APROSYS European In-Depth Pedestrian Database

CE Neal-Sturgess[1], E. Carter[1], R. Hardy[2], R. Cuerden[3], L. Guerra[4], J. Yang[5].
1 Birmingham Automotive Safety Centre (BASC)
2 Cranfield Impact Centre (CIC)
3 TRL Ltd Crowthorne
4 INSIA UPM
5 Chalmers University

Abstract:
The EU FP 6 Integrated Project on Advanced Protection Systems (APROSYS) is exploring the relevance of vehicle pedestrian protection systems in the real world. A pedestrian injury database was compiled of in-depth information to permit reconstructions of the pedestrian/ cyclist/ vehicle/ground interactions.
The database consisted of 63 pedestrians cases and 7 cyclist cases. Results were obtained on: injury risk as related to impact speed; the locations of primary head impacts with vehicles; the proportion and frequency of ground impacts; and the over representation of elderly fatals with MAIS3. It is concluded that (i) the head impact locations for pedestrian protection need to be reviewed to include the windscreen, A pillars and scuttle areas, and (ii) a calibration of MAIS and ISS against fatality/non fatality for a large sample of pedestrians is necessary, with children / adults/elderly (>60 years of age) ranked separately.

INTRODUCTION

In order to compile a number of detailed Vulnerable Road User (VRU) pedestrian and cyclist accident cases from around Europe containing sufficient detail for computer reconstruction work, an in-depth database (IDD) was developed in MS Access. The cases were compiled from five different sources from four different countries (the UK, Spain, Germany and Sweden).

ANALYSIS

The database contents are summarised here and some of the variables are compared with the UK pedestrian accident epidemiology (1997 – 2001) [1] to gauge how well the reconstruction cases represented that population, since 90% of in-depth cases were pedestrian and 70% of the cases came from the UK. Some German In Depth Accident Study (GIDAS) data is also used for comparison for some variables not available in the UK epidemiology. Despite the relatively small sample size, the database yielded some interesting observations on variables not available from the epidemiological studies – particularly concerning injury body region, severity and head impact location on the vehicle, and age versus injury outcome. Statistical tests were carried out where applicable to determine significance.

Table 1 – Road user type

Vulnerable Road User type	No. of in-depth cases	% of in-depth cases	% of total UK VRU accidents
Pedestrians	63	90%	66.5%
Cyclists	7	10%	33.5%

Table 2 - Gender

Gender	No. of in-depth cases	% of in-depth cases	% of total UK pedestrian accidents
Male	39	56%	58%
Female	28	40%	42%
Unknown	3	4%	0%

Pedestrian Orientation

In the in-depth sample, 89% of the pedestrians were hit on either the right (41%) or left side (48%). The observation that most of the pedestrians in the sample were struck side-on is in agreement with the literature [2]

Age

The age of the victim was known for 64 out of the 70 cases. Since the BASC cases were all fatal, they had a higher proportion of older pedestrians than the population (which includes all severity pedestrian accidents), but this was balanced by the other data sources which mostly provided serious but non-fatal cases. The frequency analysis of the in-depth sample resulted in the same mode [1] but found that it was over-represented in the older age categories (mainly due to the UK fatal contribution).

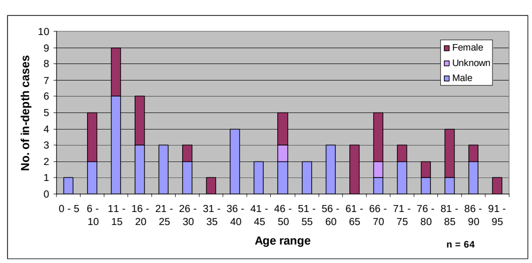

Figure 1- In-depth sample: Age of vulnerable road user

Age vs. Severity

According to several studies and the UK pedestrian epidemiology, the chances that a pedestrian will receive fatal injuries from an accident increases with age. This pattern is less obvious but still apparent in the in-depth sample, Figure 2 for which fatal accidents were over-represented as explained previously.

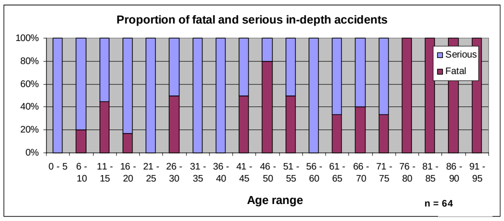

Figure 2- In-depth sample: Age vs. severity (proportion)

Table 3 – Age vs. severity (comparison with epidemiology)

	Mode (all severities)	Mode (fatal)	Mode (serious)
In-depth sample	11 – 15	81 - 90	11 – 20
UK ped. accidents	11 – 15	71 - 80	11 - 20

This comparison Table 3 shows the in-depth database to be a reasonably good representation of the epidemiology with respect to age vs. severity.

Table 4 – Age vs. severity (in-depth cases)

	Age (years)				
	Mean	**Median**	**Min**	**Max**	**SD**
Fatal (n=27)	56.2	61.0	10	94	27.6
Serious (n=37)	34.5	28.0	5	75	22.1

In Table 4 the difference in mean age between serious and fatal accidents is 22.6 years. This difference is highly significant ($p<0.01$).

Vehicle details

The year-of-manufacture frequency Figure 3 shows the distribution of ages of the vehicles involved. Although the average age is relatively low (1995), which is mainly a reflection of the age of the European fleet, half of the in-depth cases involve vehicles manufactured in 1997 or later, but with a large range.

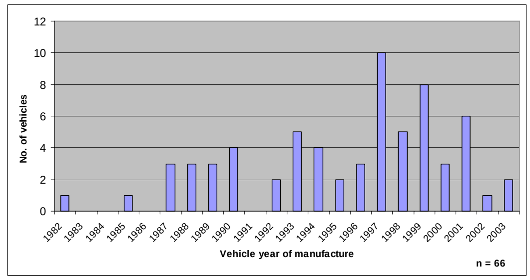

Figure 3 – In-depth sample: Vehicle year of manufacture

Impact speed

Figure 4 below compares the in-depth sample impact speeds with those found in the GIDAS sample. The in-depth sample (mean impact speed of 40km/h) tended to have higher impact speeds then the GIDAS sample (approximate mean impact speed of 28 km/h). This is a consequence of having a disproportionate number of fatal and serious accidents, which are more likely to be the result of higher speed impacts.

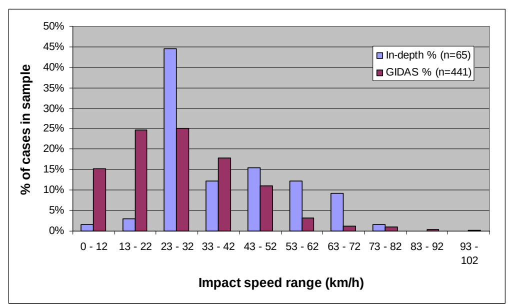

Figure 4 – Comparison with GIDAS data

Impact speed vs. injury severity

Previous work [3] has established the significant relationship between impact speed and pedestrian injury severity. This relationship is presented for the current study using 3 different definitions of injury severity: fatal / non-fatal, MAIS (Maximum AIS) and ISS (Injury Severity Score).

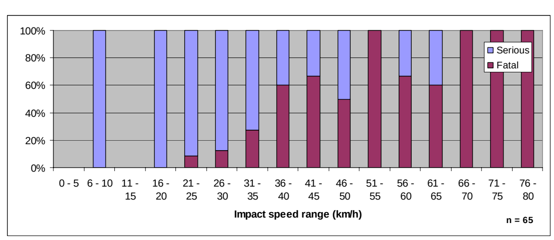

Figure 5 – In-depth sample: Impact speed vs. severity (proportion)

Table 5 – Impact speed vs. severity

	Impact speed (km/h)					% of accid. at ≤ 40km/h
	Mean	Median	Min	Max	SD	
Serious (n=39)	32.6	30.0	8.0	64.4	12.1	79%
Fatal (n=26)	49.3	49.1	25.0	75.6	13.3	31%

The difference between the mean impact speeds for serious and fatal accidents is 15.9km/h. This difference is highly significant ($p<0.01$).

The approximate proportion of serious accidents occurring at impact speeds of less than 40km/h is 0.79 ± 0.13 at a 95% confidence level ($p<0.05$). The approximate proportion of fatal accidents occurring at impact speeds of less than 40km/h is 0.31 ± 0.13 at a 95% confidence level ($p<0.05$). The difference between these proportions is highly significant ($p<0.01$).

Table 6 – Impact speed vs. MAIS (n=66)

MAIS	Impact speed (km/h)					Accidents at ≤ 40km/h (%)
	Mean	Median	Min	Max	SD	
2 (n=24)	30.3	28.0	20.0	56.3	9.0	88
3 (n=23)	44.8	49.0	8.0	70.8	16.8	39
4 (n=7)	46.3	40.2	22.5	75.6	17.1	57
5 (n=11)	42.8	41.0	27.4	62.8	10.3	46
2-3 (n=47)	37.4	32.2	8.0	70.8	15.1	64
4-5 (n=18)	44.1	40.6	22.5	75.6	13.4	50

The difference between the mean impact speeds for MAIS 2-3 accidents and MAIS 4-5 accidents is 6.6km/h. This difference is not significant ($p>0.05$).
88% of MAIS 2 accidents occurred at speeds of less than or equal to 40 km/h. To extend this to the population with a 95% confidence level, the proportion of MAIS 2 accidents occurring at speeds ≤ 40km/h would be approximately between 75% and 100% ($p<0.05$). It can also be estimated that approximately 51% - 77% of MAIS 2-3 accidents would occur at speeds of ≤ 40km/h ($p<0.05$).

Due to the very low number of MAIS 4 accidents, both MAIS 4 and MAIS 5 accidents are presented together in Figure 6. The majority (63%) of MAIS 2 cases were at impact speeds of between 21 and 30km/h. Less conclusively, the speed range mode for MAIS 3 cases was 31 – 40 km/h and for MAIS 4 – 5 cases, 62% were within a broader range of 31 – 50 km/h. The MAIS 2 distribution is more 'normal' and has a relatively low Standard Deviation (SD) of 9 whereas the MAIS 3 and MAIS 4-5 do not demonstrate a good normal distribution curve and have significantly spread (as shown in Table 6 above).

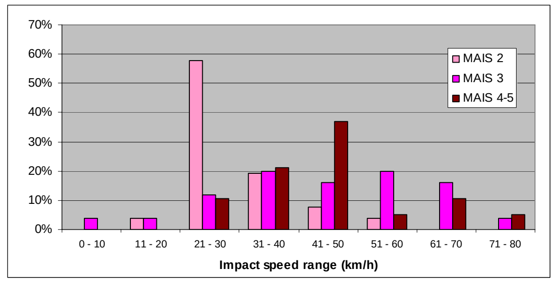

Figure 6 – Impact speed vs. MAIS

ISS vs. impact speed

The Injury Severity Score (ISS) was presented in 1974 [4] as a method of numerically describing the overall injury severity of patients with injuries to more than one area of the body. It could be argued that since pedestrian fatalities in particular are often caused by multiple injuries as opposed to one single injury, ISS would be a more meaningful representation of the severity of such accidents. In order to test this hypothesis with respect to the current study, the relationship between ranges of ISS scores and their corresponding impact speed was observed (Figure 7). Looking at each ISS range in Figure 7, a tendency to more normal distributions can indeed be seen than those for MAIS vs. impact speed.

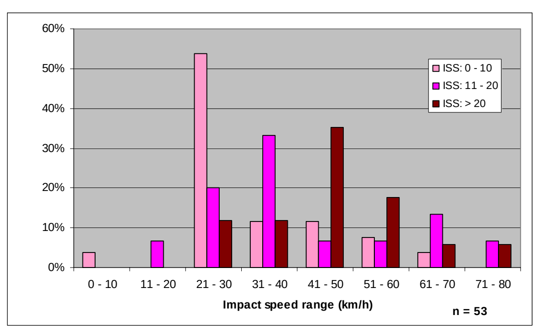

Figure 7 – Impact speed vs. ISS

Probability of injury vs. impact speed

Figure 8 shows a comparison between injury severity and impact speeds for pedestrian injuries from studies spanning 26 years, from Ashton and Mackay [5] Anderson,[6] Hannover [7] and now the current study (APROSYS 2005). The curves drawn are for the relationship:

$$\text{Probability of Injury} \propto V^3$$

From Neal-Sturgess [8] where it is shown that pedestrian injuries can be correlated with impact speed using the concept of Peak Virtual Power.

The trends in the data show that the APROSYS results correlate well with the previous results for serious injuries. For fatal injuries, the APROSYS results are closer to the Hannover results for 2001, indicating that the impact speed for fatalities may be increasing slightly compared to that for the data from 1979 and 1995.

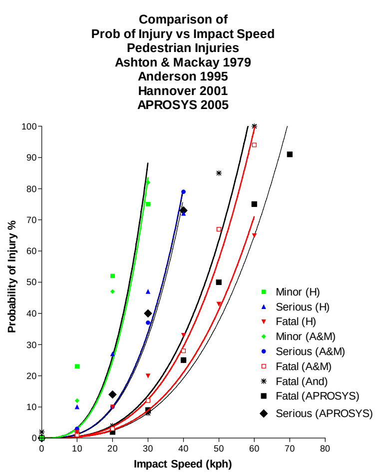

Figure 8 - Probability of injury vs. impact speed

Vehicle braking

Table 7 – In-depth sample: vehicle braking (n=62)

	No. of cases (%)
Hard braking	10 (16)
Some braking	26 (42)
No braking	26 (42)

The braking behaviour of vehicles in the sample as presented in Table 7 is comparable with the braking deceleration found in the GIDAS database.

Injury severity

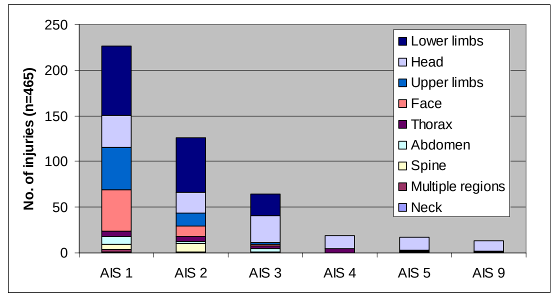

Figure 9 - No. of injuries at each level of severity

Table 8 – Gender vs. severity

Gender	Minor injuries (AIS 1, 2)	Serious injuries (AIS 3+)	All injuries
Male (n=39)	198 (78%)	49 (19%)	254
Female (n=28)	137 (71%)	50 (26%)	193
Unknown (n=3)	17 (94%)	1 (6%)	18
Total (n=70)	352 (76%)	100 (22%)	465

The number of injuries of a given severity are shown in Figure 9, and the Gender breakdown in Table 8. Males had a mean of 6.5 injuries and females a mean of 6.7 injuries. The females in the sample tended to have more serious injuries, but this could have more to do with the fact that a higher proportion of VRU's over the age of 60 were female.

Table 9 – VRU type vs. severity

VRU type	Minor injuries (AIS 1, 2)	Serious injuries (AIS 3+)	All injuries
Pedestrian (n=63)	316 (75%)	94 (22%)	423
Cyclist (n=7)	36 (86%)	6 (14%)	42

Cyclists had a mean of 5.8 injuries and pedestrians a mean of 6.6 injuries. Also, cyclist injuries tended to be less serious, although the sample size is too small to make inferences about the population.

An analysis of the IDD for ISS gave Figure 10 as shown below. It is to be expected that the injury severity will increase towards the upper right hand quadrant, but the clear demarcation shown here is probably an artifact of the small sample size. Nonetheless there are only 1-3 (1-3/23) fatalities below an impact velocity of 32 km/h, which equates to 20 miles/h, and is in accord with Figure 8. Also it can be seen that there are no fatalities below an ISS of around 10. The threshold of an ISS of 16, which is supposed to equate to a 10% risk of fatality Robertson & Redmond, 1991[9] ; Seow and Lau, 1996 [10] is also shown, but here it coincides with a risk of 8/23 = 35% risk of fatality. There already is some concern in the literature that even for large sample studies ISS shows some sample bias Henary et.al [11], and here it seems that the normal large vehicle occupant sample ISS limit does not accord with these results.

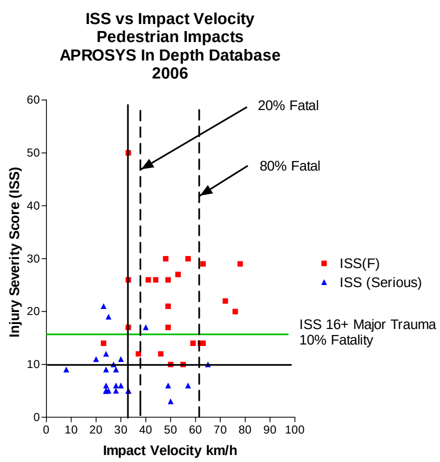

Figure 10.

The statistics are:
Fatals ISS: mean = 21.6 N=23
Standard deviation = 9.5
Serious ISS: mean = 8.1 N=19
Standard deviation = 4.6
These results are statistically significantly different p < 0.0014.

Examining the ISS scores for all types of case in the database child (<12 years old), adult fatal and serious, and elderly fatal and serious gives Figure 11. From Figure 11 it can be seen that the ratio of elderly fatalities below ISS = 16 is 5/12 = 42%, whereas the ratio of adult fatalities below ISS = 16 is 1/9 = 11%, which are in the same rank order as Henary et.al. [11] with 5/27 seniors and 0/28 adults respectively. Again the results are skewed here due to the nature of the sample.

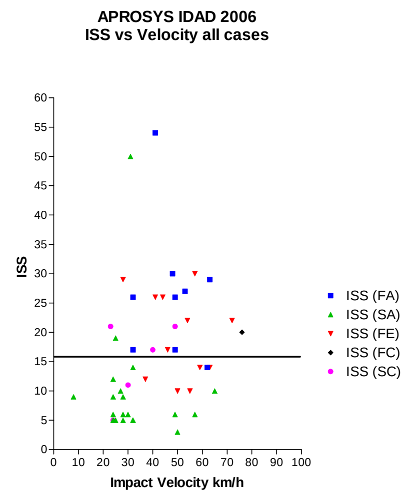

Figure 11.

Injury severity by body region

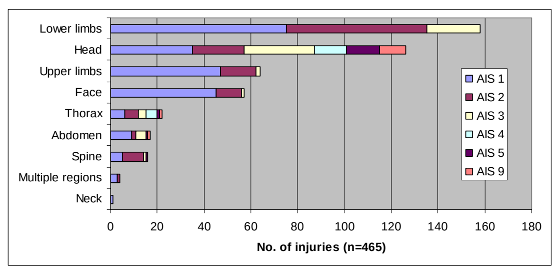

Figure 12– Injuries per body region (In-depth database 1997 - 2004)

The most frequently injured body regions are the head and lower limbs. However, a higher proportion of the head injuries are AIS 3+ compared with the lower limb injuries. In AIS and consequently in the current study, the face is treated as a separate body region. In a similar earlier study done at Hannover (Figure 20) [12] on accidents from 1985 - 1995, facial injuries are considered together with head injuries and consequently head injuries outnumber lower limb injuries. Accounting for this difference in methodology, the results are in agreement with the exception of the different relative proportion of injuries to the thorax and upper limbs in the two studies. This could be explained by the influence of the changing shape of vehicles on injured body regions since the earlier study.

The injury severity is also plotted against the contact zone on the vehicle in Figures 13 to 19 below. When reading these Figures, the table on the left hand side is the relative frequency of all the injuries recorded in the database, whereas the numbers in the boxes on the arrows are the relative frequencies of injuries where the contact location was identified. There are a significant number of injuries recorded in the database for which no contact location was identified, hence the percentages are generally different.

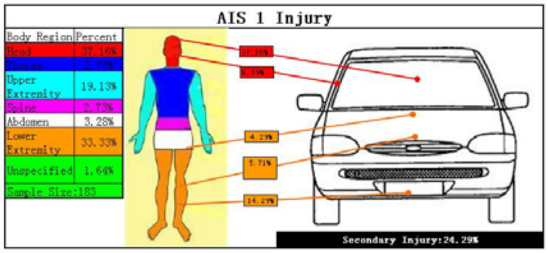

Figure 13.

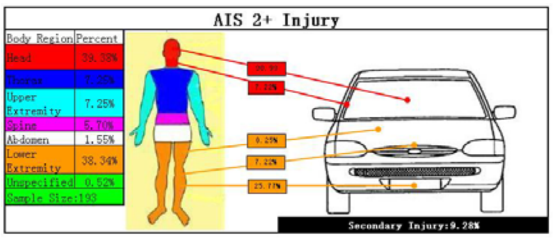

Figure 14.

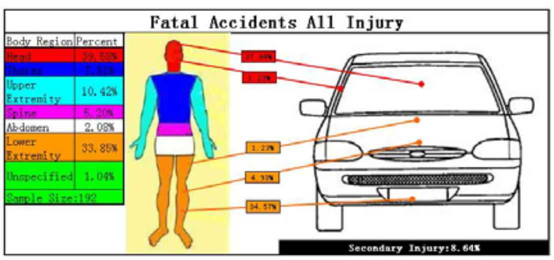

Figure 15.

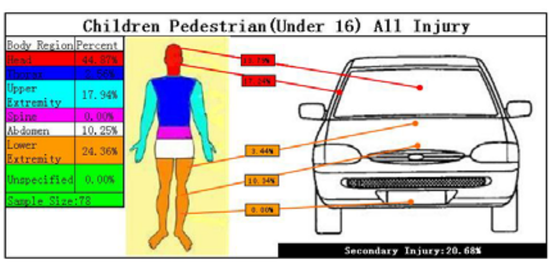

Figure 16.

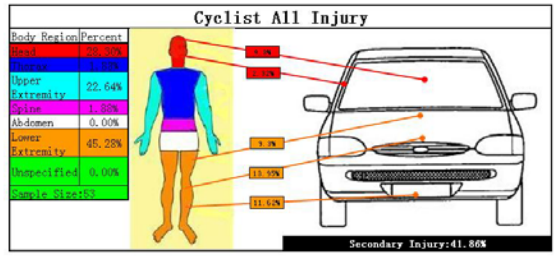

Figure 17.

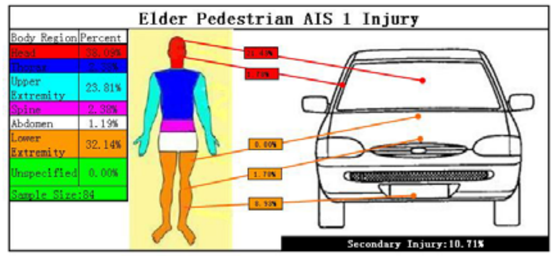

Figure 18

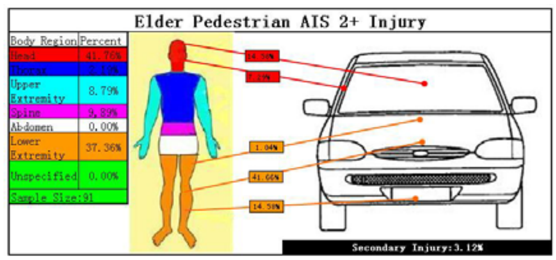

Figure 19.

The results from this study are compared to Otte and Pohlemann [13] Figure 20 below.

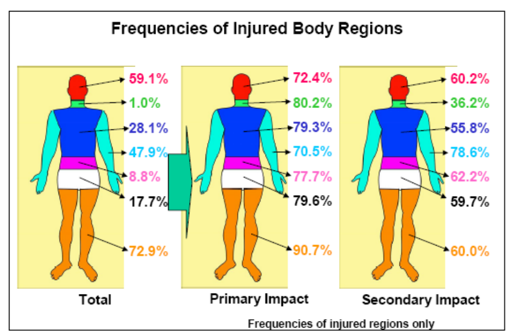

Figure. 20.

From Figs. 13 to 19, and a comparison with Figure 20, it can be seen that the frequencies of the injuries to the body regions are broadly comparable in the two studies. The head and lower extremities are the most frequently injured regions, and the frequencies of the secondary impacts decrease as the severity of the injuries increase.

Head impact location

The locations of head impacts for all the cases were plotted schematically on one standard vehicle – similar to the representation of Otte's 1999 IRCOBI paper [7]. Head impact locations have been plotted in their relative positions as opposed to absolute positions for the sake of comparing accidents involving different shaped vehicles (i.e. a head impact occurring on the top left corner of the windscreen will be shown on the top left corner of the windscreen in the diagram regardless of what the WAD is).

As shown in Figure 21, the fatal head impacts occurred predominantly on and around the windscreen frame (A-Pillars and scuttle). The only impacts occurring in the centre of the windscreen were non-fatal. Of the 3 head impacts occurring on the bonnet away from the scuttle, all were non-fatal and 2 were children.

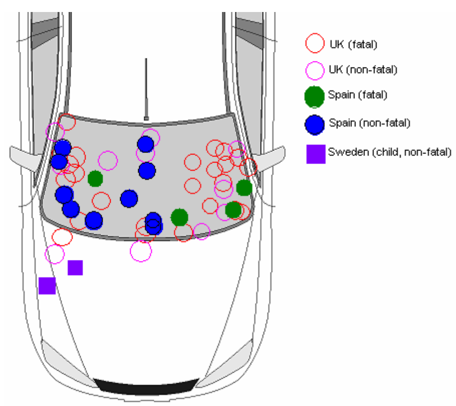

Figure 21 – Head impact locations by severity and country.

The head impact positions were also plotted and coloured according to which country the accident occurred in the see if impacts occurred on a certain side for left–hand and right-hand drive countries respectively - i.e. right-hand drive for UK, left-hand drive for Mainland Europe (Spain and Sweden) (Figure 21). There is a broad trend for more serious head strikes to occur on the side of the vehicle nearest the kerb.

Secondary Impact

Of interest in this project is the significance of the secondary ground impact. This is a difficult parameter to assess, as the vast majority of pedestrian and cyclist collisions ultimately result in the victim lying on the ground. An analysis of the database was conducted to see what evidence it contained, the results are shown below.

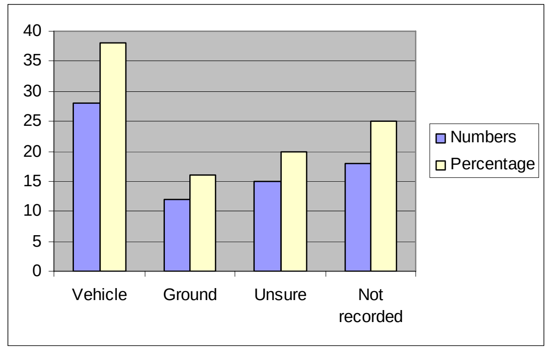

Figure 22. Percentages of injury sources

It is obvious from the Figure 22 that in 18 cases no information was recorded, and so there is a large margin of uncertainty. In this sample the percentage of the most serious injuries arising from the secondary ground impact are around 43% of the injuries ascribable to the vehicles. This is slightly lower, but of the same order as GIDAS, who give a percentage of around 463/933 = 49% of injuries caused by the secondary impact [13].

A summary table of the results displayed in Figs 13 to 19, is shown below:

Pedestrians			
Injury Severity	**Primary Impact %**	**Secondary Impact %**	**Ratio Pri./Sec.**
All	68	16	4.25
AIS1	68	24	2.8
AIS2+	79	9	8.8
Serious ALL	62	22	2.8
Fatal All	80	9	8.9
Child All	45	21	2.1
Elderly All	78	12	6.5
Elderly AIS1	34	11	3.1
Elderly AIS2+	79	3	26.3
Cyclists			
All	48	42	1.1

Table 10.

From table 10 it can be seen that in general for all categories of cases the secondary impacts are a larger proportion of the injuries for categories of lower injury severity. The primary impact appears particularly important for the elderly victims. Secondary impacts appear more significant for children than adults, and particularly important for cyclists; although the sample for the cyclists is very small. However, caution is necessary when interpreting the frequency tables. A case by case analysis here (Table 11 below) shows that often the severity of the secondary impact is equal to the primary impact.

Relative severity of primary and secondary impacts			
Case No in IDD	Severity	MAIS in Impact	AIS Secondary Impact
BC001	fatal	3	3
BP001	fatal	3	3
BP002	fatal	5	5
GC001	serious	2	2
GC002	serious	2	2
IP007	serious	3	3
GP002	serious	3	3
OC002	serious	2	2

Table 11.

Elderly Fatal Pedestrians

The elderly cases were extracted to give Figure 23 shown below. From Figure 23 it is obvious that there are a large proportion of elderly casualties dying at low ISS scores (5/12). This should be compared to the study by Henary et.al [11] who reported 5/27 elderly deaths with ISS < 16. Following through on this possible anomaly it is necessary to consider the injury severities and frequencies in the various parts of the IDD, such as comparing the frequencies of adult and elderly of injury severity. The mortality rate for the elderly was almost three times that for the adults (100% cf. 37.5%), which again is similar to Henary et.al. [11], but here this was obviously influenced by the nature of the sample.

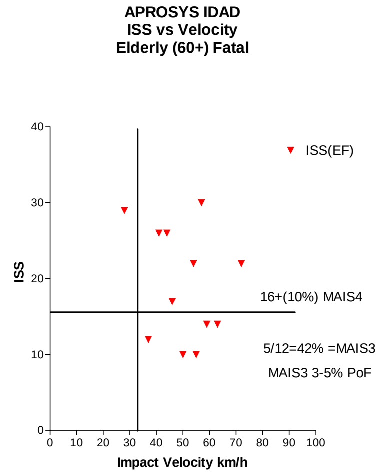

Figure 23.

From the IDD the Adult Fatal cases are as shown in the table below;

Adult Fatal			
Vel. km/h	Body Region	MAIS	ISS
53	H	3	27
48	H	5	30
49	H	3	17
62	H	3	14
63	H	5	29
41	H	5	54
32	T	4	17
49	H	5	26
32	H	5	26

Table 12.

Key for body region: H = Head, T = Thorax, S = Spine, P = Pelvis, E = Extremity.

From Table 12 it is evident that the proportions of the various injury severities are MAIS3 = 3/9 = 33%, MAIS4 = 1/9 = 11%, and MAIS5 = 5/9 = 66%. The body regions are Head 8/9 = 88%, and Thorax 1/9 = 11%. The table of Elderly Fatals is shown below:

Elderly Fatal			
Velocity km/h	**Body Region**	**MAIS**	**ISS**
54	S/H	3	22
55	P	3	10
37	E	2	12
57	S/H	5	30
72	H	3	22

28	H	4	29
63	H	3	14
41	H	5	26
59	E	3	14
46	S/H	3	17
50	H	3	10
44	H	5	26

Table 13.

From Table 13 it is evident that the proportions of the various injury severities are MAIS2 = 1/12 = 8%, MAIS3 = 7/12 = 58%, MAIS4 = 1/12 = 8%, and MAIS5 = 3/12 = 25%. Whereas the body regions are head (including cervical spine) 9/12 = 75%, extremities 2/12 = 16% and Pelvis 1/12 = 8%. A body region analysis for the elderly fatals gives Figure 28 shown below.

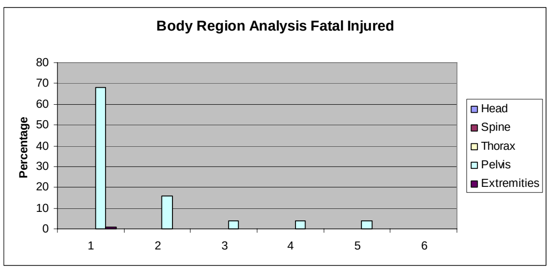

Figure 24.

From both Tables 12 and 13 and Figure 24 the body region overwhelming associated with the primary cause of death is the head. It is often thought that one of the confounding factors in elderly deaths after road traffic accidents (RTA's) is the length of stay in hospital, and hence the increased risk of secondary infection. To examine this the time-to-die was investigated, this is not necessarily the time in hospital, but it is believed to be an acceptable surrogate. Of the data in the database there were 15 instances of fatal injuries where the time to die was not recorded, which heavily reduced the number of valid entries; the valid entries are shown in Tables 14 and 15. Note that the numbers in these tables are not necessarily the same as in other categories of analysis, because the missing data may be either, gender, age, time to die, or ISS value. Two cases where the time-to-die was 100 and 150 days respectively were omitted from the analysis as they do not conform to the definition of death (<= 30 days) used for the rest of the analyses.

Time to Die – Elderly (>60)				
Days	0	2	13	14
N	6	1	1	1
MAIS (ISS)	2 (12)	3 (10)	2 (12)	5 (26)
	3xMAIS3 (22,14,17)			
	3xMAIS4 (29,21,24)			

Table 14.

Time to Die - Adult (12<Y<60)		
Days	0	30
N	5	1
MAIS (ISS)	3 (27)	4 (NC)
	4	
	3xMAIS5 (30,54,26)	

Table 15.

There are too few entries to form significant conclusions, but it appears that, in this sample, the majority of the casualties were declared either dead at the scene or on arrival in the hospital. The elderly do show a number of intermediate stays in hospital, however the sample is small, whereas the adults show just one outlier at 30 days.

To compare the incidence of the injury severities in the IDD it is necessary to consider the frequencies of injury severities in a large population study. No large sample studies of pedestrians for the calibration of MAIS yet exist, therefore a study of CCIS Phase 6 & 7 1999 - 2005 (Neal-Sturgess and Hassan, BASC Report 2006 [14]) for vehicle occupants is taken as representative of large sample calibration of MAIS, as an example for comparison. It should be remembered that the injury data taken for the calibration of HIC i.e. Prasad-Mertz [15] is taken from vehicle occupant studies. In the study conducted here the cases were selected on the basis of belted passenger car occupants with a valid Estimated Test Speed (ETS) [a measure of impact speed], to maximize the sample size. The frequency table is as shown below:

Belted drivers in passenger cars – known ETS (kph)

CCIS 1999 – 2005			
MAIS	Fatal	Total Injured	% Fatal
1	0	745	0.0
2	1	202	0.5
3	7	112	6.2
4	17	25	68.0
5	19	23	82.6
6	4	4	100.0
Totals	48	1111	

Table 16.

Further considering fatals at a given MAIS value as a ratio of total fatals, to account for frequency effects in a sample of fatals, gives:

Belted drivers in passenger cars – known ETS (kph)

CCIS Fatals		
MAIS	Ratio	Percentage of Total
1	0	0.0
2	1/48	2.1
3	7/48	14.6
4	17/48	35.4
5	19/48	39.6
6	4/48	8.3
Total		100.0

Table 17.

Comparing the significance of the frequency of the injury severities between the IDD and CCIS gives the following table:

Significance levels CCIS vs IDD		
MAIS	**Fatals Adult**	**Fatals Elderly**
1	0	0
2	0	Chi-square = 1.051 not significant.
3	Chi-square = 1.168 not significant.	Chi-square = 5.353 *p* <= 0.025. The distribution is significant.
4	Chi-square = 1.240 not significant.	Chi-square = 2.08 not significant.
5	Chi-square = 0.300 not significant.	Chi-square = 0.436 not significant.
6	0	0

Table 18.

From Table 18 it can be seen that for the categories of Elderly Fatals the incidence of MAIS3 is very significant compared to the CCIS sample i.e. $p < 0.025\%$.

DISCUSSION

The in-depth database of pedestrian and cyclist developed for the reconstruction activity was analysed to assess whether or not it was representative of the European epidemiology. Data for which a reasonably direct comparison was possible included type, age and gender of the vulnerable road user, and also the relationship between age and severity. Cyclists were not well represented – only 7 cases were available which allowed few conclusions to be drawn about the characteristics of cycling accidents or injured cyclists. The younger age ranges (under 30) were represented in proportion with the epidemiology but the older age ranges were slightly over-represented (explained by the BASC contribution of all-fatal accidents and the higher proportion of older people in this category), male and female were well represented. When comparing age and severity, the general trend of increased age leading to increased risk of fatality could be seen to some degree in Figures 1 and 2. The difference in mean age of those seriously injured and those fatally injured was found to be statistically significant (Table 4). An assessment of the vehicles represented by the sample was more reflective of the fleet than any prevalence for a particular age or make of vehicle to be involved in a VRU collision. The average year of manufacture was 1995 but half the vehicles were 1997 or later.

The standing orientation of the pedestrian prior to impact was 89% stuck side-on – which agreed with the literature.[16] The in-depth sample impact speeds were presented and compared with those found in the GIDAS sample (Figure 4). The former tended to have higher impact speeds than the latter (mean of 40km/h and 28km/h respectively) - a consequence of having a disproportionate number of fatal and serious accidents which are more likely to be the result of higher speed impacts. The relationship between impact speed and injury severity was presented using 3 different definitions of injury severity: fatal / non-fatal, MAIS (Maximum AIS) and ISS (Injury Severity Score). The difference between the mean impact speeds for serious and fatal accidents was highly significant. The MAIS vs. impact speed relationship, presented and discussed in detail in the main section, was found to be quite non-linear with an anomaly at MAIS 4. As expected, a better relationship was found between ISS and impact speed due to better suitability of this description of injury severity to the multiple injury nature of VRU accidents. There is a good correlation between the injury risk curves for serious injuries vs. impact speed derived from the current study and those from similar studies. For fatal injuries, the APROSYS results are closer to the 2001 study,[13] indicating that the impact speed for fatalities may be increasing slightly compared to that for the data from 1979 [5] and 1995 [6]. The mean impact speed of vehicles which braked before impact and those which did not was compared but no significant difference was found.

For each case, detailed injuries were recorded (total n=458). Lower limb injuries were most common followed closely by head injuries. Facial injuries were considered separately according to AIS protocol – if considered as one body region, the most common injury region would be the head as found by an earlier study [7]. Also interesting to note is that out of 458 injuries, only 1 was to the neck, AIS 1. Looking at AIS 4- 5 injuries only, the thorax is the next most significant region after the head, but including AIS 3 injuries, the upper limbs become the next most significant region after the head, followed by the thorax.

The head impact locations for all impacts were plotted schematically on one generic vehicle diagram, showing the positions of primary head impact relative to the windscreen, scuttle and A-Pillars for fatal and non-fatal impacts (Figure 21). The fatal head impacts occurred predominantly on and around the windscreen frame (A-Pillars and scuttle). The only impacts occurring in the centre of the windscreen were non-fatal. Of the 3 head impacts occurring on the bonnet away from the scuttle, all were non-fatal and 2 were children. The head impact positions were also plotted according to which country the accident occurred in the see if impacts occurred on a certain side for left–hand and right-hand drive countries respectively - i.e. right-hand drive for UK, left-hand drive for Spain and Sweden (Figure 21). All 13 non-fatal head impacts in Spain and Sweden were located on or to the right of the windscreen centre-line, but the 3 remaining Spanish fatal head impacts did occur on the left side. The UK head impacts had only a slight skew towards the left side of the windscreen centre-line. Together, this does suggest that head impacts are slightly more common on the nearside of the vehicle.

The analysis of ground impact in this study, although subject to uncertainty due to the variables not being recorded in a number of cases, it was found that the injury severity from the ground impact was generally less frequent than the injury severity attributed to the vehicle, which is similar to recent analyses in the literature. However, a case by case study showed that the injury severity in the secondary impact can be similar to that in the primary impact. A recent study was conducted by Hannover University to address this specific issue [13]. Secondary injuries were found to be less severe - for example, 36% of the pedestrians received a head injury due to secondary impact compared with 43% due to primary impact, a greater proportion of which were AIS 2+. However, secondary impacts were still significant with over 2/3 (65%) of the pedestrians in the study received some kind of injury from the road. Both the Pedestrian Crash Data Study (PCDS) and the Pedestrian Injury Crash Study (PICS) conducted in the US [17-19] and Australia [20] found that most injuries caused by the environment (i.e. the road and roadside objects) were minor and that the more recent accidents involving newer cars had a much lower proportion of injuries caused by the road. A review of the literature by McLean et al [21] concluded that pedestrian injuries caused by impact with the environment were less severe than those caused by direct contact with the vehicle and in a later in-depth study of 77 cases by the same authors [22], analysis showed that while the environment was the most common cause of head injuries in general, it was not the cause of any serious head injuries (AIS 3+). Although this contradicts Otte's findings for all-severity head injuries (i.e. that the vehicle was the more common cause of head injuries in general), they are in agreement on the point that the vehicle was usually the cause of the serious head injuries. This agrees with earlier work by Ashton et al [23] that found that a head impact with the car is more likely to be the cause of significant brain injury to a pedestrian than contact with the road surface, although this does involve much older vehicle designs. This topic is complex and requires further study, as the proportion of pedestrian/cyclist injuries from the ground (environment) represents the injuries that cannot be influenced by vehicle design, and so the base-line of injuries that cannot be reduced.

It is now generally acknowledged that the energy required to cause an injury reduces as a person ages Augenstein, 2001 [24] , and older drivers are more vulnerable to injury in a crash. Their skeletal structures are more easily damaged, and the consequences of any assault are likely to be more serious compared with younger drivers (Dejeammes and Ramet, 1996 [25] ; Evans, 1991 [26] ; Mackay, 1989 [27] ; Viano et al, 1989 [28]). The influence of osteoporosis particularly on females is now well established (Berthel, 1980 [29]). Dejammes and Ramet, 1996 [25]) concluded that the most elderly population could withstand a chest load of 5,000N, whilst the younger population could withstand a chest load of 8,000N. The implications of this are that older occupants may be several times more likely to sustain a life threatening chest injury (Padmanaban, 2001 [30]), and this can occur in a relatively moderate crash [24]. A study by Morris et.al AAAM 2002 [31] and Welsh et.al. 2006 [32]. found that skeletal injuries to the elderly were the major difference compared to a younger population, and that the major contact injuries were seat belt induced multiple rib fractures. This indicates the need for intelligent restraints and the BOSCOS project (Watson and Hardy 2006 [33]) aims to mitigate these age related injuries by bone scanning and automatic adjustment of restraints to compensate for increased fragility.

Pedestrian-motor vehicle trauma affects all age groups, and the results from several epidemiological studies have indicated that the annual pedestrian mortality is substantially higher among seniors than any other age group (Aronson et al., 1984 [17] ; Ashton et al., 1979 [23] ; Harruff et al., 1998 [18] ; Hoxie et al., 1994 [34] ; Knoblauch et al., 1995 [19] ; NHTSA, 2001 [35] ; Oxley & Fildes, 1996 [36]). In addition to the increased exposure, a number of epidemiological studies have indicated that senior pedestrians also are more likely to get killed or severely injured once involved in a crash [37]. Kong et al. 1996 [38] conducted a retrospective review of 273 pedestrian victims from 1991 to 1994. They reported significantly ($p < 0.05$) higher average ISS (11.6 vs. 8.8) and mortality (13 percent vs. 5 percent) for the senior (age ≥60 years), than for the adult (age 16–59 years) victims. Kong's results were confirmed by Peng and Bongard 1999 [39]. The most recent statistics from NHTSA on the morbidity and mortality of various age groups of pedestrians indicate that the mortality for the senior (age ≥ 60 years) pedestrian victims in the United States during 2003 was approximately 12.9 percent, which was twice as high as for the corresponding adult (age 19–50 years) group (NHTSA, 2005 [40]). A recent study by Henary, Ivarsson, and Crandall [11] compares the morbidity and mortality of senior (age ≥60 years) and adult (age 19–59 years) pedestrian victims while controlling for other confounding factors that may influence this relationship. They used the NASS Pedestrian Crash Data Study (PCDS) database for a cross-sectional study to compare the outcome of senior (age ≥60 years) and adult (age 19 to 59 years) pedestrian victims. There were 352 pedestrian victims included in the study, of which 262 (74 percent) were adults and 90 (26 percent) were seniors. Compared to the adult victims, the seniors had a higher average ISS (23 vs. 16, $p = 0.018$) and higher mortality (30 percent vs. 11 percent, $p \leq 0.001$). The seniors were also more likely to have an ISS ≥9 (odds ratio = 2.72; 95 percent CI: 1.31–5.68) and to die (odds ratio = 6.68; 95 percent CI: 2.37–19.88). The results showed that mortality rate among subjects with an ISS ≥16 was 61 percent for the seniors compared to only 37 percent for the adults. Also, five out of the 27 seniors who died had ISS <16 while none of the 28 adults who died had ISS <16. This finding is in agreement with what was previously reported, that ISS has a relatively low correlation with mortality in trauma victims over age 70 (Oreskovich et al., 1984 [41]). It was concluded that the adjusted age-dependent risks should be considered when calculating or projecting pedestrian morbidity and mortality.

In the study conducted here the "expectation" of cases with a MAIS3 in a random sample of fatals in the CCIS analysis was 12%. Therefore, adjusting for frequency, in a random sample of 12 cases, only 17% of 12 = 2 cases should be evident with MAIS <= 3. In the In-Depth APROSYS Database sample of elderly fatals there are 8/12 = 75%, and so the MAIS <= 3 are very seriously over represented. Although this is a small sample, this highly significant degree of over representation is considered indicative that there are probably significant differences between the proportion of elderly pedestrian casualties who have died with only a MAIS3 injury, and a general vehicle occupant population. These statistics are broadly in agreement with the findings of Henary et.al. 2006. The consequences of this could be very significant, because **IF** MAIS3 or ISS = 9 is the relevant injury threshold level for fatals in elderly pedestrian casualties, and a 15%tile is taken as reasonable (cf. HIC 1000 = 15%tile of MAIS4), then a level of HIC = 600 is more suitable for the elderly vulnerable road users (Prasad-Mertz [15]). Which casts doubt on the HIC levels chosen for the upcoming European Legislation (Phase 1: HIC = 1000 for 50% of bonnet area, and HIC = 2000 for 50% of the bonnet area, and Phase 2 possibly HIC = 1000 over the whole bonnet), which have been read-across from large sample vehicle occupant studies conducted by NHTSA, in terms of the possible relevance to elderly vulnerable road users in pedestrian impacts. Therefore a calibration of MAIS and ISS for a much larger sample of pedestrians is necessary, with the elderly (>60 years of age) ranked separately to the under 60's population, and the appropriate injury risk functions derived to see what are deemed to be the relevant HIC values for elderly vulnerable road users in pedestrian impacts.

CONCLUSIONS

1. Cyclists were under-represented in the database, making it impossible to draw definitive conclusions on the characteristics of cyclist accidents or injured cyclists.
2. A better relationship was found between ISS (Injury Severity Score) and impact speed than between MAIS and impact speed, due to better suitability of this description of injury severity to the multiple injury nature of VRU accidents.
3. There was a good correlation of injury risk as related to impact speed between the cases in the In-depth database and previously published studies.
4. The locations of primary head impacts with vehicles lay principally on the windscreen, scuttle and A-pillar. Child head impacts were also identified in these regions.
5. Head impacts were identified as being slightly more common on the nearside of the vehicle (that is, nearest to the kerbside) regardless of which side of the road vehicles drive on.
6. The proportion of ground impacts found in this study were broadly comparable with the literature, the secondary impacts being generally associated with lower injury severity than injuries attributed to the vehicles. However, a case by case analysis showed that the severity of the secondary impact can be comparable to that of the primary impact.
7. There was a considerable over representation of elderly fatals at MAIS3 than would be expected from population studies conducted on vehicle occupants, which again are similar to recent findings in the US.
8. It is concluded that a calibration of MAIS and ISS against fatality/non fatality for a much larger sample of pedestrians is necessary, with the elderly (>60 years of age) ranked separately to the under 60's population, and the appropriate injury risk functions derived to see what are deemed to be the relevant threshold injury values for elderly vulnerable road users in pedestrian impacts.

REFERENCES

1. Carter, E., *APROSYS WP3.1.1 Accident Data: UK National epidemiological studies on pedestrian and cyclist accidents*. 2005.
2. Janssen, E.G. and J. Wismans. *Experimental and mathematical simulation of pedestrian-vehicle and cyclist-vehicle accidents.* in *10th ESV (Int. Tech. Conf. on Experimental Safety Vehicles).* 1985. Oxford, UK.
3. Neal-Sturgess, C.E., G. Coley, and P. De Olivera. *Pedestrian injury - effects in impact speed and contact stiffness.* in *Vehicle Safety 2002*. 2002. London: IMechE.
4. Baker, S.P., et al., *The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care.* Journal of Trauma, 1974. **14(3)**: p. p. 187-196.
5. Ashton, S.J. and G.M. Mackay. *Some Characteristics of the Population who Suffer Trauma as Pedestrians When Hit by Cars and Some Resulting Implications.* in *IRCOBI*. 1979.
6. Anderson, R.W.G., et al. *Vehicle Travel Speeds and the Incidence of Fatal Pedestrian Crashes.* in *IRCOBI*. 1995.

7. Otte, D. *Severity and mechanism of head impacts in car to pedestrian accidents.* in *IRCOBI (International Research Council On the Biomechanics of Impact)*. 1999. Sitges, Spain.
8. Neal-Sturgess, C.E.N., *A Thermomechanical Theory of Impact Trauma.* Proc. IMechE, Part D: J. of Automobile Div., 2002. **216**: p. p. 883-895.
9. Robertson, C. and A.D. Redmond, *The management of major trauma.* 1991, New York: Oxford University Press.
10. Seow, E. and G. Lau, *Who dies at A&E? The role of forensic pathology in the audit of mortality in an emergency medicine department.* Journal of Forensic Science International, 1996. **Vol. 82**: p. pp. 201–210.
11. Henary, B.Y., J. Ivarsson, and J.R. Crandall, *The influence of age on the morbidity and mortality of pedestrian victims.* Traffic Injury Prevention, 2006. **7**(2): p. 182 - 190.
12. Otte, D., *Pedestrian impacted by front of car*, in *Private communication from Accident Research Unit*. 1997, Medical University of Hannover: Hannover.
13. Otte, D. and T. Pohlemann. *Analysis and load assessment of secondary impact to adult pedestrians after car collisions on roads*. in *IRCOBI*. 2001.
14. Neal-Sturgess, C.E. and A.M. Hassan, *Calibration of AIS against fatality CCIS 1999-2005*. 2006, Birmingham Automotive Safety Centre.
15. Prasad, P. and H.J. Mertz. *The Position of the U.S. Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment*. in *SAE*. 1985.
16. Otte, D., *Pedestrian impacted by front of car, in Private communication from Accident Research Unit. Medical University of Hannover*. 1997.
17. Aronson, S.C., et al., *Traffic fatalities in Rhode island: Part IV the pedestrian victim.* Rhode Island Medical Journal, 1984. **Vol. 67**: p. pp. 485–489.
18. Harruff, R.C., A. Avery, and A.S. Alter-Pandya, *Analysis of circumstances and injuries in 217 pedestrian traffic fatalities.* Accident Analysis and Prevention, 1998. **Vol. 30**(No. 1): p. pp. 11–20.
19. Knoblauch, R., et al., *Older Pedestrian Characteristics for Use in Highway Design.* US Department of Transportation. DOT FHWA-RD-93-177., 1995.
20. Fildes, B.N., et al. *Older Driver Safety – A challenge for Sweden's 'Vision Zero'*. in *Proceedings of the Australian Transport Research Forum*. 2001. Hobart.
21. McLean, e.a., *PEDSPEED (1 & 2)*. 1994.
22. Anderson, R.W.G. and Maclean, *Vehicle design and speed and pedestrian injury*. 2001. **http://www.monash.edu.au/oce/roadsafety/abstracts_and_papers/110/110_revised.pdf**.
23. Ashton, S.J., S. Bimson, and C. Driscoll, *Patterns of injury in pedestrian accidents.* Proc. American Association of Automotive Medicine, 1979. **Vol. 23**: p. pp. 185–202.
24. Augenstein, J. *Differences in Clinical Response between the Young and the Elderly.* in *Aging and Driving Symposium, Association for the Advancement of Automotive Medicine*. 2001. Des Plaines, IL.
25. Dejammes, M. and M. Ramet. *Aging Process and Safety Enhancements of Car Occupants.* in *Proceedings of Enhanced Safety in Vehicles Conference*. 1996. Melbourne, Australia.
26. Evans, L., *Traffic Safety and the Driver*. 1991, New York: Van Nostrand Reinhold.
27. Mackay, G.M. *Biomechanics and the Regulation of Vehicle Crash Performance*. in *Proceedings of 33rd AAAM Conference*. 1989. Baltimore, USA.
28. Viano, D., et al. *Involvement of Older Drivers in Multi-Vehicle Side Impact Crashes*. in *Proceedings of 33rd AAAM Conference*. 1989. Baltimore, USA.
29. Berthel, M., et al., *La Perte Minerale Ousseuse Liee a L'age.* Medicine et Hygenie, 1980. **38**: p. pp 1828-1831.
30. Padmanaban, J. *Crash Injury Experience of Elderly Drivers.* in *Proceedings of the Presentation at Aging and Driving Symposium, AAAM, Des Plaines, IL*. 2001. Southfield, MI.

31. Morris, A., et al. *An Overview of Requirements for the Crash Protection of Older Drivers*. in *AAAM*. 2002.
32. Welsh, R., et al.,*Crash Characteristics and Injury Outcomes for Older Passenger Car Occupants.* Transportation Research, Special Issue, 2006: p. (Accepted for publication, in press).
33. Watson, J. and R. Hardy. *The BOSCOS System for Automotive Vehicles.* in *Design for Impact and Crashworthiness in Aerospace and Automotive Vehicle Structures*. 2006. Loughborough: IMechE.
34. Hoxie, R.E. and L.Z. Rubenstein, *Are older pedestrians allowed enough time to cross intersections safely?* Journal of American Geriatric Society, 1994. **Vol. 42**: p. pp. 241–244.
35. *Ageing and Transport: Mobility Needs and Safety Issues*, O.S.E. Group, Editor. 2001, OECD: Paris, France.
36. Oxley, J.A., et al. *Differences in traffic judgments between young and old adult pedestrians*. in *Proc. 40th AAAM*. 1996.
37. Leaf, W.A. and D.F. Preusser, *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*. 1999, U. S. Department of Transportation National Highway Traffic Safety Administration.
38. Kong, L.B., et al., *Pedestrian-motor vehicle trauma: An analysis of injury profile by age.* Journal of American College of Surgeons, 1996. **Vol.182**: p. pp. 17–23.
39. Peng, R.Y. and F.S. Bongard, *Pedestrian versus motor vehicle accidents: An analysis of 5,000 patients.* Journal of the American College of Surgeons, 1999. **Vol. 189**: p. pp. 343–348.
40. NHTSA, *Traffic safety facts 2003: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimates System.* 2005.
41. Oreskovich, M.R., J.D. Howard, and M.K. Copass, *Geriatric Trauma: Injury patterns and outcome.* J Trauma, 1984. **Vol. 24**: p. pp. 565–572.