Safety Level of Vulnerable Road Users on European Roads – a Statement of In-Depth-Investigation GIDAS

Dietmar OTTE
Accident Research Unit, Medical University Hannover, D30629 Hannover, Germany
Carl-Neuberg-Str. 1, D30629 Hannover
otte.dietmar@mh-hannover.de

Abstract: Road accidents are a worldwide situation while taken part in traffic behaviors. Today this results in over 1.18 million deaths (1999 World Health Report) and over 20 million persons being injured or dying every year worldwide. Due to the different population structures and the traffic behaviors in the different countries and continents the risks for the groups of participants differ. The main victims of road accidents especially in developing countries are the vulnerable road users (pedestrians, cyclists, motorized two-wheeler riders). For this common group many results and experiences are exists in Europe about driver behaviors, risks, injury situations and accident and injury mechanisms. The possibilities and the effectiveness of many countermeasures can be shown and discussed how they are implemented on the roads in different countries, where the vast majority of injuries still exist. Vulnerable road users are less safe in their protective equipments and passenger cars tend to be better equipped with safety tools. Accident documentation from GIDAS (German In-Depth-Accident Study) is used for this presentation, differentiated as pedestrians, motorcyclists and bicyclists, focused on car accidents. 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. Recommendations for future countermeasures are given on the basis on In-Depth-Investigation.
Keywords: accident analysis, vulnerable road users, pedestrian, bicycle, motorcycle

Introduction and Approach

The vulnerable road users are an unprotected group in the road traffic and are living under special risk when been hit by a car or truck. This group of traffic participants consists of pedestrians, bicyclists and motorized two-wheelers and comparing to the occupant situation they have no outer shell for giving survival space or energy absorption. Especially motorized two-wheelers are equipped with different power engines and reaches therefore partly high speed. In an accident event this could be influencing the injury severity. Very popular are currently in Europe heavy and high powered motorcycles and scooters, all of these have different driver behaviours and therefore different accident scenarios. On the other hand there can be registered a different acceptance of protective dives like helmets and protective clothes. For the large group of pedestrians many safety activities were implemented in road infrastructure and safer car front shapes over the last decades. It is remarkable that the numbers of fatalities and injured pedestrians shows a declination over the last decades in many European countries while the numbers on fatal motorcycle riders as well as bicycle riders are not shown so strong declination (Figure 1). It can be established that nowadays the accident situation for Europe can be declared as positive; there is a constant trend line for declining of fatalities and injured causalities. For a Country like Germany a number of 5100 killed people in road traffic could be registered in the year 2006 (declination since 1970ies). In Europe the total number is calculated with approximately 27000 fatalities annually for 2004. For the German situation 18% of fatalities are motorcyclists, 9% bicyclists and 14% pedestrians, comparing for Europe 21% of the fatalities are motorcyclists, 5% bicyclists and 17% pedestrians. Opposite to the European accident situation the trend line for Asia and Africa shows an inclination.

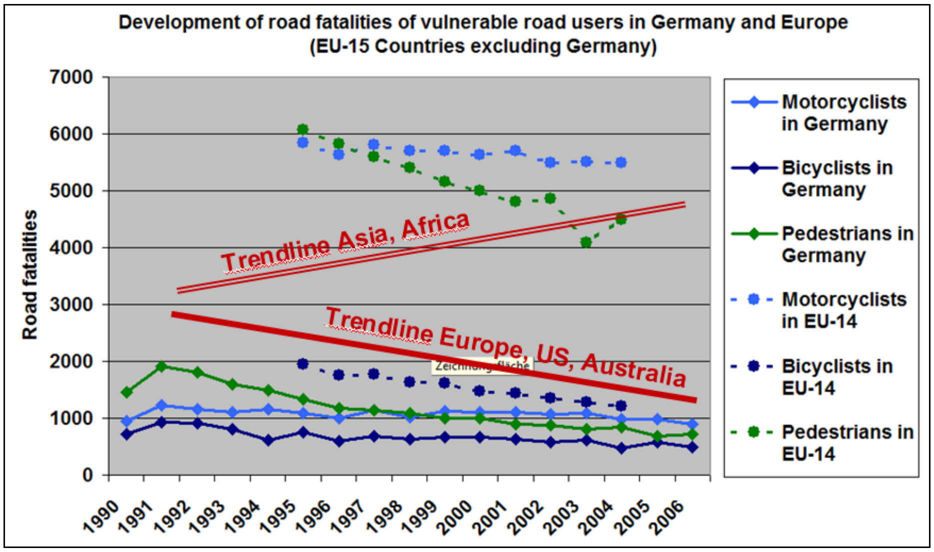

Figure 1 Numbers of fatalities of vulnerable road users in road traffic of Europe with trendline for different continents

How is the injury situation today and what kinds of countermeasures are needed for an optimized safety of this traffic group? To answer this question, detailed accident studies are needed to describe injury pattern and injury sources.

Beside accident statistical data on national basis using data of police reports, more detailed information can be collect by so called "In-Depth-investigations". Those tools are implemented in many countries for getting detail information on deformation, injuries and accident circumstances. In Europe major In-Depth-investigations are carried out for instance in Germany (GIDAS German In-Depth-Investigation-Study), in UK (OTS On Spot Study and CCIS) in France (INRETS and LAB), Spain (IDIADA), an overview is given in Figure 2. Special teams are educated and mostly sponsored by the governments and/or in combination with the car industry. Such In-Depth-Research activities can be done retrospective based on hospital and/or police reports up to prospective methodology with the access to the scene. In-Depth-Investigation are carried out directly after an event (on scene in time) or later on scene based on police documentations. With continuation of in-depth-research over many years it is possible to analyse and observe the trend situation. As the literature shows, in-depth data collection has been done since the beginning of the sixties Brühning (2005). It provides detailed knowledge on vehicle deformations, injury patterns and collision relationships. The first teams were formed in the USA, Australia, France, England and Germany, partly they are still active today in modified and optimised form. The methodology of such In-Depth-Investigation is described on the example of GIDAS by Otte (1994).

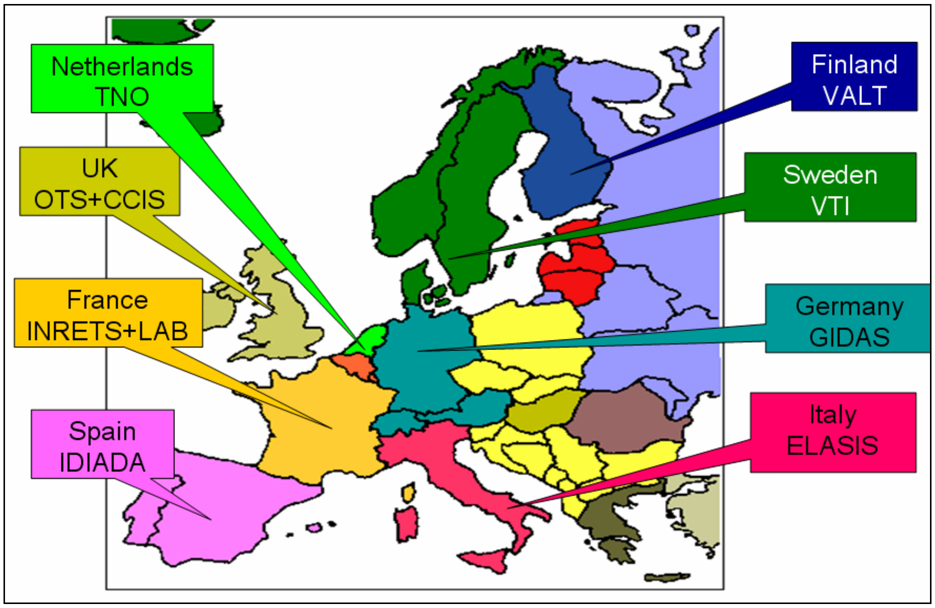

Figure 2 In-depth research teams in Europe

Data Source for the current study

The data used for this report for showing the situation on accidents of vulnerable road users is based on GIDAS. At the request of the Federal Institute for Road Traffic Safety BASt, data collection in Hanover at the Medical University Hanover has been continuously financed and set forth since 1999 in cooperation with the Association of Automobile Industry (FAT) which is carried out together with the Technical University in Dresden on 2 sampling areas of Hannover and Dresden.

Based on data collection at the accident scene with documentation of all tire marks and artefacts at the scene, the final position of vehicles and vehicle deformation pattern, the motion of casualties during the collision phase can be reconstructed after the accident and the speed of vehicles can be determined. A true to scale drawing based on 3-D-Laser-Scans are the basis for the technical-physical analysis as well as for the replication of the vehicle motion and other important parameter for describing the accident severity, i.e. delta-v and EES.

A random sample plan is used to examine accidents in representative manner, that can be done by analysing single accidents or for example in GIDAS in combination with a statistical weighting process, the results can be considered representative approaches of the country. For representatives the following criteria are fulfilled: defined area for accident sampling, random collection of cases, definition of time frame, comparison of accident sample with total number of all traffic participants.

For the injury assessment the injury severity classification system AIS 90 (Revision 98 - 1998) was used.

GIDAS cases form the years 1999 to 2005 were used for this analysis accidents in which passenger cars collided with pedestrians (n= 1107), bicyclists (n= 1801) and motorcyclists (n= 798) were selected.

Characteristics in the Accident Scenario

Different conflict situations are happened inside the traffic scenarios of different countries depending on the different rules and driver behaviours. The major accident situations can be found by the analysis of in-depth-accident data, for instance for Germany described on GIDAS data.

Within the study all accidents with personal injury outcome of was filtered according the different accident scenarios in the road infrastructure. For this purpose, the classification according to accident types (FGSV - 1990) and the recording of the environment of the accidents according to categories such as urban/rural, straight road/junction, with/without traffic lights, with/without line-of-sight obstructions was used.

For this purpose, the accident incidences for all pedestrians, bicyclists and motorcyclists for all such accidents as well as separately for severely injured /killed victims in a collision with a passenger car were illustrated (Tables 1 to 3). It can be seen that for pedestrians accidents on straight roads without safety features are the most frequent, more than 50 % and accidents at intersections with traffic lights at around 10% and without traffic lights at 14.4% of all and at 19% of severely injured pedestrians are the second most frequent, in each case for passenger cars traveling straight ahead and pedestrians traversing the road. Taken together, these constitute already about 70% of all collisions resulting in severely injured pedestrians MAIS 3+.

Table 1 Location of pedestrian accidents (n=1107)

		Movement of Pedestrian							
70 % of cases	total	contrary to car	same direction as car	from left no obstruct.	from left with obstruct.	from right no obstruct.	from right with obstruct.	enter or aboard	others, unknown
total	100.0%	9.0%	3.2%	16.8%	13.9%	24.4%	22.6%	3.7%	6.4%
Movement of Car									
intersection, no traffic light straight ahead	14.4%	0.5%	0.6%	2.6%	2.0%	3.7%	3.3%	0.7%	0.9%
intersection, no traffic light, turning left	2.5%	0.8%	0.2%	0.5%	0.0%	0.7%	0.2%	-	0.1%
intersection, no traffic light, turning right	1.5%	0.3%	0.1%	0.3%	0.1%	0.7%	0.0%	-	-
intersection, traffic light, straight ahead	10.8%	1.0%	0.1%	2.8%	1.0%	4.2%	1.3%	0.1%	0.3%
intersection, traffic light, turning left	3.8%	0.8%	0.2%	1.5%	0.1%	1.1%	-	-	0.1%
intersection, traffic light, turning right	1.5%	0.1%	-	0.4%	-	1.1%	-	-	-
curve	3.8%	1.2%	-	0.3%	0.6%	0.9%	0.8%	-	0.0%
straight line, no crosswalk	51.1%	3.8%	1.4%	6.4%	9.0%	9.1%	15.1%	2.9%	3.5%
straight line, crosswalk no traffic light	2.8%	-	-	1.0%	0.1%	1.4%	0.3%	-	-
straight line, crosswalk traffic light	0.4%	-	-	0.1%	0.1%	0.2%	-	-	
others	7.3%	0.5%	0.5%	0.9%	0.9%	1.4%	1.5%	0.1%	1.5%

For Bicyclists (table 2) some other major scenarios can be established. 64% of all accidents happened on intersections, where no traffic light does exist and the car is driven strait ahead (43,2%), and a straight line without traffic light is given priority to the car driver not expected the crossing of the bicyclist (16,7%).

Nearly the same constellations can be seen in the accident scenarios of motorcyclists (table 3). Also 37,2% happened on intersections, where no traffic light does exist and the car is driven strait ahead, and a straight line without traffic light is given priority to the car driver not expected the crossing of the cyclist could be registered with 20,5%, but here accident situations while turning left are established with 12,3% too.

Table 2 Location of bicyclist accidents (n=1801)

		Movement of Bicycle							
64 % of cases	total	contrary to car	same direction as car	from left no obstruct.	from left with obstruct.	from right no obstruct.	from right with obstruct.	enter or aboard	others, unknown
total	100.0%	8.4%	14.7%	33.8%	9.5%	24.1%	7.6%	-	1.9%
Movement of Car									
intersection, no traffic light straight ahead	43.2%	3.2%	2.6%	16.3%	5.0%	11.4%	3.7%	-	0.9%
intersection, no traffic light, turning left	5.6%	0.6%	0.7%	2.1%	0.2%	1.5%	0.2%	-	0.3%
intersection, no traffic light, turning right	4.0%	0.4%	0.9%	1.0%	0.4%	1.1%	0.2%	-	0.1%
intersection, traffic light, straight ahead	6.6%	0.1%	0.4%	2.7%	0.3%	2.6%	0.4%	-	0.1%
intersection, traffic light, turning left	3.8%	0.5%	0.2%	2.1%	0.0%	0.8%	0.0%	-	0.1%
intersection, traffic light, turning right	4.2%	0.4%	0.5%	1.3%	0.1%	1.8%	0.1%	-	-
curve	1.9%	0.6%	0.4%	0.5%	0.1%	0.2%	-	-	0.1%
straight line, no traffic light	16.7%	1.5%	7.9%	3.5%	1.0%	1.8%	0.9%	-	0.1%
straight line, traffic light	1.3%	0.1%	0.2%	0.5%	0.1%	0.4%	0.0%	-	0.1%
others	12.6%	0.9%	1.0%	3.8%	2.2%	2.4%	2.1%	-	0.2%

Table 3 Location of motorcyclist accidents (n=798)

		Movement of Motorcycle							
67 % of cases	total	contrary to car	same direction as car	from left no obstruct.	from left with obstruct.	from right no obstruct.	from right with obstruct.	enter or aboard	others, unknown
total	100.0%	16.4%	30.9%	22.3%	3.9%	19.8%	5.7%	-	1.1%
Movement of Car									
intersection, no traffic light straight ahead	37.2%	5.3%	4.0%	10.2%	2.2%	11.5%	3.8%	-	0.3%
intersection, no traffic light, turning left	12.3%	3.6%	3.0%	3.5%	0.8%	1.1%	-	-	0.4%
intersection, no traffic light, turning right	0.9%	-	0.6%	0.2%	-	0.1%	-	-	-
intersection, traffic light, straight ahead	7.2%	0.7%	3.6%	0.5%	0.0%	2.1%	0.1%	-	0.1%
intersection, traffic light, turning left	5.7%	1.9%	0.7%	2.2%	0.2%	0.5%	0.3%	-	-
intersection, traffic light, turning right	0.6%	-	0.5%	0.0%	-	-	-	-	-
curve	3.4%	1.9%	1.3%	-	-	0.2%	-	-	0.1%
straight line, no traffic light	20.5%	1.7%	13.1%	2.5%	0.1%	2.8%	0.4%	-	-
straight line, traffic light	2.4%	0.3%	1.6%	0.1%	-	0.4%	-	-	-
others	10.0%	1.2%	2.6%	3.0%	0.6%	1.3%	1.1%	-	0.2%

Almost 90% of all accidents occur for each group of participants in principle at 3 different major local destinations:

pedestrians

- Straight lines no crosswalks 53%
- Intersections no traffic lights 12%
- Intersections traffic light straight drive 12%

bicyclists

- Intersections no traffic lights 40%
- Straight line no traffic light 17%

- Curves 13%

motorcyclists

- Intersections no traffic lights 39%
- Intersections no traffic lights, turning left 11%
- Straight line no crosswalk, no traffic light 19%

Injury Situation

The injury situation can be describe according to the scientific abbreviated injury scale AIS (American Association of Automotive Medicine), assessing each single injury on the body regarding a 6 digit code from 1 as minor injured to 6 as worst/fatal with no treatment possibility. The whole bodily injury severity is classified as MAIS (maximal AIS) followed as the maximal severity of all injuries of the human body. For the vulnerable road users the following distribution of injury severity can be established and compared each other (Figure 3):

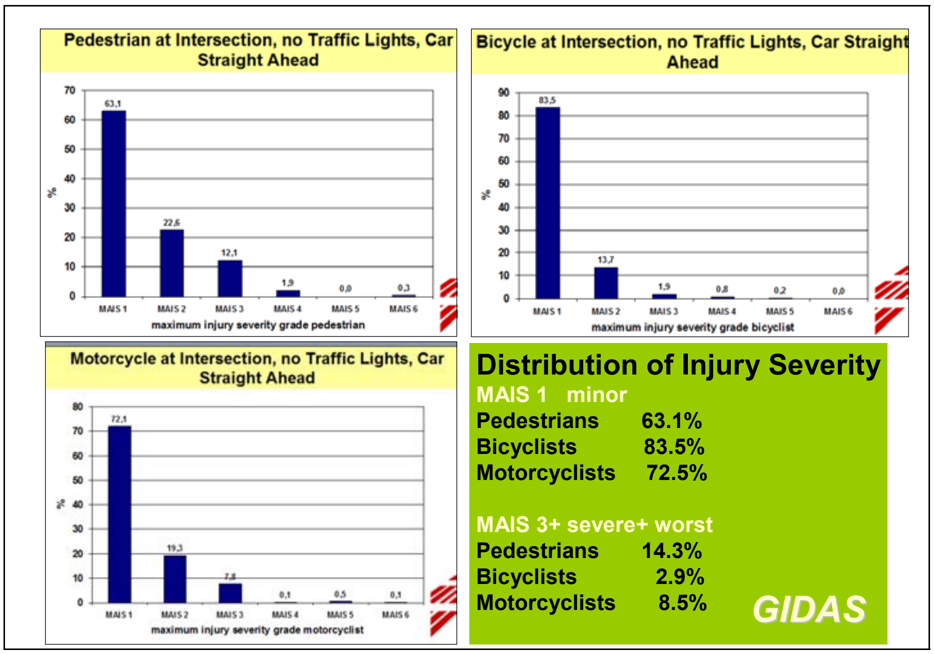

Figure 3 Distribution of injury severity

Herewith it can be confirmed a high safety standard as the low portions of severely and worst injured pedestrians, bicyclists and motorcyclists are shown, only 2.9% of bicyclists, 8.5% of motorcyclists but 14.3% of pedestrians involved in road accidents with injured persons are severely injured in the German road traffic scenario:

It can be expected, that for pedestrian, bicyclist and motorcycle accidents the following major influence parameter for the injuries are existing:

- Level of speed of driving + impact speed for pedestrians and bicyclists and the relative speed range in motorcycle accidents
- Speed absorption from driver reaction until impact of car to human body
- Kind of Collision partner + impact areas on the vehicle
- Impact conditions and impact angles
- Impacted body areas + biomechanics of injuries
- Kind of protection devices on the body + vehicle

It can be established that there is a correlation between speed at impact and the injury severity outcome. This can be seen for all kinds of vulnerable road users and is in principle based on the force and energy transmission and their physical based correlation. The analysis shows a probability for severe injuries for impact speeds of above 40 km/h and a high incidence for worst /fatal injuries in speed ranges of greater 60 km/h (Figure 4). Countermeasures have to consider this.

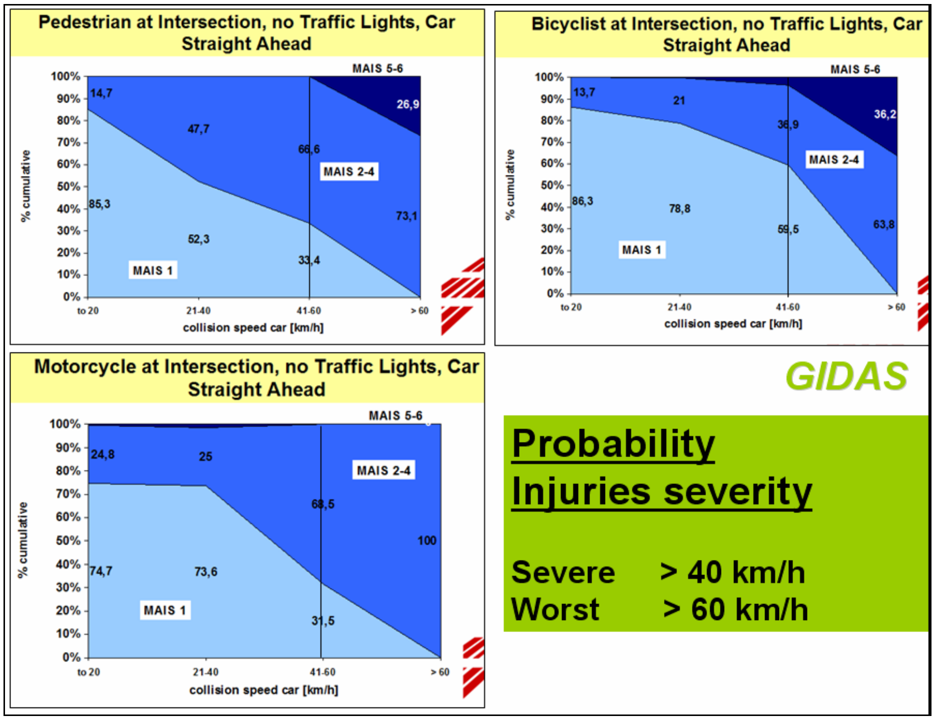

Figure 4 Probabilities of injury severities

Injury Causation

Cars are not anymore aggressive and induce severe injuries! This can be seen if analysing the frequencies of injured body areas and the correlation to the injury causation parts on the vehicle. This statement needs to be added with some comments regarding speed and vehicle fleet aspects. It could be seen in many surveys that the front shapes of modern cars are not leading anymore to severe pelvis, abdomen and thorax injuries (Figure 5). The rates for knee injuries for instance decreased from 3% in cars of production years 1985 to 1990 comparing to 1.2% in cars of production years 2000 to 2005. The head is with approx. 60% of all injuries of a pedestrian as well as of bicyclist the most injured body area, these injuries are mainly based on windscreen and roof edge impacts on the car. Therefore a windscreen replication test in the pedestrian test regulations is proposed by accident researchers. Two third of all kind of vulnerable road users suffered injuries from impact onto the road surface, they are mostly not so severe than those from primary impact on the car.

Assessment of Countermeasures for Injury Reduction

There are different possibilities to reduce the injury severity. A reduction of the transmitted energy within the collision could be effective on one hand, the use of protective devices onto the human body could be another improvement on protection on the other hand and having better roads and a safe roadside infrastructure could be a further way in avoiding risky impact conditions and reduce the impact speed.

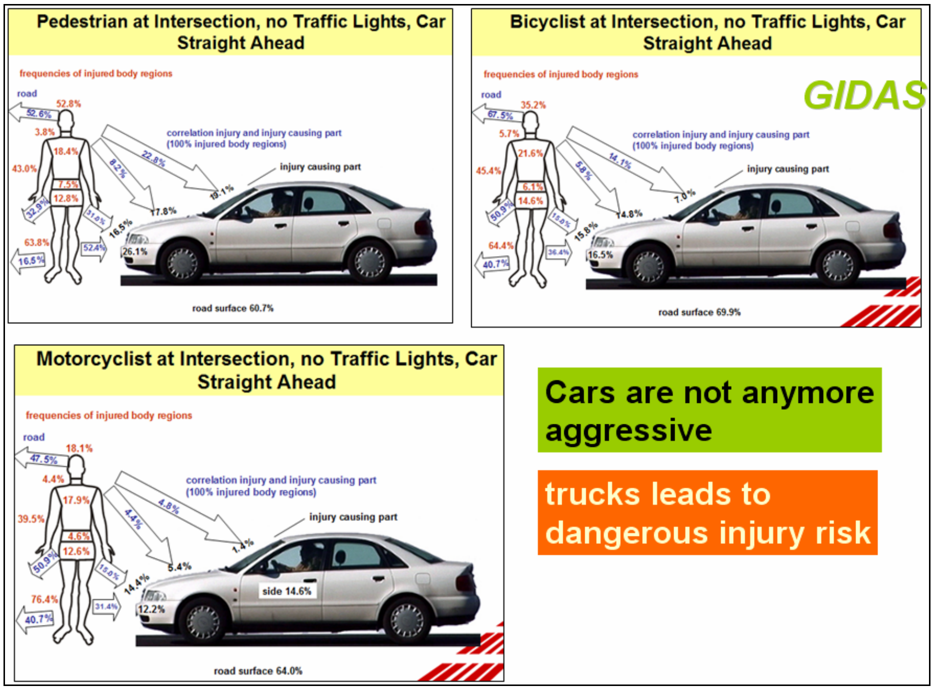

Figure 5 Frequencies of injuries and injury causing parts

Speed Reduction

The speed can be seen as the major influence parameter responsible for the amount of energy. Therefore speed is the best factor to be reduced by the driver.

It could be seen also that nearly 10% only of all accidents with vulnerable road users happened within the reaction time of the driver, i.e. the driver had no possibility to reduce the speed. But 70% of all drivers had more than up to 2 seconds time for reaction up to the impact and 20% had longer time of more than 2 seconds. This leads to the conclusion that speed reduction by earlier information of the driver could be a large potential for accident avoidance on one hand and injury reduction on the other hand.

In the course of the study it was shown that the time that elapsed from the moment of reaction until the collision lasted up to 2 seconds in 80 % of the cases, the speed reduction to the point of collision was up to 25 km/h in 80% of the cases; up to approximately 40% of the cars did not reduce speed until the collision. Thus a significant potential for further reductions of the collision speed can be made out.

The study postulated that a reduction of the response time by 0.3 seconds, for instance, would result in a collision speed reduced by about 9 km/h for the car and that the expected injury severity for the accident population regarded could be reduced by about 10 % by using the AIS Scale as linear and carried out an exponential regression analysis on injury vs. speed relation (figure 9). The study was thus able to confirm the expected potential of a potential of driver assistant system that influence this speed in a collision, i.e. by pre brake assist systems. A speed reduction of minus 10% brings a lower injury severity. If reducing the speed by minus 10km/h, an injury severity MAIS minus of 0.2 in average is expected.

The accident study GIDAS has shown that a maximal speed range of 40 to 60 km/h can be a border for avoidance of severe injuries greater than MAIS 2.

<u>Helmet</u>

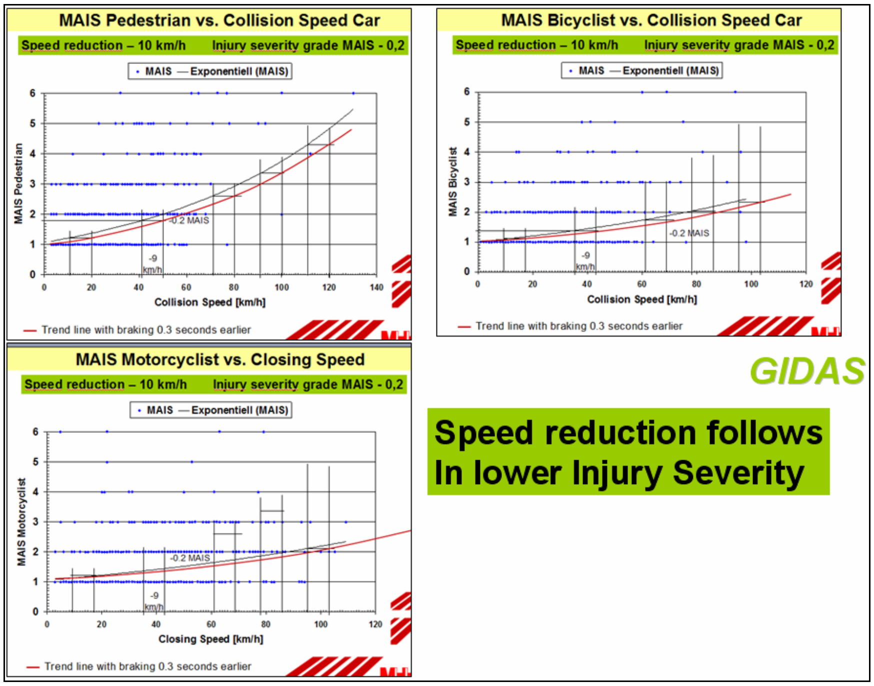

Figure 6 Injury severity as function of MAIS and assessment of speed reduction

It is important that bicyclists are wearing a helmet as well as the motorcyclist. Based on the 100% helmet wearing rate for motorcyclists in Germany only 18% are suffering head injuries compared to 35% of the bicyclists and 53% of pedestrians. The full face helmet is the highly and safely standard for that group in protecting skull, face and chin. The helmet use for motorcyclists follows in a reduction of severe injuries AIS 2 and 3 by minus 10% and of minor injuries AIS1 too by minus 20% (Figure 7). The helmet can reduce injuries for bicyclists as well; it can be seen in accident studies a lower injury severity by up to 50% for each head injury grades of adults and for children too.

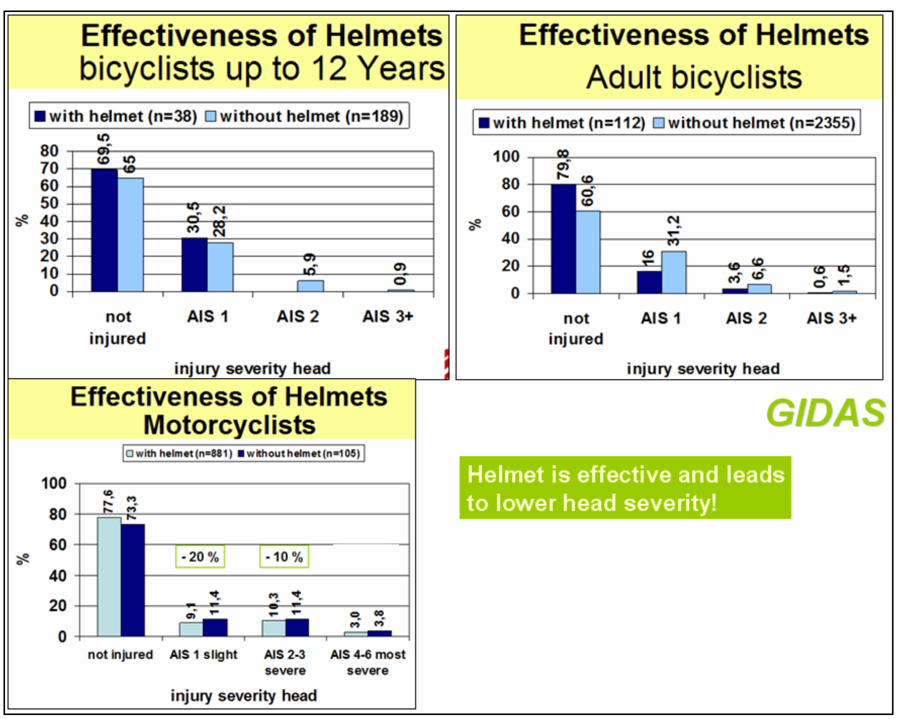

Figure 7 Effectiveness of helmets

Protective Clothes

Motorcycle riders have the possibility to use protective clothes. An European CEN standard prEN 13594, 13595 parts 1-4 give requirements and measure the shock absorption by a drop test prEN 1621-2 for the production and guaranties an optimized protection of those body areas that suffered highly injury rates. Especially lower arms including elbows, shoulders, back and spine, hips and knee and tibia are under high risk. Accident studies are shown injury reduction by using protective clothes.

- protectors decrease the load by secondary impact on road and objects nearby the street
- reduction of load up to 40% by using combination of foam and plate
- fractures cannot be avoided totally but the severity is reduced

Figure 8 CEN standard for protective clothing

It was contradictory discussed between accident researchers and the motorcycle industry), that protectors on the motorcycle lead to lower injury pattern. There could be an effect on the head movement after an accident by having covered protection of legs. Nevertheless accident studies pointed further out that the leg is one of the most frequent injured body region and with special devices on the cycle by covering the legs against lateral and frontal impacts, the high risk for long term consequences of such long bone soft tissue injuries and complexity of bone fractures could be avoid. Further research on that subject is needed.

Conclusions

For this study, statistically representative accidents between cars and pedestrians, bicyclists and motorcycles collected in GIDAS (German-In-Depth-Accident-Study) were evaluated. From this population the most frequent accident situations for these different groups of vulnerable road users involved in accidents with passenger cars were extracted. It turned out that 90 % of all collisions occur in principle only in three major accident situations; therefore it seems possible to find optimized countermeasures for such characteristic scenarios.

This study was able to show that for accidents occurring at locations with safety features for pedestrians, such as crossings or traffic lights, the distribution of injury severity occurring here resulted more frequently in slightly injured persons than for locations without any safety features. A significant potential for further reductions of the collision speed can be made out. The study postulated that a reduction of the response time by 0.3 seconds, for instance, would result in a collision speed reduced by about 9 km/h for the car and that the expected injury severity for the accident population regarded could be reduced by about 10 % by using the AIS Scale as linear and carried out an exponential regression analysis on injury vs. speed relation. The study was able to confirm the expected potential of selfprotection activities of bicyclists and motorcyclists by using helmets and protective clothes a brake assist system based on an analysis of accidents. In addition, the result of this study can support the evaluation of different accident scenarios regarding the different technical assisting systems applicable. For instance, assistance systems that are constantly monitoring the driving situation ahead would be able to reduce response time in accidents involving pedestrians walking or bicyclists in the same or opposite direction facing the vehicle. This would cover 12% of all accidents involving pedestrians and 18% of all pedestrians injured MAIS 3+ as a target group.

As a review of the current results on detailed accident investigations the following counter-measures can be stated as effective tools to be implemented for

- **Minimization of Injury Situation + Severity and Accident Avoidance** by **Optimized Infrastructure, Vehicle safety and Self protection**
- **Test regulations and governmental laws** can support the safety standard.
- **Speed reduction** is an important tool to reduce injury severity and avoid accidents at all. **Driver Education, Motivation and Acceptance** is needed to reach the goal of **high safety standard.**
- Accident statistics have to be implemented for **Controlling the accident and injury situation by In-Depth-Studies focused on data of injury pattern, vehicle and driver behavior and accident causation**

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