target parameter (MAIS) are visible. The CART method is an empirical, statistical method based on recursive partitioning analysis (Breiman *et al*, 1984); the aim is to form prediction rules by constructing binary trees.

First there is an upper change of significance at a statistically evaluated delta-v of 61.5 km/h describing an over proportional significance to high injury severity grades. Above this delta-v value the injury severity is increasing rapidly, explained by the highly deformation of the cars similar to catastrophic pattern. Next level of remarkable change can be found for a statistically evaluated delta-v of 27.5 km/h. This value of delta-v 27.5 km/h is approximately the discussed test speed of 29 km/h.

The CART-analysis gives the indication that real world side to pole impacts have a significant level of accident severity at 27.5 km/h, where the injury severity is expected to increase over proportional (Figure 20).

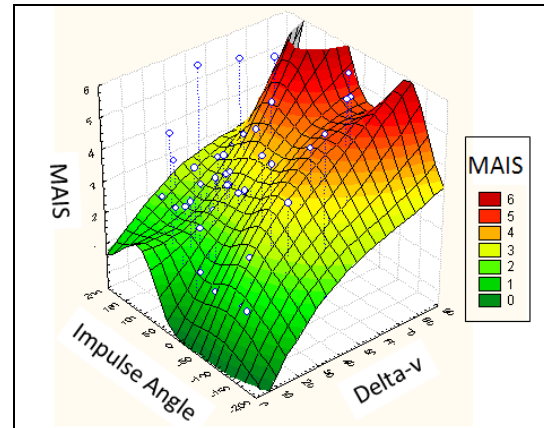


**Figure 20:** CART-analysis of car side impacts with poles

It can be seen in the analysis, that delta-v has a significant influence, first there is an upper change of significance at a statistically evaluated delta-v value of 61.5 km/h describing an over proportional significance to high injury severity grades. Above this level of accident severity the injury severity is increasing rapidly, explained by the highly deformation of the cars similar to catastrophic pattern. Another level of remarkable changes can be found for a statistically evaluated delta-v value of 27.5 km/h. This value of delta-v 27.5 km/h is nearly the discussed test speed of 29 km/h and is shown that current real accidents are having here an important

level of accident severity where the injury severity are increasing over proportional.

A 3-dimensional graphic (fig. 21) is shown for all impacts on the compartment area the overall correlation of significant influence on pole impacts on the lateral part of the vehicle BF + BR:



**figure 21 :** Injury severity MAIS vs impulse angle vs delta-v

There are major impact conditions leading in relatively high injury severity, i.e. angle of force momentum = 90 degree, delta-v 40 km/h onwards, especially very severe are impact conditions from rectangular combined with high delta-v.

## CONCLUSION

From this study the following conclusion can be drawn:

- Pole impacts are relatively rare events compared to other impact types. But the importance of side to pole impacts increases by focussing on seriously injured occupants (MAIS3+).
- Cars equipped with ESC show a by far lower share of car side to pole impacts and in consequence have reduced numbers of injured car occupants. Currently 10% of the vehicles in the GIDAS dataset were equipped with ESC. In the future the higher market penetration of ESC will further reduce the number of car side to pole impacts.
- In GIDAS 50% of the occupants in single side to pole impacts receive a delta v less than 35 km/h, in CCIS this 50% rate is reached at 29 km/h. This is in contrast to the injury severity distribution in both studies. The share of MAIS3+ injured occupants in single side to pole impacts is in CCIS with 37.5% clearly higher than in GIDAS 26.4%.
- The most frequent direction of impact in car side to pole impacts is oblique from the front. Perpendicular impacts are the sec-

ond frequent one. Damaged passenger compartments causing the vast majority of severe and fatal injuries.

- The injury outcome does not correlate with the vehicle mass.
- The highest proportion with approximately 50% of all car side to pole impacts happen to poles with a diameter of less than 40 cm (CCIS 48% and GIDAS 60%).
- Head and thorax injuries of the occupants are of highest importance when looking at severe and fatal injuries. Their share is above 70% of all MAIS 3+ injuries.
- Delta-v can be identified as most significant influence factor for MAIS.
- At a delta-v value of 27.5 km/h the injury severity is expected to increase over proportional.

Most critical point in the discussion of future side impact testing criteria is the test speed. However a comparison between individual cases and a categorisation of the cases into cases of comparable severity within the individual in-depth study is possible.

Several studies have already demonstrated the potential of ESC in terms of traffic safety. The list below (table 2) provides a brief overview of what has been investigated so far.

Reference	Estimated traffic safety effect	Source of data
Sferco et al. (2001)	34% reduction of fatal accidents 18% reduction of injury accidents	EACS
Aga and Okado (2003)	35% reduction of single car accidents	ITARDA
Grömping et al. (2004)	44% reduction of loss of control accidents	GIDAS
Lie et al. (2004)	22.1% ( $\pm 21$ ) reduction of accidents more efficient on slippery road conditions	Insurance data (Folk-sam)
Lie et al. (2006)	16.7% ( $\pm 9.3$ ) reduction of all injury crash types 21.6% ( $\pm 12.8$ ) reduction of fatal and serious crashes more efficient on slippery road conditions	Insurance data (Folk-sam)

Page and Cuny (2006)	44% reduction of relative risk of ESP pertinent accidents	French national accident census
Farmer (2004)	41% (27-52) reduction of single vehicle crashes involving personal injury	State data System maintained by NHTSA
Langwieder et al. (2003)	25-30% reduction of all car crashes involving personal injury	Several data bases

**Table 2:** Estimated Traffic Safety Effect of ESC [1] For the presented study based on GIDAS especially the share of accidents with rollover and pole impacts is definitely lower for cars equipped with ESC compared to cars without ESC.

## ACKNOWLEDGEMENTS

This paper uses accident data from the United Kingdom Co-operative Crash Injury Study (CCIS) collected from 1996 to 2006. CCIS is managed by TRL Limited on behalf of the UK Department for Transport (DfT) Transport Technology and Standards Division who fund the project along with Autoliv, Ford Motor Company, Nissan Motor Company and Toyota Motor Europe. Daimler-Chrysler, LAB, Rover Group Ltd, Visteon, Volvo Car Corporation, Daewoo Motor Company Ltd and Honda R&D Europe(UK) Ltd have also funded CCIS. The data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham, the Vehicle Safety Research Centre at Loughborough University, TRL Limited and the Vehicle & Operator Services Agency of the DfT. Further information can be found at <<http://www.ukccis.org>>.

For the present study accident data from GIDAS (German In-Depth Accident Study) was used. GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest. Due to a well defined sampling plan, representativeness with respect to the federal statistics is also guaranteed. Since mid 1999, the GIDAS project has collected on-scene accident cases in the areas of Hannover and Dresden. GIDAS collects data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and its causation. The project is funded by the Federal Highway Research Institute (BAST) and the German Research Association for Automotive Technology (FAT), a department of the VDA

(German Association of the Automotive Industry). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist.

Further information on GIDAS can be found at <http://www.gidas.org>

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