Possibilities and Limitations of Injury Protection of Vulnerable Road Users based on an In-Depth Accident Study

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Abstract – Road accidents are a worldwide problem and today result in over 1.18 million deaths (1999 World Health Report) and over 20 million persons being injured or dying every year. The main victims of road accidents especially in developing countries are the vulnerable road users (pedestrians, cyclists, motorized two-wheeler riders). Even in Europe the amount of traffic victims from the group of vulnerable road users is quite high. Each year in the European Union approximately 17000 vulnerable road users are killed as the result of being struck by a motor vehicle. Accident documentations from 1985 to 2003 are used for this study. The vulnerable road users were differentiated as pedestrians n=1200), motorcyclists (n=875) and bicyclists (n=2285). The injuries are described in detail with location on the body and injury severity AIS. The injury related speed distributions and the parts of cars to which the injuries can be attributed are shown and discussed in the paper. Proposals for countermeasures are discussed in the conclusions. In the study the methodology of GIDAS (German-In-Depth-Accident Study) and the possibilities of In-Depth-Investigations will be described in detail. The presentation will give an overview of the existing interdisciplinary research worldwide, include accident and injury statistics and will conclude with recommendations for future research.

Keywords: accident analysis, injury pattern, vulnerable road users, pedestrian, bicycle, motorcycle

1 Introduction

Pedestrians, bicyclists and users of motorized two-wheelers are considered vulnerable road users in traffic. Only bicyclists and motorcyclists can protect themselves from injuries in then course of a traffic accident by wearing suitable crash helmets or protective clothing, as opposed to pedestrians. Otherwise all VRU have to depend on protective measures on the vehicles. Injuries are induced by a high impact energy, which exceeds the biomechanical limit forces of the human body. Thus in case of an accident it depends on the individual accident scenario, in how injuries occur, or the corresponding type of collision and/or the collision partner and/or the impact velocity between persons and vehicle make for safety potential. Thus it is reasonable that accidents involving VRU occur globally with different degrees of frequency and severity, as the specific structures of the traffic events and the considerable (in part) temperature differences in the individual countries result in a different acceptance of protection types.

1.1 Significance of the accident numbers worldwide

In 2002, an estimated 1.18 million people died from road traffic crashes worldwide [WHO report on traffic injury prevention - 1], 2.1% of all global deaths. In addition an estimated 20 to 50 million people are injured in road crashes each year. Due to the different population structures and the traffic behavior in the different countries and continents the risks differ. Thus in some European countries – for instance Germany – only 2.2% of all persons injured in the course of traffic accidents are died, in other European countries such as Austria 2.8%, in the countries of southern Europe with an increased frequency of two-wheeler traffic such Portugal 3,9% or Spain, where even 6.5% of the casualties are injured or killed. In eastern countries outside Europe for instance in Romania 32% and in Russia 17% of all persons injured in traffic accident were recorded as fatal [UNECE Working Party on Road Traffic Safety, statistic 1997 for ECE Countries - 2]. Table 1 shows an overview concerning the selected countries, for which the corresponding numbers of accidents were available.

Table 1 Statistical data of casualties in road traffic accidents for selected countries worldwide (UNECE) with percentage of persons killed and portion of killed vulnerable road user (VRU)

Country	Accidents involving personal injury	Persons killed		
		n	%	portion % VRU
Austria	39695	1105	2,8	35,4
Belgium	50078	1364	2,7	33,5
Canada	152689	3064	2,0	19,3
Czech Republic	28376	1597	5,6	43,2
Denmark	8004	489	6,1	40,5
France	125202	7989	6,4	32,0
Germany	380835	8549	2,2	34,7
Hungary	19097	1391	7,3	54,1
Israel	25491	530	2,1	44,5
Italy	190031	6226	3,3	37,9
Netherlands	11238	1163	10,3	46,5
Norway	8765	303	3,5	29,0
Poland	66586	7310	11,0	51,5
Portugal	49417	1939	3,9	51,7
Romania	8801	2863	32,5	56,7
Russian Federation	156515	27665	17,7	51,2
Slovenia	6973	358	5,1	33,5
Spain	86067	5604	6,5	35,4
Sweden	15752	541	3,4	30,1
Turkey	61480	5125	8,3	30,5
Ukraine	37944	5988	15,8	63,0
United Kingdom	240046	3599	1,5	46,3
United States	2222000	41967	1,9	19,6
Total	4129797	164677	4,0	36,8

Road traffic death rates have decreased in high-income countries like Europe and the US since the 1970s, for example Germany 65%, North America 27%. Meanwhile, rates in low-income countries have increased substantially, in Asia the fatality rates rose by 44% in Malaysia and by 243% in China [Peden - 3]. That study pointed out that low- and middle-income countries represent 85% of the deaths. In many developing nations, though vehicle use has skyrocketed, the vast majority of people still walk or bicycle to work. Those traveling in motorized vehicles are often bus passengers or motorized two-wheeler riders. Vehicles are less safe in developing nations. Passenger cars tend to be older and do not have air bags, collapsible steering columns or other crash-protection features. In addition, vehicles are not as well maintained in developing countries. Poor road and land-use planning often leads to a deadly mix of high-speed through-traffic, heavy commercial vehicles, motorized two-wheelers, pedestrians and bicyclists on developing-country roads. Accommodations for vulnerable road users, such as sidewalks and bicycle lanes, are rare and the portion of vulnerable road users on all casualties, as table 1 pointed out, is different too and various from 19.6% in US to approximately 30 to 40% in Europe and 50 to 60% in Asia or the Eastern countries.

1.2 Which vulnerable road users are at risk?

In Europe and Northern America nearly identical accident structures can be found. 13% of the fatalities in 1997 in Germany were using motorized two-wheelers, another 13% were pedestrians and 8% bicyclists. In Spain also 16% of the deaths in traffic in 1997 were motorized two-wheeler users, only 2% bicyclists and even 17% pedestrians. In the US only 5% powered two-wheeler users were killed, also 2% bicyclists and another 13% pedestrians.

Overall Asia, Hong Kong, (China) had the highest share of pedestrian deaths (two third of all fatal accidents) followed by Dhaka, Bangladesh (India) with 63%, Pakistan 50%, Republic of Korea 48%, Fiji 43% and Papua-New Guinea 33% [Hoque - 4]. Conversely, the percentage of pedestrian deaths in Thailand and PR China were particularly low, and even cyclist fatalities were reported to be low in China at 6 %.

1.3 Aims and options of finding main problems by in-depth investigation

Considering the relatively diverse emphasis of the different traffic participants, an differentiation has to be made between accident sequence and the collision sequence. Whereas the latter induces the resulting injury pattern and severity of the injuries, the former determines the resulting kinematics of the impact and the injuries mechanics. Accident analyses supply conclusions concerning these basics.

Such accident analyses are based on accident reports by the police, which as a rule are supplied for every country as so-called National Accident Statistics and which is internationally available on the web for many countries. Additionally, for a number of years the so-called „In-Depth-Investigation“ Teams have been in existence, which collect information concerning the damage to the vehicle(s), injury patterns and the origin of the accident at the site of the accident immediately or within days of the event. Such teams came up in the 60s in Europe and in the US, today there is a wide-spread network of established teams. Fig. 2 shows a map of European team distribution.

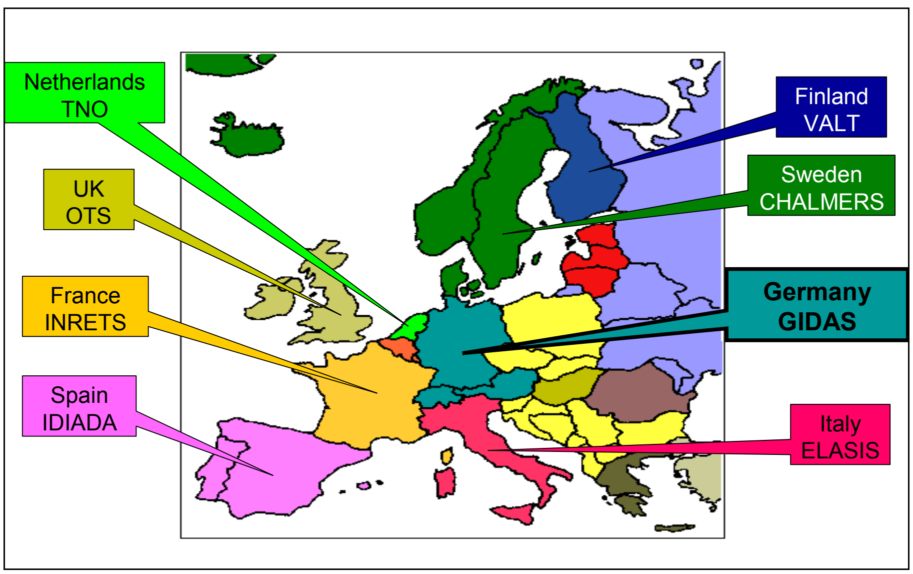

Fig. 1 Distribution of accident research teams in Europe

Whereas in the US the NASS (National Accident Sampling System) started collecting accident data on site by teams, the first German team was set-up in Hanover, which belongs to the first and most important teams globally. It started collecting accident data in 1973 for the Federal Road Research Institute BAST in the greater Hannover area and since 1999 it jointly with the TU Dresden as GIDAS-network (German In-Depth Accident Study) merges accident data on Germany in a database [Otte - 5, Brühning - 6].

The geographical areas of the GIDAS teams are shown in figure 2. The area Hanover covers the city of Hanover and the surrounding rural areas within a diameter of approximately 80 km. There are 1.2 million residents in this area and the surface area is approximately 2,289 km². 10% is designated as urban. The area Dresden includes the city of Dresden as well as parts of the counties within a diameter of approximately 60 km. There are approximately 925,000 residents in the area and the surface area is approximately 2,575 km².

Fig. 2 Geographical area of the In-depth investigation area Hanover + Dresden

2 Methodology of an In-Depth-Study taking GIDAS as an instance

Accidents involving personal injury are investigated according to a statistical sampling process. In both areas, the respective police, rescue services, and fire department headquarters report all accidents continuously to the research team. The team then selects accidents according to a strict selection process and investigates these cases following detailed procedures contained in a handbook and coding manual. In order to avoid any bias in the database, the data collected in the study is compared to the official accident statistics for the respective areas and weighting factors are calculated annually. This process explains why the data captured by the research teams can be seen as representative for their areas. Accident investigation takes place daily during two six-hour shifts following a 2-week cycle. This makes it possible to cover all periods of the day throughout the whole year for the random approach.

During each shift, a team consisting of two technicians, a physician and a coordinator is on duty. The coordinator manages the team by using the sample plan and the defined praxis orientated criteria “last happened accident in time” on the information list of accident events by the police dispatching centers. Each team, Hanover and Dresden, has two specially equipped vehicles available. These are equipped with flashing blue lights, sirens, special signals and emergency radio equipment. Various cameras and instruments are available for measuring and recording purposes. Accurate scale sketches of the scene of the accident are created using a technique known as "photogrammetry" (Fig. 3).

For producing such drawings a comprehensive procedure is used in GIDAS as a 3 step-methodology is used:

First step: tape measurement

Second step: photogrammetric 2 D analysis from pictures additionally used with aerial photos

Third step: the 3D Laser technique

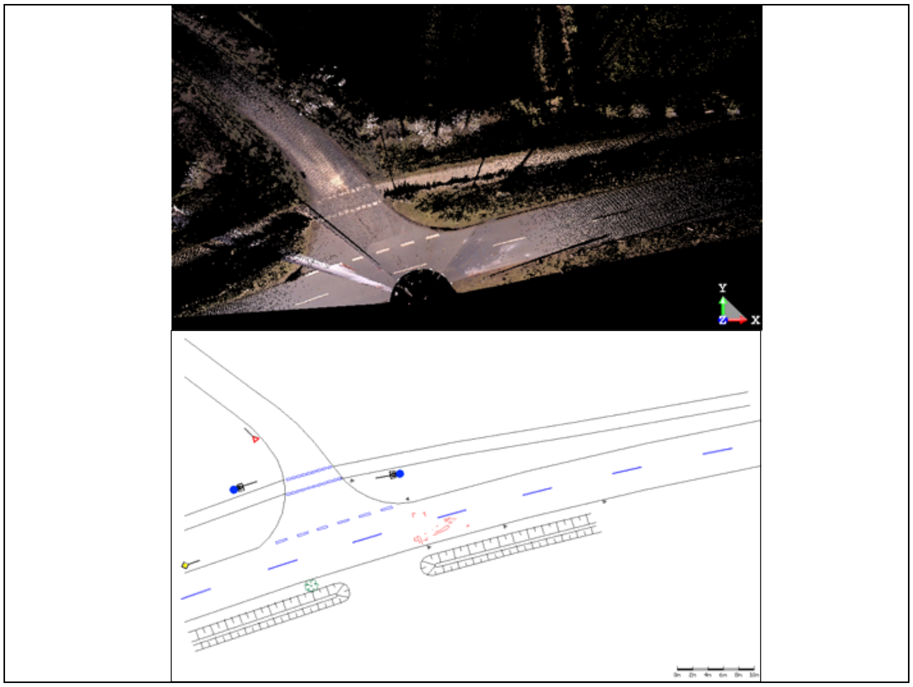

Fig. 3 True to scale drawing form accident scene by 3D-Laser technique

It is shown that the investigated cases have the same distribution of traffic participants as the police reported, therefore no weighting of the data is required, but a similar distribution on injury severity with following weighting factors. In total 24 weighting factors have to be considered. Statements about the national situation are only possible for those accident features that are relatively independent of regional influences. This is true for the variables, which have an effect on the injuries sustained in crashes. Therefore the findings from the study can be considered as representative for most aspects of passive safety.

Between the two centers, about 2000 accidents are investigated annually. The studies include such information as:

- Environmental conditions, road design, traffic control, accident details and cause of the accident, crash information, e.g. driving and collision speed, Delta-v and EES, degree of deformation, vehicle deformation, impact contact points for passengers or pedestrians, technical vehicle data, information relating to the persons involved, such as weight, height etc.

The information collected "on the scene" is complemented by more detailed measurement of the vehicles (usually on the following day), further medical information about injuries and treatment and an extensive accident reconstruction generated from evidence collected at the accident scene. By applying established physical principles, the impact events are reconstructed (e.g. collision speeds) using proven software such as PC-Crash[1]. The output can be graphically displayed to allow a full understanding of the crash events (Fig. 4).

Approximately 500 to 3,000 pieces of information per accident are obtained in total. Any personal data included is processed according to data protection regulations. Medical confidentiality and the rights of the individuals are guaranteed. All information is stored anonymously in a database produced using SIR (Scientific Information Retrieval) software[2] and is available for evaluation.

[1] Steffan Datentechnik, Graz
[2] Scientific Information Retrieval, Sydney

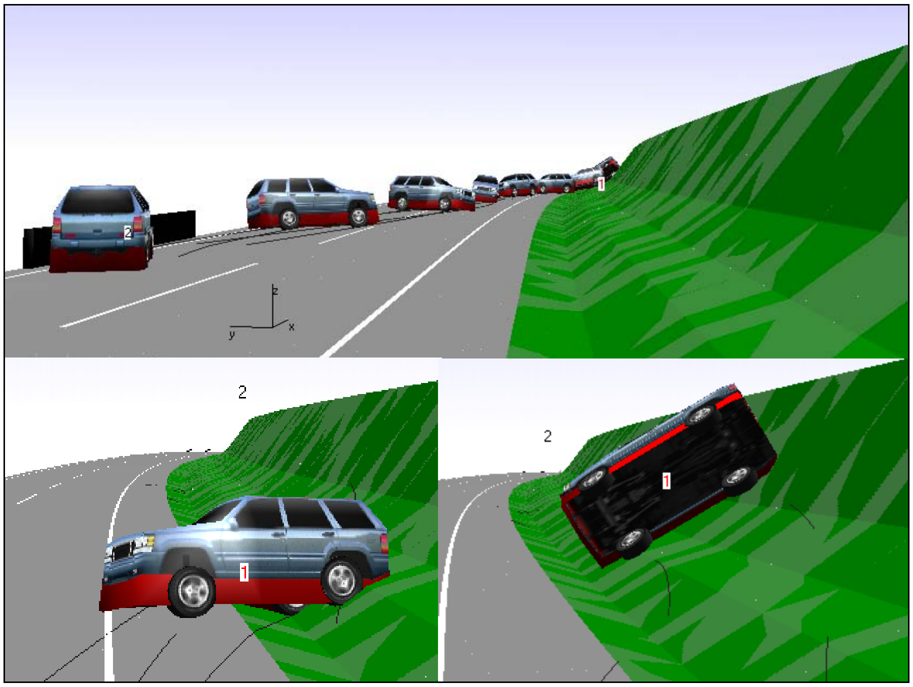

Fig. 4 Reconstruction of vehicle movement by simulation based on documented traces

Different classification systems are used, i.e. AIS [7], CDC [8], and other scores [Otte - 9].

The In-Depth-Investigation on scene in time is best practice for the analyzing process of complex situations of accidents with vulnerable road users. The data can be regarded as representative for the survey area Hanover [Hautzinger 2004 - 10].

3 Basis of a special study on vulnerable road users

Accident documentations of the Accident Research Unit of the Hanover Medical School that were collected in the years 1985 to 2003 by a scientific research team were used for the analysis. For the present study only adult vulnerable road users were selected, who collided with cars and were injured or killed, respectively. Motorcyclists were only regarded if they wore a helmet, whereas bicyclists were subdivided into two groups, those who wore and those who did not wear a helmet, as a group "motorcyclists" all motorized two wheeler users were grouped together (motorcycles, mofas, mopeds, scooters, light motorbikes). Thus the following numbers (sample sizes) for the study result:

1200 pedestrians

2285 bicyclists, 31 persons of which were wearing a helmet

875 motorcyclists

4 Injury situation of the vulnerable road users

Motorcyclists are, as long as they wore a crash helmet, the group of traffic participants with the lowest probability for head injuries at 18.1% (Fig. 5). In comparison 53.0% of the pedestrians, 45.0% of the bicyclists not protected by a helmet and only 35.4% of those protected by a helmet suffered injuries of the head in the course of accidents with cars. It is significant that for nearly all regions of the body, with the exception of the head and the neck, a nearly identical injury incidence occurred for the different types of the vulnerable road users. Thus cervical spine injuries occurred for 4.2 % of the pedestrians, 5% of the bicyclists without helmet, and 8.9% for motorcyclists as opposed to 13.5% for the bicyclists protected by helmets. Primarily this indicates that the bicycle helmet results in an increase of the injury incidence of the cervical spine, but a detailed analysis of the severity of these cervical spine injuries indicates that all these cervical spine injuries the occurred with a degree of severity AIS 1, whereas without helmet 2.8% suffered severe cervical spine injuries AIS 2+ fractures and ligamental injuries. Injuries of the neck of the degree of severity AIS 1 are so-called cervical spine strains otherwise known as whiplash injuries. The cervical spine of motorcyclists is also injured frequently AIS 2 at 12.8% and AIS 3+ at 2.3%. The protective effect of the crash helmet can also be proved by the fact that in this sample no case with most severe head injuries AIS 3+ were recorded.

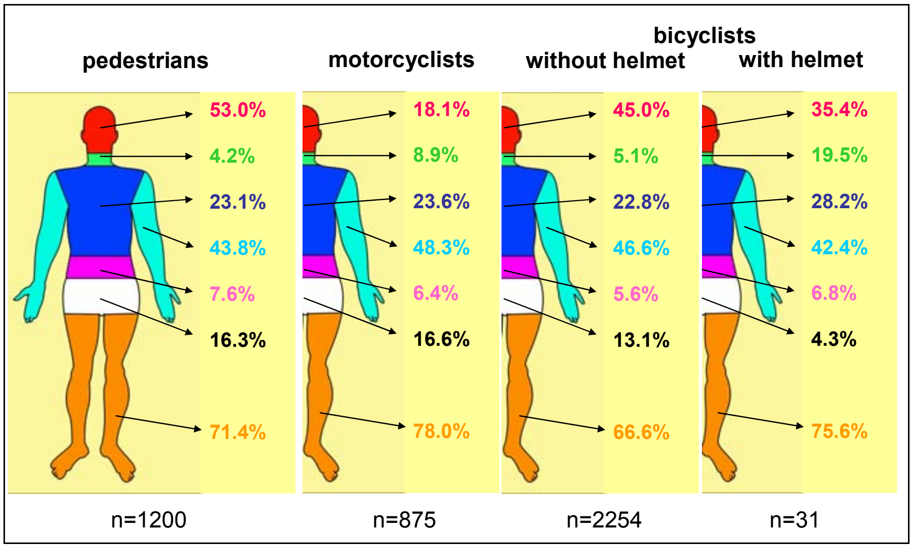

Fig. 5 Frequencies of injured body regions of different vulnerable road users

The severity of the injuries was classified according to AIS (American Association for Automotive Medicine), there every injury was evaluated according to an AIS value and then a maximum injury severity for every body region (AIS-K) as well as the whole body (MAIS) was established.

12% of all injured pedestrians are most severely injured MAIS 3+ in the course of a collision with a car (Fig. 6).

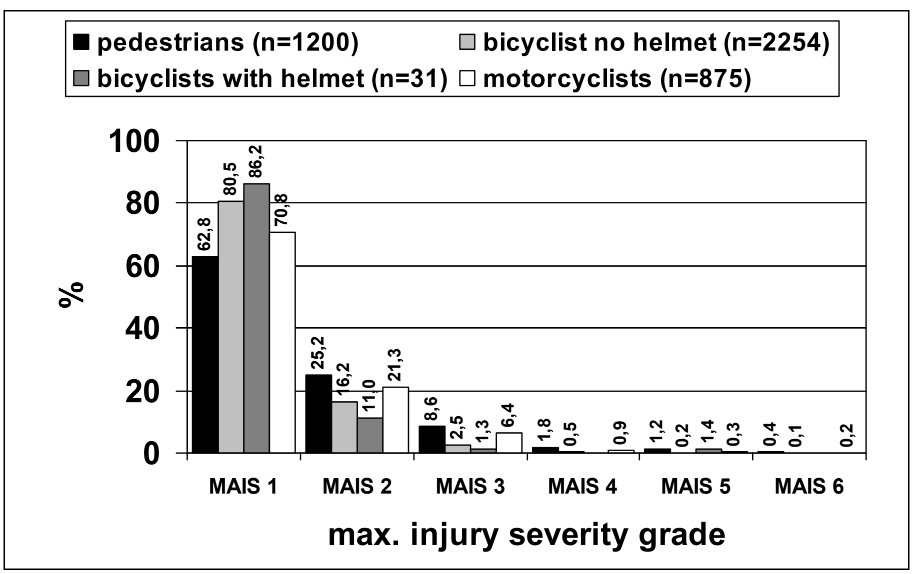

Fig. 6 Maximum injury severity grade MAIS of vulnerable road users

In contrast only 3.3% of the bicyclists not protected by a helmet and 2.7 % of those protected by a helmet suffered most severe injuries of MAIS 3+ (Fig. 7). Whereas 63% of the pedestrians suffering from head injuries were only slightly injured AIS 1, 7.7% suffered injuries of a severity degree AIS 3+. Thorax and abdominal injuries can be classified as severe (AIS 3+) in about 12 % of the cases. 2.7% of the bicyclists without helmet and 4 % of the bicyclists protected by a helmet suffered very severe degrees of injury to the head, on the other hand 55% of those not wearing a helmet and 65% of those with helmet did not show any head injuries at all. In comparison to pedestrians, bicyclists are not as severely injured; this applies to nearly all body regions. Nearly 90% of all injured body regions of bicyclists showed slight injuries of AIS 1.

	pedestrians (n=1200)				**motorcyclists** (n=875)			
	AIS 0	**AIS 1**	**AIS 2**	**AIS 3+**	**AIS 0**	**AIS 1**	**AIS 2**	**AIS 3+**
head	47,0%	33.5%	15.4%	4.1%	81.9%	11.3%	5.7%	1.1%
neck	95.8%	3.5%	0.2%	0.5%	91.1%	8.3%	0.3%	0.3%
thorax	76.9%	16.5%	4.4%	2.2%	76.5%	17.0%	5.2%	1.3%
arms	56.2%	36.8%	5.3%	1.7%	51.7%	40.5%	6.6%	1.2%
abdomen	92.4%	5.4%	1.3%	0.9%	93.7%	5.4%	0.7%	0.2%
pelvis	83.7%	12.7%	2.5%	1.1%	83.4%	15.8%	0.3%	0.5%
legs	28.6%	52.2%	12.0%	7.2%	22.0%	63.1%	9.7%	5.2%

	bicyclists with helmet (n=31)				**bicyclists without helmet** (n=2254)			
	AIS 0	**AIS 1**	**AIS 2**	**AIS 3+**	**AIS 0**	**AIS 1**	**AIS 2**	**AIS 3+**
head	64.7%	26.4%	7.5%	1.4%	55.0%	35.1%	8.7%	1.2%
neck	80.5%	19.5%	-	-	94.8%	5.0%	0.1%	0.1%
thorax	71.8%	23.3%	4.9%	-	77.1%	18.6%	3.6%	0.7%
arms	57.6%	40.3%	2.1%	-	53.4%	43.7%	2.5%	0.4%
abdomen	93.2%	6.8%	-	-	94.4%	5.1%	0.3%	0.2%
pelvis	95.7%	4.3%	-	-	86.9%	12.5%	0.5%	0.1%
legs	24.4%	72.9%	1.4%	1.3%	33.4%	60.8%	4.2%	1.6%

Fig. 7 Injury severity grades of body regions (AIS K) of vulnerable road users

5 Parameters influencing the severity of the injuries

From the multitude of scientific studies presented up to now, it is known that the severity of injury results from the impact energy of the collision partner 'car' transmitted to the generally unprotected body of a pedestrian or a bicyclist and thus the collision velocity of the car significantly determines the extent of the injury. For two-wheelers also the impact momentum vector of the two-wheeler due to the frequently very high velocity of the two-wheeler itself applies. This can be taken into account, if the relative velocity is used, calculated from the addition of the speed vectors and by analysis of the accidents according to the different types of collisions, as described by Otte in 1980 [11]. The determination of the velocity is executed in the course of an extensive reconstruction based on the traces of the accident. Using assumptions concerning the mean spin-off deceleration of the vehicles and sliding and throwing distances of two-wheelers and persons, validated by experiments, a calculatory determination of the collision speed of the car can be conducted [Otte - 12].

Whereas 80% of the pedestrians and even 90.3% of the bicyclists with a low injury severity MAIS 1 and 2 were involved in accidents with an impact velocity of up to 40km/h, only about half of the severely injured persons MAIS 3+ were injured at such speeds (Fig. 8). For motorcyclists 62.7%

of the slightly injured (AIS 1/2) and 27.4% of the most severely injured (MAIS 3+) were injured at relative speeds of up to 40 km/h.

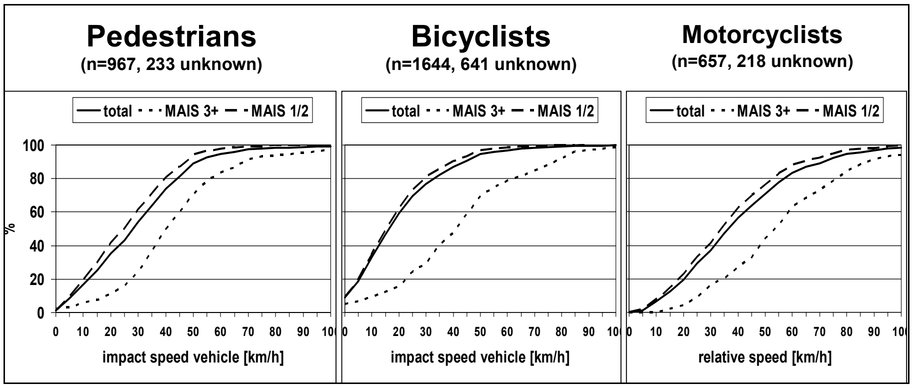

Fig. 8 Cumulative frequencies of impact speed of car for pedestrians and bicyclists or relative speed for motorcyclists

For bicyclists a somewhat lower injury probability can be stated in comparison to pedestrians nearly for every type of accident in the shape of the impact speed of the collision partner 'car'. This can obviously be traced back to the positive influence of the movement of the bicycle itself, resulting in accidents where the bicyclist does not hit the car, he is thrown off the bicycle or mostly flying over the bonnet of the vehicle laterally to the road surface. For instance in case of an impact velocity of 51 to 70 km/h 32.2% of the pedestrians were slightly injured MAIS 1, 27.6% severely injured MAIS 2 and 40.2 % suffered MAIS 3+ (Fig. 9). In contrast 47% of the bicyclists in this range of impact velocities were slightly injured, 33.7 % severely and only 19.3% of the bicyclists fell under MAIS 3+.

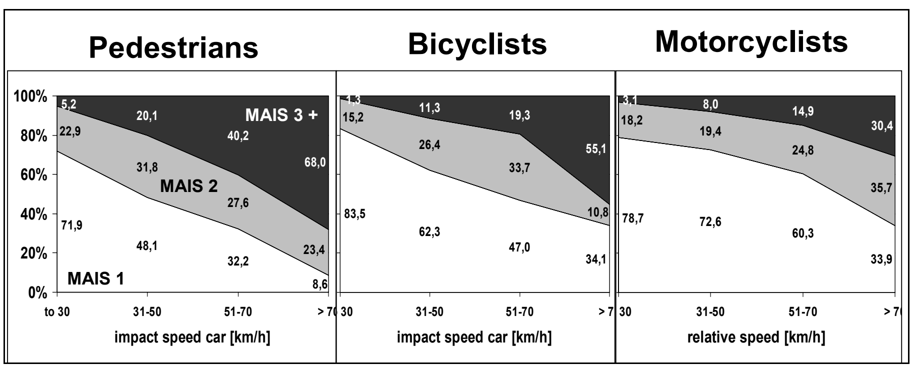

Fig. 9 Correlation of maximum injury severity and impact speed of car (pedestrians and bicyclists) or relative speed (motorcyclists)

Thus, nearly all severe injuries of pedestrians were caused by impact with parts of the vehicle, for bicyclists, however, more frequently the source of the injury was the road and for motorcyclists the road was very frequently mentioned as the cause of the injury. In the course of the study the 8 most frequent severe injuries from a list of all individual injuries AIS 3+ were evaluated (Fig. 10). For pedestrians, brain injuries occurred at 22.8% and fractures of lower leg at 21.9% as the most frequent severe injuries. 47.8% of the brain injuries were caused by the windshield and 13.3% by the front hood. 81.1% of the lower leg fractures were induced by bumper impact. For bicyclists nearly identical injury emphases occurred as for pedestrians, even the ranking of the most frequent severe injuries is similar, 27.6 % of the AIS 3+ injuries constitute brain injuries, however 38.3% caused by impact with the road and 18.7% by impact with the windshield. 18.1% of the most severe injuries are fractures of the lower leg, 58.2% caused by bumper impact. The most severe injuries of the motorcyclists can be found on the legs, 25.9% fractures of the lower leg and 16.4% thigh fractures.

pedestrians n=762 injuries AIS 3+ (100%)

22.8% brain injuries	47.8% windscreen	13.3% front hood
21.9% fracture lower leg	81.1% bumper	100%
7.0% thigh fracture	51.1% front shape	12.6% bumper
5.7% rib fracture	37.1% front hood	26.7% front shape
4.4% pelvic fracture	78.8% front shape	
4.0% fracture upper arm	33.7% front hood	14.8% A-pillar
3.7% skull fracture	51.4% windscreen	30.1% A-pillar
3.5% lung injury	50.8% front hood	13.5% roof edge

Bicyclists without helmet n=331 injuries AIS 3+ (100%)

27.8% brain injuries	38.6% road	18.9% windscreen
18.2% fracture lower leg	59.1% bumper	16.7% front shape
8.1% thigh fracture	42.6% front shape	22.3% road
5.5% rib fracture	18.8% front shape	14.8% front hood
5.5% lung injury	26.9% roof edge	24.5% car side
5.3% skull fracture	30.1% windscreen	23.4% road
4.1% fracture lower arm	52.1% front hood	16.3% road
2.6% fracture upper arm	26.3% road	23.6% roof edge

Motorcyclists with helmet n=273 injuries AIS 3+ (100%)

25.9% fracture lower leg	39.7% bumper	26.7% front plate
16.4% thigh fracture	23.2% car side	19.4% road
11.3% brain injuries	62.1% road	23.4% objects
8.8% fracture lower arm	29.0% car rearend	23.5% car side
5.8% rib fracture	23.4% rollover	22.5% objects
5.1% lung injury	36.1% road	20.1% car rearend
3.0% pelvic fracture	33.7% road	25.0% own cycle
2.2% skull fracture	31.7% road	30.3% windscreen

Fig. 10 The 8 most frequent severe injuries (AIS 3+) of vulnerable road users and their major injury causing parts

The resulting injury severity is affected by the accident situation and the connected collision situation (Figures 11 to 14). Obviously this can be different for different countries, due to the differing traffic infrastructures. For Germany on the basis of the present study it can be shown that a quarter of all pedestrians are hit by cars on pedestrian crossings (24.5%), 6.6% when the car turns and 5.2% not on the pedestrian crossing itself, but in its immediate vicinity, and another 47.8 % of the pedestrian are hit on the road when stepping into a open stretch of road. The last group showed the lowest occurrence of slight injuries (MAIS 1 55.4%) and the highest percentage of severely injured persons at 14.7% MAIS 3+. In comparison, accidents when the car turns and hits a pedestrian in the area of an intersection results in the lowest severities of injury, 69.7% were MAIS 1, 28.3% MAIS 2 and only 2.1% MAIS 3+.

Bicyclists are injured under high injury severity in accidents happened when driving not a special bicycle path (Fig. 12), even if the accident happens on a junction or a straight road. 38% of bicycles are impacted laterally by a car front (type 1 - Fig. 13). Compared to this motorcycles are colliding most frequent frontally to the lateral part of the car (type 4) in 34.8% (Fig. 14). It is obvious that the windshield area and its surround with A-pillars framing it induce most of the severe injuries AIS 3+ at 27,6%. But also the frontal area with bumper (22,5%), radiator grill and head lights and front hood edge (16,6%) constitute a dangerous impact area, which definitely has to be taken into account in the course of the search for protective measures on the vehicle. These areas are also frequently the cause of injuries of bicyclists, thus at 24,8% the windshield, 14,2% the bumper and 13,6% the frontal surface. In contrast for motorcyclists only 7,1% of the injuries were caused by an impact of the windshield, but 12.8% were caused by parts of the lateral compartment structure.

Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	
crosswalk	crosswalk after turning	nearby crosswalk	road, no crosswalk	not road	others	accident types pedestrian
24.5%	6.6%	5.2%	47.8%	10.1%	5.8%	total
67.4%	69.7%	66.4%	55.4%	74.1%	74.1%	MAIS 1
19.8%	28.3%	22.8%	29.9%	19.3%	17.5%	MAIS 2
12.8%	2.1%	10.8%	14.7%	6.6%	8.4%	MAIS 3+

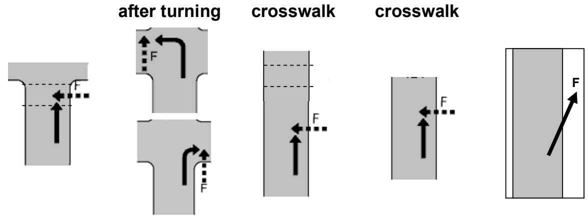

Fig. 11 Accident types with pedestrians

Type 1	Type 2	Type 3	Type 4	
junction with	junction without	straight road with	straight road without	side path
				accident types bicycles
51.6%	20.0%	14.8%	13.6%	total
83.9%	75.3%	81.2%	75.0%	MAIS 1
14.0%	18.9%	15.7%	20.5%	MAIS 2
2.1%	5.8%	3.1%	4.5%	MAIS 3+

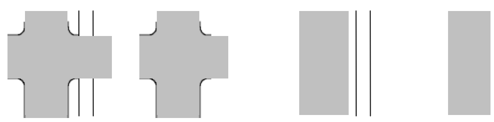

Fig. 12 Accident types with bicyclists

Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		collision types bicycles
90° ± 20° 270° ± 20°	180° ± 70°	90° ± 20° 270° ± 20°	all, except Type 3	all	all		collision angle
Front Side	Front Front	Side Front	Side Front/Side	Rear front	Front Rear		impact car impact cycle
38.0%	11.8%	9.8%	16.2%	2.9%	18.3%	n=2285	total
79.2%	79.5%	85.1%	83.8%	79.5%	78.6%		MAIS 1
17.0%	16.7%	13.1%	14.6%	17.9%	16.7%		MAIS 2
3.8%	3.8%	1.8%	1.6%	2.6%	4.7%		MAIS 3+

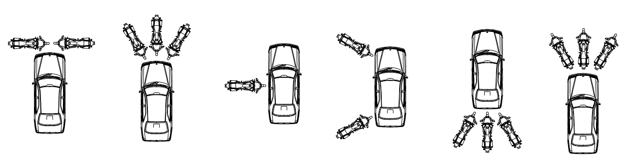

Fig. 13 Collision types of accidents with bicyclists

Type 1	Type 2	Type 3	Type 4	Type 5	Type 6		collision types motorcycles
90° ± 20° 270° ± 20°	180° ± 70°	90° ± 20° 270° ± 20°	all, except Type 3	all	all		collision angle
Front Side	Front Front	Side Front	Side Front/Side	Rear front	Front Rear		impact car impact cycle
8.7%	17.3%	8.9%	34.8%	16.5%	12.6%	n=875	total
71.2%	61.9%	79.0%	71.7%	73.7%	73.7%		MAIS 1
23.6%	25.1%	9.6%	21.9%	19.7%	20.1%		MAIS 2
5.2%	13.0%	11.4%	6.4%	6.6%	6.2%		MAIS 3+

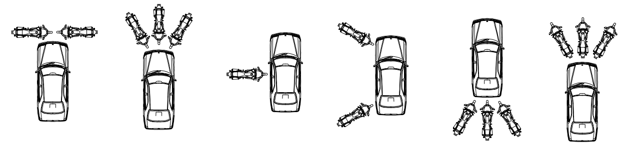

Fig. 14 Collision types of accidents with motorcyclists

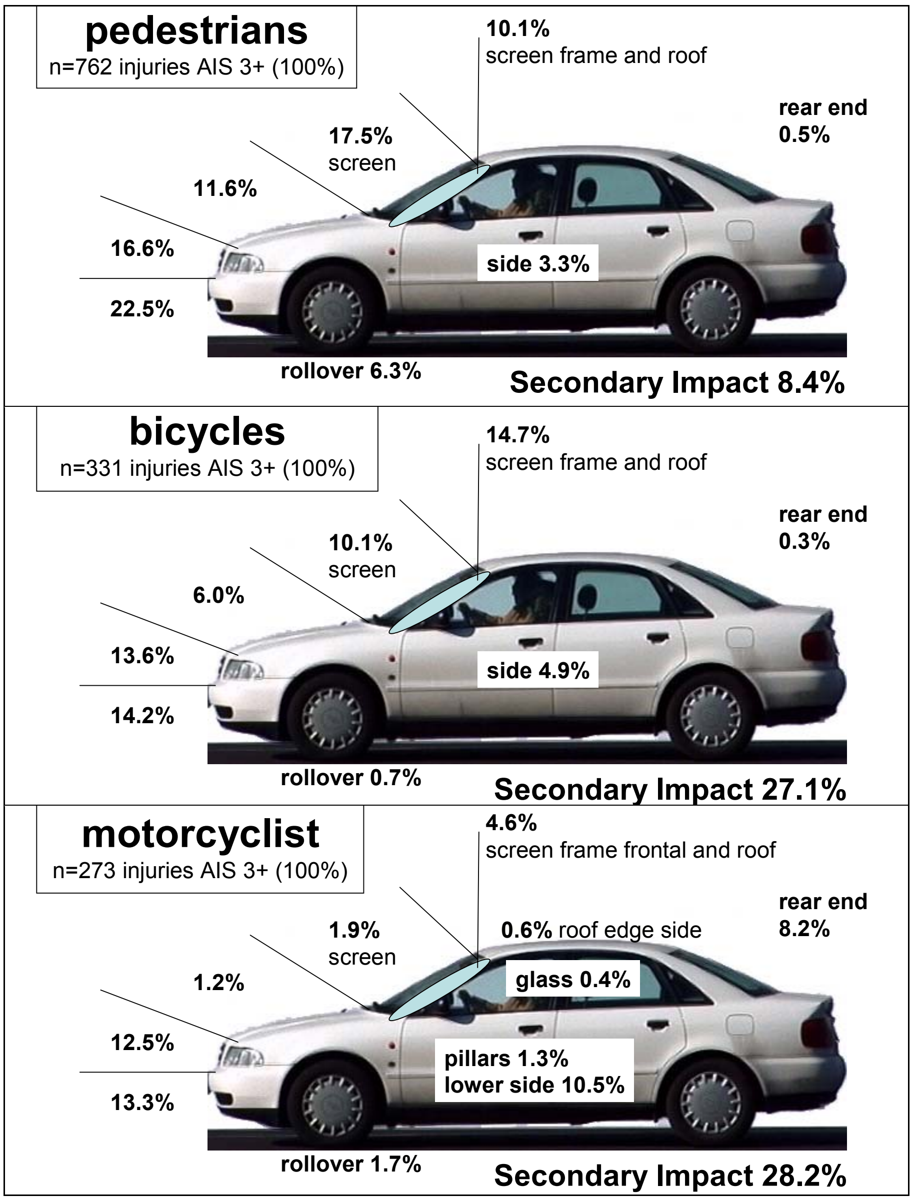

Fig. 15 Frequency of injury causing parts of severe injuries AIS 3+

6 Conclusions

The study shows the particularities of the accident and collision events for vulnerable road users and emphasizes that the kinematics of the sequence of the collision is basically characterized by the accident constellation and the resulting severity of injuries can then be determined by the speed vectors. Protective measured taken by the vulnerable road users themselves are only feasible in a very limited way.

Motorcyclists can protect themselves from head injuries by the use of crash helmets, but special protective clothing with integrated protector systems can only contribute to a limited reduction of the collision energy, thus only in the so-called low speed range injuries can be prevented. An older study by this author came to the conclusion that special protector systems on the basis of a board foam-plastic composite system do not prevent fractures in the higher ranges of relative speeds, but the resulting injuries can be treated more easily [Otte - 13]. For motorcyclists thus integral crash helmets (full-face helmets) according to ECE 22 -6 and protective clothing according to CEN EN 13595 as well as CEN EN 1621 seem to be the best preventive measures the motorcyclist can take. Furthermore fairings, cowls and tails on motorcycles in the accident event turned out to be less injury causative.

Bicyclists can protect themselves well, if they wear a special bicycle helmet tested according to CEN EN 1078. The above study showed for only 35 % of those bicyclists wearing a helmet injuries of the head, 2,7% were severely injured (AIS 3+), whereas 45% of the bicyclists without helmet suffered from head injuries, only 1,3% were classified as severe. But the design of the road can also definitely contribute to keeping the resulting injury consequences low. As was shown in the study, there could be measure a lower injury risk if the bicyclist was driving on a special bicycle path, even have accidents on junctions or straight roads.

Pedestrians number without doubt among the most vulnerable road users. Thus for these the incidence of head injuries is greatest. Also out of all vulnerable road users, they suffer the most severe injuries (7,7 AIS 3+). As the study pointed out, these occur most frequently by hitting the area of the windshield of the car. As the pedestrian can not protect himself from injuries of the head by wearing a crash helmet as opposed to the two-wheeler rider, in these cases the car has to take over the main part of the required protective measures. For pedestrians too, the accident type of road condition influenced the outcome of injury severity. Collisions with pedestrians were then generally light, when the speed of the car had been reduced beforehand, owing to structural or traffic control measures, such as on pedestrian crossings (32,6% MAIS 2+), and after a vehicle has turned (30,3% MAIS 2+). The most severe injuries occurred when the pedestrian was hit after he suddenly walked onto the open road in an unobstructed area (44,6% MAIS 2+).

Such a detailed presentation of the accident correlations is only possible based on an In-Depth-analysis. It will be easy to transmit these results to other accident scenarios as they exist on roads of developing countries. For that the accident scenarios have to be analyzed by standardized collision types and the injury relation have to be discussed on available countermeasures.

In-depth investigations are always necessary for assessing detailed information of traffic accidents. Such detailed documentations are not available from the usual statistics of traffic accidents, which are based on police protocols. Therefore special teams trained in medicine and technical sciences document the accident at the site immediately after the event. Based on data collection at the accident scene with documentation of all traces, the final position of vehicles and vehicle deformation pattern, the motion of casualties during the collision phase can be reconstructed after the accident. Research teams that reach the scene of accidents in vehicles equipped with blue flashing lights immediately after an accident are able to record all traces and prepare a true to scale drawing, which is then the basis for the technical-physical analysis for determining the driving and collision speed as well as reproduction of the vehicle motion and other important parameters, i.e. delta-v and EES for car accidents and relative speed for motorcycle accidents and absolute impact speed for accidents with pedestrians. The objectivity of research is mostly related to the assessment and correlation of the severity of injury and the severity of the accident. It is important to use statistical weighted and representative accident data.

If a random sample plan is used to examine accidents, that can be done by analyzing single accidents or for example as is the case in GIDAS, the results can be considered using representative approaches. For representatives the following criteria have to be fulfilled:

- defined area for accident sampling
- random collection of cases
- definition of time frame
- comparison of accident sample with total number of availability

Meanwhile many teams were implemented round the world, i.e. NASS (National Accident Sampling System) and CIREN (Crash Injury Research and Engineering Network) in the US, OTS (On the Spot-investigation) in the UK and GIDAS (German In-Depth Accident Study) in Germany working for the same goal of detailed accident analysis, but using different approaches and different methodologies.

The method of in-depth investigation can differ between on scene, on scene in time and retrospective, depending on the fact, when the team arrives the scene of the accident. There are advantages and disadvantages of an investigation on scene in time, but such teams are able to collect traces parallel to and independently of the police work. It is possible to prepare a true to scale drawing for the basis of a technical reconstruction and determination of collision speed. With such a basis a reconstruction of vehicle movement can be started and the determination of collision and driving speeds can be carried out in quality, i.e. in a pedestrian accident there is a possibility to determine the speed of the car based on skid marks of the vehicle, but if no collision point on the road does exist, the calculation can be possible if there is other evidence on the road, i.e. from the throwing and sliding distances of the pedestrian and cyclist, the final position or the composition of the glass field on the road surface.

Many of the current traffic safety aspects are used internationally, therefore such teams should be implemented in many countries worldwide. The demands for an exchange of data and experiences does exist, methods of data sampling and reconstruction procedures have to be concentrated internationally and a network of in-depth investigation centers has to be founded. There are many points describing the benefit of in-depth investigation approach. The shown example of the analysis of vulnerable road users has given the major impact configurations, which are responsible for severe injuries of that mostly unprotected group. With this knowledge an optimized research on an engineering and scientific level can be started to make the traffic participation for vulnerable road users safer.

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