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Powered Two-Wheeler Accidents – First Results of APROSYS SP 4 Implying GIDAS 2002 Data

Abstract

In recent years special attention has been paid to reducing the number of fatalities resulting from road traffic accidents. The ambitious target to cut in half the number of road users who are killed each year by 2010 compared with the 2001 figures, as set out in the European White Paper "European Transport Policy for 2010: Time to Decide" implies a general approach covering all kinds of road users. Much has been achieved, e.g. in relation to the safety of car passengers and pedestrians but PTW accidents still represent a significant proportion of fatal road accidents. More than 6,000 motorcyclists die annually on European roads which amounts to 16% of the EU-15 road fatalities. The European Commission therefore launched in 2004 a Sub-Project dealing with motorcycle accidents within an Integrated Project called APROSYS (Advanced PROtection SYStems) forming part of the 6th Framework Programme. In a first step, the combined national statistical data collections of Germany, Italy, the Netherlands and Spain were analysed. Amongst other things parameters like accident location, road conditions, road alignment and injury severity have been explored. The main focus of the analysis was on serious and fatal motorcycle accidents and the results showed similar trends in all four countries. From these results 7 accident scenarios were selected for further investigation via such in-depth databases as the DEKRA database, the GIDAS 2002 database, the COST 327 database and the Dutch element of the MAIDS database. Three tasks, namely the study of PTW collisions with passenger cars, PTW accidents involving road infrastructure features, and motorcyclist protective devices have been assessed and these will concentrate inter alia on accident causes, rider kinematics and injury patterns. A detailed literature review together with the findings of the in-depths database analysis is presented in the paper. Conclusions are drawn and the further stages of the project are highlighted.

Notation

IP	Integrated Project
SP	Sub-Project
PTW	Powered Two-Wheeler
WP	Work-package
AIS	Abbreviated Injury Scale

Introduction

More than 6,000 of the 40,000 fatalities on European roads in 2001 were related to powered two-wheelers (PTWs). Compared to the overall number of victims on the roads, this figure represents 15% of the toll of this dreadful aspect of our society. The European Commission has launched the 3rd European Road Safety Action Plan with the ambitious goal of reducing the fatalities by 50% by 2010. By 2025, it is intended that the number of persons killed or severely injured on the road each year shall be reduced by 75% compared with 2001. Against this background the EC launched the Integrated Project APROSYS (Advanced PROtection SYStems) within its 6th Framework Programme The APROSYS Integrated Project on Advanced Protective Systems is focussed on scientific and technology development in the field of passive safety. It concerns, in particular, human biomechanics, vehicle and infrastructure crashworthiness and occupant and road user protection systems. World-wide, vehicle safety experts agree that significant further reductions in fatalities and injuries can be achieved by using passive safety strategies. APROSYS aims to offer a significant contribution to the reduction of road victims in Europe. In other words, the general objective of the IP is the development and introduction of critical technologies that improve passive safety for all European road users in all relevant accident types and over all ranges of accident severity. Measures and strategies for powered two-wheelers are included within Sub-Project 4 dealing with motorcycle accidents. The purpose of this SP is to reduce the number and severity of user injuries associated with PTWs (including mofa/moped) for the most relevant accident types. This will be achieved by means of in-depth analysis of the different accident scenarios in which motorcyclists were involved (WP1). Interest is to be concentrated on "forgiving" types of road infrastructure features and design (WP2) and

advanced protection systems for motorcyclists (WP3). As a first step within the context of WP1, data from various national statistical offices have been analysed. This included SP consortium data from Italy, Germany, Spain and the Netherlands.

National Statistics Analysis

Except for Italy the data from four different countries have been analysed for the years 2000 to 2002 [1]. In the case of Italy the years 1999 to 2001 were chosen because no data were available for 2002. For each country, the differences in data acquisition methods and database restrictions are described prior to the analysis. Therefore a comprehensive understanding of the results as well as of the limiting factors has been gained. A separation of the PTWs into mofa/moped and motorcycles has been made in order to highlight possible differences for the selected variables. A general summary of the PTW situation for the country concerned is followed by an analysis of the population characteristics such as gender and age patterns. The accident circumstances were split into area, time, month, road alignment, road conditions, weather and light conditions. Urban and non-urban areas have been separated. A more precise differentiation of the non-urban roads into highway and other roads has been made. As for the selection of the accident scenarios, which are further addressed in the following work-packages, the focus was on four main variables such as type of vehicle (mofa/moped or motorcycle), type of accident (single vehicle accident or various vehicles involved), type of road alignment (straight, bend, curve, etc.) and area (urban, non-urban). These variables have been cross-linked in order to obtain the different accident scenarios. The figures taken into account for the scenario definition focused only on severe and fatal accidents.

Italy

The analysis was carried out using the Italian accident database owned by the Italian Institute of Statistics (ISTAD) in which only accidents involving at least one injured person are included. It is not possible to distinguish between slight and severe injuries. Moreover, conclusions regarding helmet use cannot be drawn.

In Italy an increasing trend in the number of licensed PTWs is observable. Whereas the moped population remained almost constant, the number of motorcycles rose significantly from 2,967,906 in the year 1999 to 3,729,890 in the year 2001. The PTW group covers 21% of all licensed vehicles in the country. A powered two-wheeler was involved in 35% of all accidents in Italy while for 25% of all casualties at least one PTW was involved. In total, 235,409 accidents with personal injury were recorded in the year 2001, of which 82,451 were PTW accidents. As far as age groups are concerned, in urban and non-urban areas the group of drivers aged 26-35 years is the most significant one in terms of fatal motorcycle accidents and in urban areas the moped drivers aged 18-25 years are mostly involved in accidents resulting in injured persons. Regarding gender, the number of female PTW driver casualties is noteworthy, amounting to some 19%. It is worthy of mention that most fatal accidents involving both mofa/mopeds and motorcycles occur inside urban areas. This is also consistent with other recent studies, which reveal that Italy, Portugal and Greece are the only EC-countries where more fatal PTW accidents are recorded inside than outside urban areas [2]. In that context the vast mofa/moped population is a highly significant factor. The time of day when most accidents happen is between 6 p.m. and 8 p.m. and, as expected, the major proportion of those accidents happens in the summer period. As anticipated, the passenger car is the most frequent collision partner within PTW accidents in urban as well as in non-urban areas which occur on straight roads, intersections and bends. In terms of run-off-the-road accidents on straight roads and intersections, in most cases the kerb is hit, whereas on curves and bends ditches and safety barriers are the objects most frequently hit on rural roads.

Germany

The legal basis for compiling the data is the law and the Statistics of Road Traffic Accidents. Pursuant to this the Federal Statistics are compiled each year from accidents involving vehicular traffic on public roads or places, complete with the number of persons killed or injured and any material damage. According to the relevant law, the police authorities whose officers attended the accident are obliged to submit the report. This implies that the statistics cover only those accidents which were reported to the police. These are primarily accidents with serious consequences. To a relatively large extent,

traffic accidents involving only material damage or slight personal injuries are not reported to the police. Since only aggregated data rather than raw data are available in the published yearbooks, some queries could only be pursued to a limited extent. Persons killed are defined as those persons who died within 30 days as a result of the accident, while seriously injured persons are defined as all those who were immediately taken to hospital for inpatient treatment (lasting over a period of at least 24 hours). The data review period covered the years 2000 to 2002.

Because the absolute numbers of killed and injured riders of PTWs since the early 1990s are more or less constant, the relative proportion they represent of the still decreasing number of all victims of road accidents in Germany shows a rising trend. Taking into account that e.g. the share of pedestrians killed in Germany over the years 1980 to 2003 decreased continuously, an increase in the proportion of the users of powered two-wheelers killed over the years 1992 (11.1%) to 2003 (16.6%) is noticeable, Figure 1. As far as the number of injured traffic participants in Germany is concerned, an upward trend in the share of the powered two-wheeler riders injured is also apparent.

In the year 2002 some 54 million licensed vehicles were on German roads and 9% of these were powered two-wheelers. The number of licensed PTWs has remained almost constant in recent years. In respect of all traffic accidents in Germany the involvement of PTWs plays a significant role. A powered two-wheeler is involved in more than 15% of all fatal and 18% of all severe accidents. In the years 2000–2002 most moped casualties were in the age group 18-25. Regarding motorcyclists alone, a shift from the age group 25-35 to the age group 35-45 is observable as far as number of casualties is concerned. This is true for both urban and non-urban traffic accidents where the PTW drivers involved are predominantly of male gender. Most PTW accidents occur inside urban areas. Within these road category statistics the most frequent injury level is the slight injury. As distinct from the motorcycle accidents where only 20% of the accidents with fatal injuries occur inside urban areas, the proportion of fatally injured mofa/moped riders inside urban areas is nearly 50%. Noteworthy is the fact that as far as motorcyclists are concerned the category of highway accidents associated with (mostly) elevated travel speeds is of minor significance in terms of the number of fatally injured PTW riders in general. Most of the

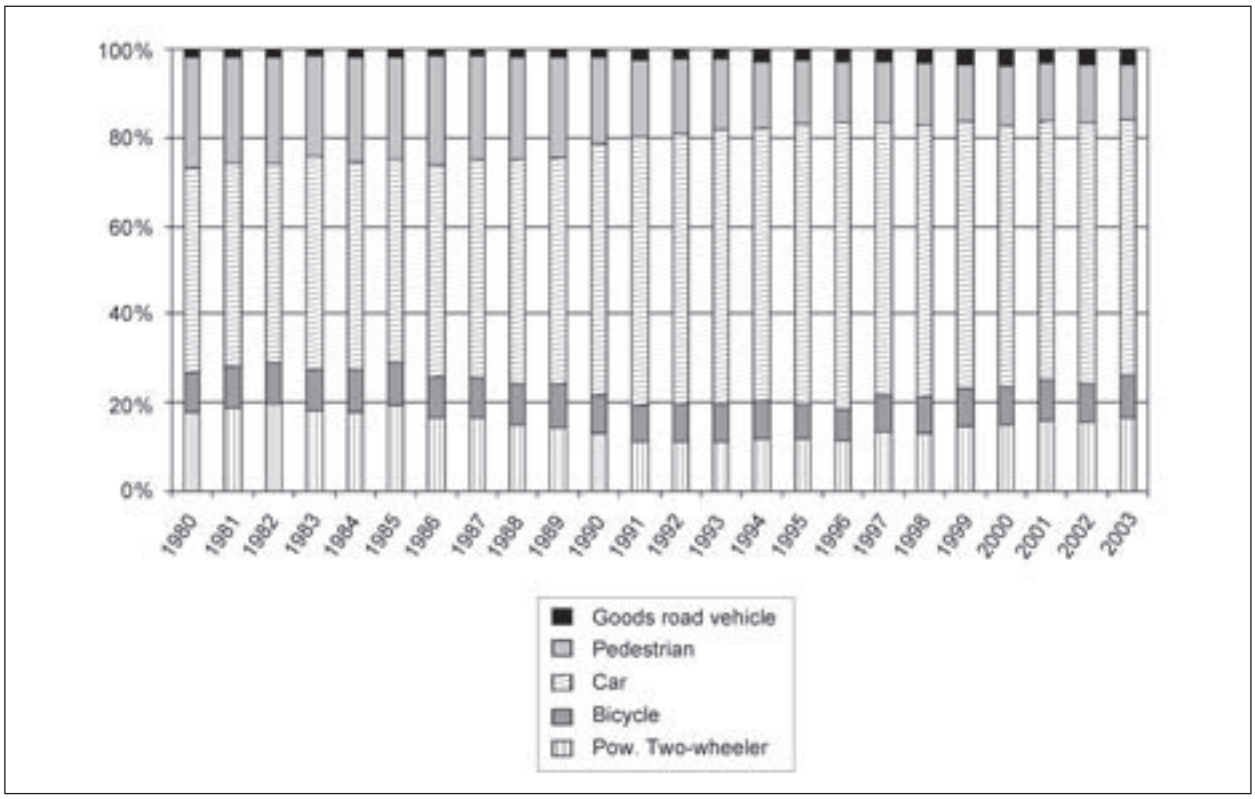

Figure 1: Time history of the specific shares of killed road users among each other in Germany for the period 1980 to 2003

PTW traffic accidents resulting in personal injuries take place in the period from spring to autumn. An observable small gap in July is related to the summer holidays in Germany. PTW accidents happen mostly in dry weather conditions, related to the fact that motorcycle riding is often a leisure activity. Wet and snowy/icy weather conditions are of interest regarding mofa/moped accidents. Here, mofa and mopeds are a common means of travel inside urban areas to go to work. Most PTW accidents take place in the daytime. A particular correlation between light conditions and injury severity is not detectable. In about 70% of the cases in urban areas and in about 45% of the cases in non-urban areas involving injuries to persons the passenger car is the other vehicle concerned. In rural areas the single vehicle accident is of special interest. In 46% of such accidents physical injury results. Because in Germany there are no public data available which deal with road alignment, individual PTW accident scenarios could singly be defined in a very restricted way.

The Netherlands

The VOR (Traffic Accident Registration) database is a national Dutch database of the Adviesdienst Verkeer en Vervoer (AVV). The AVV is part of the Dutch Ministry of Transport, Public Works and Water Management. The data in the database comes from police records. The nature of the report about an accident depends upon the severity of the accident: the more severe an accident is the better is the extent ad quality of the report. Regarding the injury level classification a fatality is coded when a person dies at the accident spot or if a person is hospitalised and dies within 30 days after the accident; a seriously injured person is coded if hospitalised.

The Dutch statistics for 2002 show a total of 8,676,393 licensed vehicles including 968,922 PTWs (11.2%). Mofa and Mopeds are roughly 4 times more common than motorcycles. In only 4% of all accidents a powered two-wheeler was involved but these were accountable for more than 17% of all fatalities and almost 26% of all seriously injured persons in the year 2002. During the last few years the overall trend in The Netherlands for PTW accidents has been downwards. The main age group of moped riders is the 16-18 year olds and for motorcycle riders the 25-35 year olds. This is true for both urban and non-urban areas and again the predominant gender of PTW users is male. Regarding accident location, most mofa/moped casualties happen inside urban areas on dry roads whereas no clear distinction is possible for motorcyclists. Although for motorcycles the proportion of urban and rural accidents is nearly the same, as would be expected the more serious accidents tend to happen outside urban areas. As far as the time of day of the accident is concerned, the rush hour in the evening between 3 p.m. and 8 p.m. is when most accidents occur. Even though road usage intensity statistics show a double peak with an additional one in the morning rush hour, inexplicably a concentration of PTW accidents at that time cannot be observed. Most of the accidents occur in the months where there are many PTWs on the road, in both early and late summer. During summer holidays in July the overall road use is less. The majority of PTW accidents occur on rural straight roads and at urban intersections with a car as the other vehicle involved, while motorcycles are associated with a significant share of severe single accidents taking place on curves outside urban areas. In more than 25% of all run-off the road accidents with PTWs involved a tree or a pole is hit.

Spain

The Spanish road accident database is managed by the DGT (General Directorate of Transport), a public organisation subordinate to the Ministry of Interior. The Spanish road accident database contains the whole population of accidents in Spain in which, at least, one person has been injured as consequence of the accident. Information contained in Spanish DGT database is collected by the police forces. In a reported accident between two vehicles the design of the database forms fails to distinguish which vehicle is the target and which one is the bullet. The variable “accident type” refers only to the global configuration of the accident, but there is no information regarding the kind of impact received by each vehicle. Regarding the injuries, the DGT database contains four categories of injured people: fatal, serious, slight and uninjured. Police agents judge the severity of the injuries and assign one of these values to each casualty. Furthermore, subsequent information about casualties is given within 24 hours and not within 30 days. To compensate for this deviation from the European standard, calculated correction factors are provided by the DGT.

In Spain 3,561,450 powered two-wheelers were registered in 2002. This amounts to 13% of all

licensed vehicles in the country. A PTW was involved in more than 32% of all accidents with almost 22% of all accidents involving mofas/mopeds. In traffic accidents PTWs accounted for more than 14% of the fatally injured and nearly 23% of the severely injured persons in 2002, even though in recent years a decreasing trend for mofas/mopeds and an increasing trend for motorcycles is observable. Considering age groups, most of the fatalities and severely injured people are below 35 years old. In respect of mofa/moped users, casualties are younger than for motorcycle users as anyone can ride a mofa/moped once they are 14 years old. In Spain, too, the majority of PTW casualties is of male gender. Within urban areas the number of accidents is higher than outside urban areas. This is true for both categories of powered two-wheelers. These accidents usually occur on dry and clean roads in daylight in the summer period. As far as accident scenarios are concerned, large numbers of severe and fatal PTW accidents happen within urban areas at intersections and involve a car. Also run-off-the-road accidents with or without hitting a hazardous object are significant. Outside urban areas accidents at intersections, on straight roads or within a curve are highlighted.

Accident scenario selection

Following a study of the national statistics of the four different countries similar trends regarding powered two-wheeler accidents could be recognized. Although some minor differences (legislation issues, different vehicle classification etc.) have also been identified, their influence when selecting the main accident scenarios is of minor importance. When determining the most frequent and dangerous scenarios it is necessary to differentiate between those taking place in urban areas and those in non urban areas – see Table 1. Additionally, mofas/mopeds and motorcycles have been recorded separately. Consequently seven scenarios were identified as being the most significant.

Urban Area	Non Urban Area
Moped against car at intersections	Motorcycle against car at intersections
Moped against car on straight roads	Motorcycle against car on straight roads
Motorcycle against car at intersections	Motorcycle single vehicle accidents
Motorcycle against car on straight roads	

Table 1: Selected PTW accident scenarios

Taking the four analysed countries as a whole these accident scenarios can be listed in order of importance in terms of the total number of accidents which occurred:

- Urban – Moped – Car – Intersection.
- Urban – Moped – Car – Straight road.
- Urban – Motorcycle – Car – Intersection.
- Urban – Motorcycle – Car – Straight road.
- Non-urban – Motorcycle – Single vehicle accident.
- Non-urban – Motorcycle – Car – Straight road.
- Non-urban – Motorcycle – Car – Intersection.

The results derived from the national statistics analyses were intended to be further examined by means of in-depth database analyses. Rider and vehicle kinematics, accident causes and sustained injury patterns have been elaborated as well as detailed impact configurations.

In-Depth Database Analysis

Within the SP 4 consortium several in-depth databases were available to explore. From Germany the DEKRA database, the GIDAS 2002 database and the COST 327 database, from the Netherlands the Dutch part of the MAIDS database. The following database descriptions were extracted literally from the public project report and give a brief insight into the database origins, particularities and data restrictions [3]. As expected, not all the requested information was obtainable from the four databases so that the composite results are the best available in those circumstances.

DEKRA database

The fundamental basis of the DEKRA accident database is the accumulation of written expert opinions containing the accident analyses that are drawn up by skilled forensic experts at the DEKRA branches throughout Germany and totalling about 25,000 annually. The particular feature of these reports is that normally the experts are called by the police or prosecuting attorney to come to the accident scene directly after the accident

happened. They have to answer case specific questions in their expert opinions. Therefore they have the right to determine the accident circumstances, which includes, if necessary, a detailed technical inspection of the involved vehicles. The DEKRA experts operate all over Germany on a 24 hour/7 day week basis. Consequently, the nearly 500 DEKRA accident experts have the opportunity to acquire all the information necessary for their task. The reports provide a substantial basis for accident research work. The DEKRA Accident Research and Crash Test Center has the opportunity to select and analyse interesting cases which normally consist of the written expert opinions, detailed accident reconstructions, sketches and photo material. Sometimes single injuries are described but by and large only the general injury severity is stated. The actual DEKRA PTW database comprises 350 cases from 1996 to 2005 with all kinds of other vehicles as well as single PTW accidents. About 300 parameters per accident are reviewed when using the DEKRA questionnaires. Since expert opinions are normally commissioned only when the accident is of a really serious nature, the main focus of the PTW database is directed towards accidents resulting in severely or fatally injured persons. These accidents happen mostly in rural areas and involve high speeds. Therefore, the outcome of each accident and the relevant impact velocities have to be interpreted under the circumstances mentioned above.

GIDAS database

GIDAS stands for “German In-Depth Accident Study” which is being carried out by two independent teams. The Hannover team is sponsored by BASt (Federal Highway Research Institute) while an industry consortium under the auspices of VDA/FAT is financing a second investigation team at the Technical University of Dresden. Both teams share a common data structure and the cases are stored in a single database. A random sampling scheme was introduced in August 1984 and is still in use. So 1985 is the first year for which this database can be considered representative of the German national statistics. Accidents are investigated at scene using blue-light response vehicles. In most cases extensive photo documentation is also available. The data cover the accident situation, participants (including cars, motorcycles, pedestrians/cyclists, trucks, buses, trams, trains), accident cause, injury cause, human factors and vehicle technologies. The qualifying criteria are that

- the road accident resulted in at least one person being injured,
- the accident occurred within specified regions around Hannover or Dresden,
- the accident occurred while the team was on duty (2 six-hour shifts per day, alternating on a weekly basis).

Approximately 2,000 new accident cases are investigated each year. The GIDAS 2002 dataset which was analysed for the several tasks within the exercise was purchased from DEKRA and relates to 230 powered two-wheelers and 248 PTW users.

COST 327 Database

The organisation European Co-operation in the Field of Scientific and Technical Research (COST) 327 was formed to investigate head and neck injuries suffered by motorcyclists by carrying out a comprehensive and detailed analysis. The COST 327 accident database consists of 253 cases collected from July 1996 to June 1998 in the UK by the Southern General Hospital, Glasgow, in Germany by the Medical School of Hannover and Munich University (LMU) and in Finland by the Road Accident Investigation Team. All cases are characterised by the following criteria:

- a powered two-wheeler was involved,
- a full or open face helmet was worn,
- head/neck injuries of AIS 1 or above were suffered – or known head/helmet contact without head injuries occurred.

Head injuries occurred in 67% of all cases. In 27%, a neck injury was sustained. The proportion of head injuries was considerably higher with MAIS 3 and above (81%) than with MAIS 1 (38%). The effect of climatic conditions on accident risk was investigated but found difficult to determine, however, due to the retrospective character of the study.

NL–MAIDS database

In order to better understand the nature and causes of PTW accidents, the Association of European Motorcycle Manufacturers (ACEM) with the support of the European Commission and other partners

conducted an extensive in-depth study of motorcycle and moped accidents during the period 1999-2000. Sampling was carried out in five areas located in France, Germany, Netherlands, Spain and Italy, resulting in a large PTW accident database called after the MAIDS (Motorcycle Accident In-Depth Study) project. The methodology developed by the Organisation for Economic Co-operation and Development (OECD) for on-scene in-depth motorcycle accident investigations was used by all five research groups in order to maintain consistency in the data collected in each sampling area. A total of 921 accidents was investigated in detail, resulting in approximately 2,000 variables being coded for each accident. The investigation included

- a full reconstruction of the accident,
- detailed inspection of vehicles,
- interviews with accident witnesses,
- collection of factual medical records relating to the injured riders and passengers. These were subject to the applicable privacy laws and were obtained with the full cooperation and consent of both the injured person and the local authorities.

The in-depth data gathered in the Netherlands by TNO are part of the MAIDS database. In this part of the database 200 accidents were investigated and coded. The accidents incorporated were all PTW accidents in the Haaglanden region (The Hague, Rotterdam), in which a police alert was sent to the Dutch accident research team. The coverage was over 90% of all PTW accidents in the region. The accidents were accordingly put into two databases:

1. Database relating to the accident configuration, vehicle and rider/passenger information.
2. Database relating to injuries. Each injury is a separate data field and is assigned to a particular accident by means of the accident identification code. Only the rider injuries were considered in the investigation, because passenger injuries had not been included yet in the injury database.

PTW–Car accidents

Data from the national accident statistics of Germany from the years 1994 to 1999 were analysed in a study by ASSING in 2002 [4] in which the principal causes leading to PTW accidents were explored. In 11% of the cases the PTW user was responsible as a result of wrong road use, in 25% by failing to respect priority or to give way and in 42% by left or right turn manoeuvres. In the cases where a car was involved 34% of the incidents were caused by a priority/give-way violation. In 2004, HUANG & PRESTON stated that in many multi-vehicle crashes involving motorcyclists, the motorcycle was either not seen or seen too late by the other involved vehicles [5]. This has to do with the size of a motorcycle, which is rather small, and the fact that they are less frequently encountered in traffic situations. On the whole other drivers are not so accustomed to their presence on the roads as they are to cars. Other than that, car drivers who ride a motorcycle themselves or who relate in some way to motorcycle riders are less likely to collide with motorcyclists. In multiple vehicle crashes the other vehicle fails to give way in two thirds of the cases. The main scenario involves a motorcycle going straight ahead and a car turning left into a side road. In single vehicle crashes a pre-accident error contributed to the actual accident. ABS will improve the active safety of the motorcycle rider. Secondary safety devices like airbags and leg protectors will improve rider safety in most cases, but may have some negative side effects. A comprehensive PTW accident study on Dutch roads was published by KAMPEN & SCHOON in 2002 [6]. Regarding the direction of impact, in more than 60% of the cases the front side of the PTW was hit. Side impacts to the second vehicle occurred in approximately 35% of the motorcycle cases and 30% of the moped cases. In 1991 KAUTZ analysed 501 motorised two-wheeler accidents in the Dresden area in Germany. He found that in 41% of the cases the PTW user was responsible for the accident, 22% were single vehicle accidents and the opponent most frequently hit was a car [7]. In the accidents caused by motorcyclists, in 23% speeding was a contributing factor and in half of all accidents a failure to see the PTW by the driver of the car led to the accident. In the accidents where faults in driving manoeuvres were made, 44% of the riders had less than 2 years riding experience. Fatal motorcycle accidents in England and Wales have been analysed by LYNAM in 2001 [8]. Within those 717 accidents about 60% involved cars but where the motorcyclist was claimed to have caused the accident. In 44% the main contributing factor was speeding. Single vehicle accidents were mostly due to loss of control and travel speeds well above 40mph in rural areas. OSENDORFER & RAUSCHER mentioned in their

BMW C1 study that 42% of the analysed PTW accidents were frontal collisions and in half of the cases a car was the other vehicle involved [9]. In 1985 SIMARD examined more than 24,000 motorcycle accidents in the Quebec region in Canada and concluded that failure to give way was a major cause of severe motorcycle-car side impacts [10]. Furthermore, another typical accident cause involved a car driving well over on the right-hand side and then turning left while the motorcycle was overtaking. As far as collision types are concerned, SPORNER stated in his study from 1995 taking 528 motorcycle-car accidents into account, that the majority of the collisions could be categorised into 14 main collision types. The principle characteristic of these was that the front of the PTW (60% of the cases) hit the front of the passenger car. A front corner of the passenger car was hit in 45% of the cases. When considering the angle between the longitudinal axes of the vehicles, more than 50% of the cases were the result of an almost perpendicular side impact (23%) or of an opposing angled (frontal-oblique) impact (32%) [11]. In a recent study from BERG regarding national German data for 2002 a brief analysis on accident types is given. It is mentioned that 70% of the motorcycle crashes in urban areas (n=20,979) involved a passenger car as the second party. On rural roads (n=12,952) this was 46% [12]. A survey from OTTE in 1998 quoted that in 64% of the analysed events in German and UK national statistical data a car was the second involved party in PTW accidents [13].

In the in-depth databases the two-vehicle categories mofa/moped and motorcycle should have been analysed separately. After an initial inspection regarding the selected accident scenario distribution in the four databases (Table 2), it was decided to analyse all powered two-wheelers together because separation would have led to very small case numbers which had no statistical significance. The Dutch part of the MAIDS database is provided by TNO, the COST 327 database by LMU (Ludwig-Maximilians- University) and the appropriate abbreviations are used in Table 2.

Large differences are to be observed within the different databases. This is primarily related to the different data acquisition methods and their inclusion criteria. The only relatively high coincidence occurs in the case of urban areas with motorcycles impacting cars at intersections. In order to answer the question whether or not the PTW had the opportunity to brake before impact, the cruising speeds and the impact speeds are of interest in the case of a primary impact with the car. The possibility that the accident could have been avoided could be deduced from that information. The cruising and impact velocities were grouped into 25km/h bands and the cruising speed was cross-correlated to impact speed, Figure 2 to Figure 4. It can be seen that the impact speed is nearly always in the same band as the cruising speed. This does not mean that there was hardly any

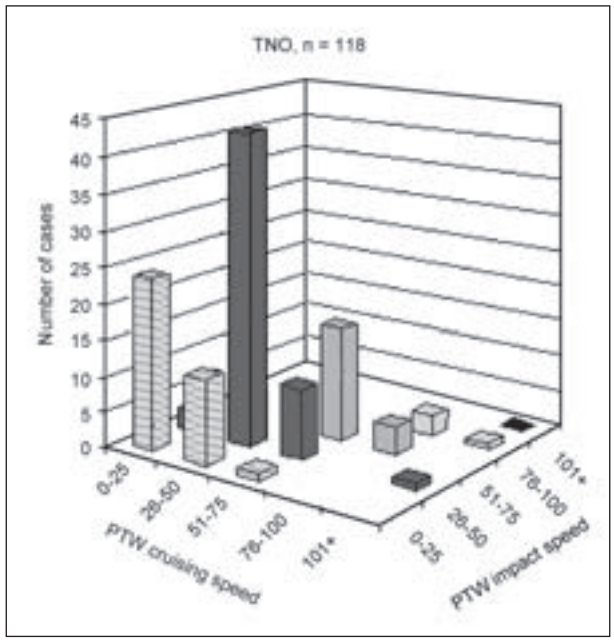

Figure 2: PTW cruising speed and impact speed, TNO MAIDS

	TNO n=85	DEKRA n=157	GIDAS n=128	LMU n=76
Urban – Moped – Car – Intersection	49%	5%	12%	4%
Urban – Moped – Car – Straight road	12%	1%	3%	1%
Urban – Motorcycle – Car – Intersection	21%	29%	55%	42%
Urban – Motorcycle – Car – Straight road	11%	11%	21%	22%
Rural – Motorcycle – Car – Intersection	4%	38%	3%	13%
Rural – Motorcycle – Car – Straight road	4%	16%	6%	17%

Table 2: Accident scenario distribution within the four databases

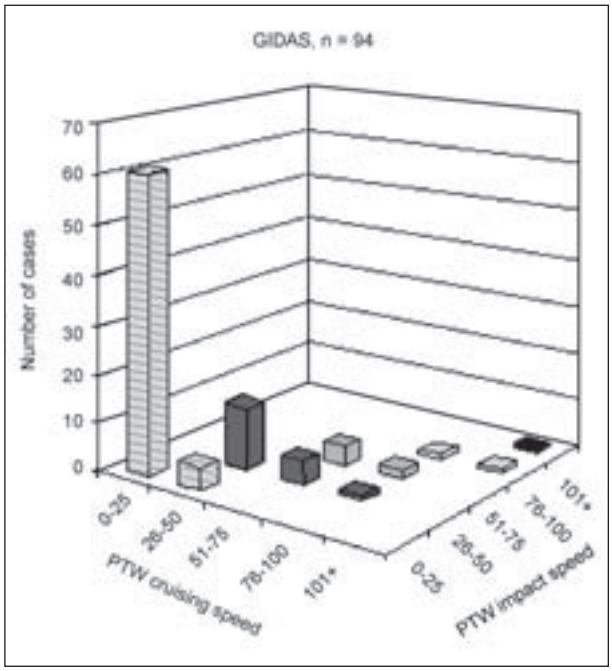

Figure 3: PTW cruising speed and impact speed, GIDAS 2002 data

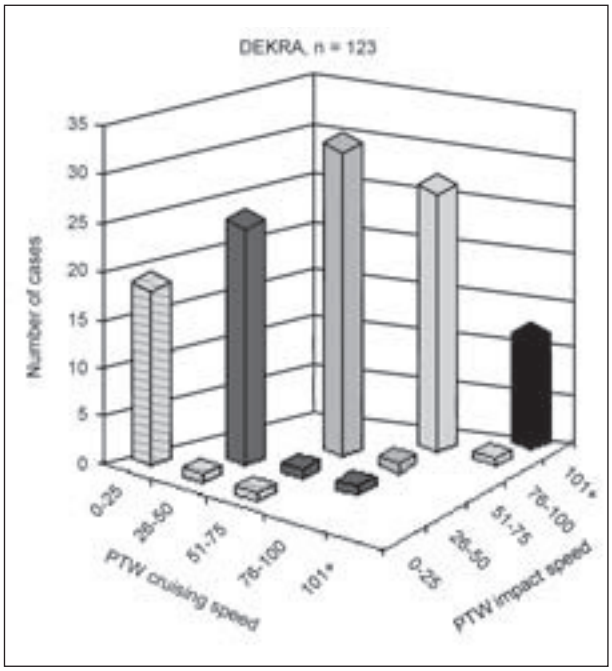

Figure 4: PTW cruising speed and impact speed, DEKRA data

speed reduction, but it does indicate that the speed reductions were not extremely high. The conspicuous high cruising and impact speeds in the DEKRA database are related to the fact that most of the severe and fatal accidents which are recorded are associated with the higher speed bands. It is possible to derive from each of the databases any accident avoidance manoeuvres that were attempted such as swerving, branking using both front and rear brakes or combined braking and swerving. Nevertheless in up to 94% of the analysed cases these actions were unsuccessful. This could often be a matter of timing, like such as braking too late or a matter of insufficient brake power due to wet roads or skidding.

PTW-to-car impacts with the PTW moving upright prior to the impact could be coded in the ISO 13232 format. This three digit code enabled a classification to be made of the contact points of the vehicles and their respective heading angle at the moment of first impact [14]. In most of the impacts the PTW was still upright and the rider was not separated from the PTW at the time of impact. This was true in typically 55% of the cases. ISO constellations could be directly gathered from the DEKRA database in which they are coded. For the TNO MAIDS database it was possible to assemble the data from the relative heading angle of PTW and car and the impact locations on PTW and car. The variety of impact constellations is substantial and they do not show a clear trend. However front-front and front-side PTW to car impacts are the most relevant ones, Figure 5. The next item to be considered is the type and severity of injuries suffered by the PTW user. In the databases from LMU and GIDAS, the lower extremities are hit most often, followed by the head, then the upper extremities and thorax. It should be noted that LMU data have the head-neck injury inclusion criterion so that the amount of injuries to that body region will be over-represented. Furthermore the lower extremities portion in the GIDAS data is very large. The object hit is primarily the car, followed by the road and the PTW. For the head and the neck there are few cases recorded where another object was hit. This could have been for instance a road-side structure, Figure 6 and Figure 7.

The injury severities reported from the GIDAS 2002 database are shown in Figure 8. The thoracic injuries are commonly not very severe when compared with the other databases. This is an unexpected result but it should be kept in mind that the head injuries in GIDAS are also relatively slight, whereas in the COST 327 database such injuries are extremely severe. This is related to the fact that the GIDAS database is representative according to the German National Statistics. Here, more than 68% of the PTW accidents occur in urban areas where the driving speeds are relatively low. The proportion of slightly injured PTW users (67%) is also representative in regard of the National Statistics.

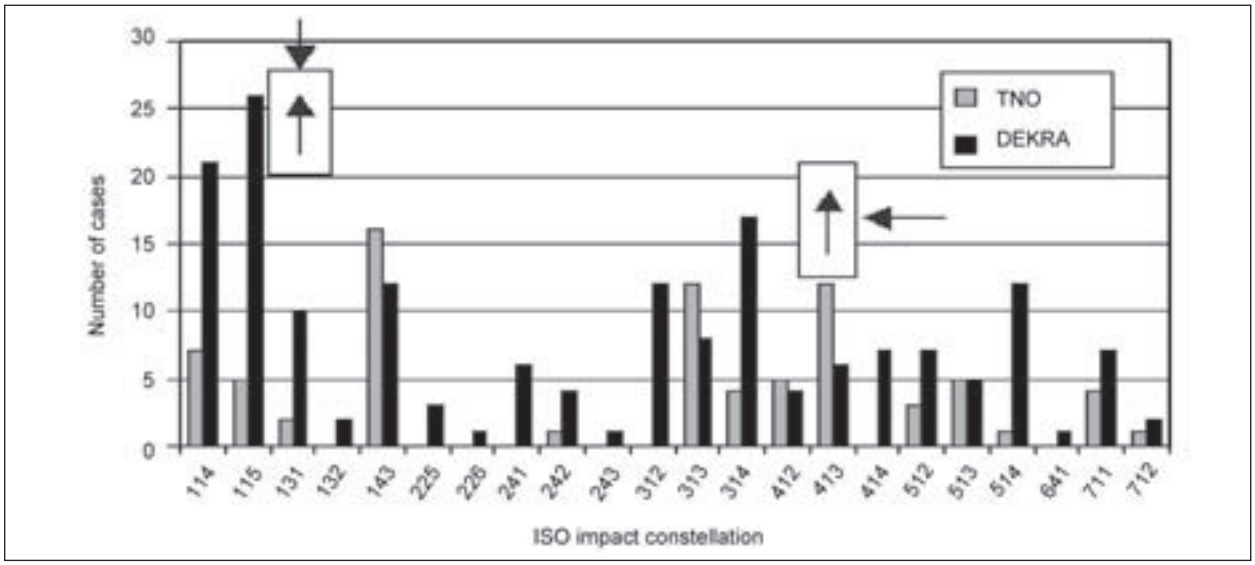

Figure 5: ISO impact constellations, TNO- MAIDS and DEKRA databases

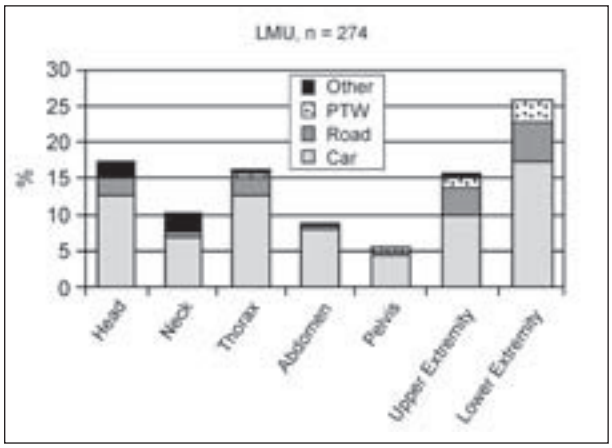

Figure 6: Primary body region affected by the impact, LMU COST 327 data

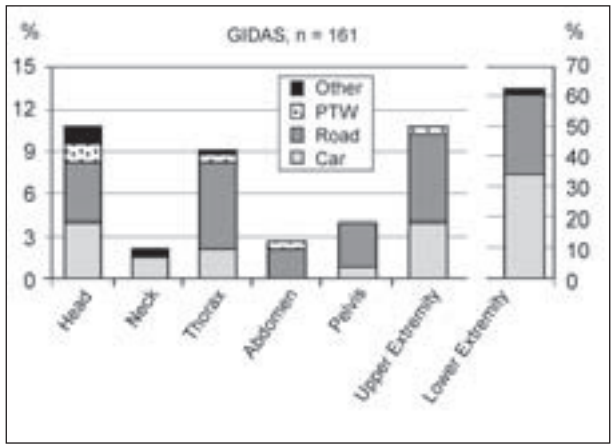

Figure 7: Primary body region affected by the impact, GIDAS 2002 data

The location where the rider finally ends up after the impact is called the rider point of rest (POR). This position is often very different from the point of impact (POI) and the distance between them can sometimes be quite large [15]. The ways in which this distance between POI and POR is covered can be very diverse and are coded differently in the databases used. The TNO data show a large number of throws, almost equal to the combined number of tumble/roll/skid types of transition, while the German LMU and DEKRA data contain a very large number of these tumble/roll/skid types of transition. Additionally the relation between POI and POR in regard to injury severity was analysed. It could be observed that contact with the car caused more severe injuries to head, abdomen and thorax, while the accidents with a large POI-to-POR distance have relatively more low-severity upper- and lower extremity injuries. When comparing

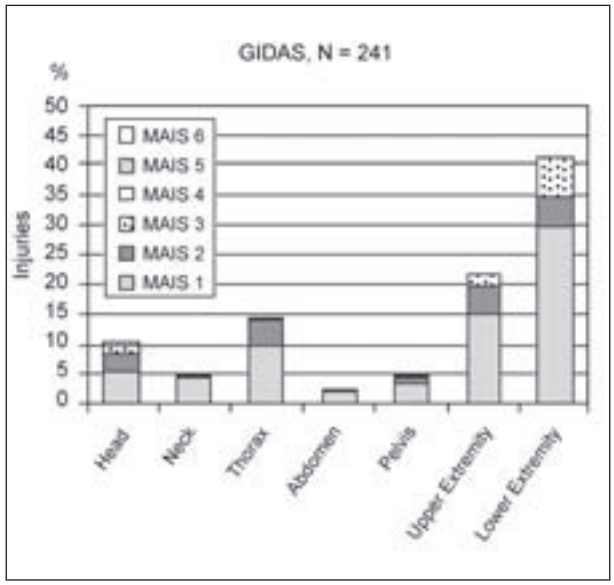

Figure 8: MAIS injury level with respect to specific body areas, GIDAS 2002 data

accidents with long POI-to-POR distances (>10m) with accidents with short POI-to-POR distances (<10m) it can be seen that in the short POI-to-POR distance accidents

- the injury is frequently caused by contact with the car;
- the injuries are more severe on average;
- head and abdominal injuries occur more often and are more severe;
- thorax injuries are more severe;
- upper and lower extremity injuries are less often encountered.

Concluding, the main cause of PTW accidents is related to perception failure. If the PTW user tries to avoid the accident, front and rear brakes are often applied, however, mostly without success. As a consequence the PTW hits the car, or the car hits the PTW with the rider seated in an upright position. The rider either hits the car first, resulting in severe head or abdominal injuries or ejects from the PTW, resulting in a vault or throw, the nature of which is dependent on the impact speed and impact constellation. As a consequence the road is hit in a secondary impact and the injuries relate mainly to the extremities, these being less severe than the injuries resulting from body impacts with the car.

PTW–infrastructure accidents

As already mentioned, the GIDAS 2002 data represent the whole accident situation in Germany. For that reason, most of the registered accidents occurred inside urban areas with relatively low impact speeds and – as a result of that – relatively low injury levels. Regarding the in-depth analysis of PTW-to-infrastructure accidents, very few cases are usually available. The GIDAS 2002 data comprise only 6 barrier and 3 tree or pole impacts. Therefore this section of the paper which focuses mainly on GIDAS database analysis only summarises briefly the main results of the overall exercise [16].

The most significant obstacles involved in accidents with a particularly severe outcome were trees/poles, roadside barriers and road infrastructure elements in general also including pavement. Analysis of the collision sequences indicates that most of the obstacle impacts took place as primary impacts. Accidents involving tree/pole impact seemed to be largely single-vehicle accidents [17]. Impact speeds in accidents involving roadside barriers as an obstacle tend to be very high, whereas impact speeds did not differ outstandingly from the whole group of accidents with a tree/pole involvement as a result of being in the median range of 30–40km/h for TNO and GIDAS and 50–60km/h for Cost 327 and DEKRA data. The angle at which a rider typically left the road seemed to be very shallow and the rider thereby seemed to be aligned nearly parallel to the road. In most impacts with trees/poles and barriers the rider was upright on his PTW. When a metal guar drail was struck, the rail seemed to be hit more often than the post. A small percentage of accidents involved road-infrastructure features. Causation issues can rarely be determined for different obstacles. The impression is gained that roadside barriers cause particularly severe injuries when hit. Taking into account the observed impact speeds, tree/pole impacts have to be considered to be at least as equally dangerous as barrier impacts. Obstacle impacts result in head injuries particularly often and when barrier impacts occur the lower extremities are injured nearly as often as the head.

PTW user protective devices

In order to obtain comparable data from the four different databases, a series of common charts was set up. The objectives of the analysis of these accident data records were the identification of the most frequently injured body region, the most severely injured body region, the typical injuries sustained by each body region and the verification of information about the performance of the motorcyclists' protective clothing. To reach a reliable conclusion from this analysis, it was decided to include all the accident scenarios in order to consider as many cases as possible. In a first step, a paired comparison between injured and uninjured motorcyclists was conducted. In this way the possible influence of the protective clothing worn could be derived. Additionally, the different kinds of injuries to each specific body region were analysed separately, enabling valuable conclusions to be drawn about how the protective elements should work to be most effective in the prevention of injuries. Three different impact speed ranges (0-35km/h, 36-70km/h and >70km/h) have been analysed with respect to different protective clothing combinations. This led to a primary overview of the miscellaneous protection levels in

the four databases. The definition of protection level is given in Table 3. As expected, the helmet was the most frequently used item of protective clothing and therefore protection level 1 was the level achieved most often, namely by an average of 66% of the PTW users. The second most frequently achieved protection level according to the databases was level 3 by a mean of 18% of the PTW users. As far as trousers, jackets and boots are concerned it was considered that only clothing made out of leather or special heavy garment material like Kevlar or imitation leather was able to offer any protection.

By relating the previously mentioned protection levels found in the four different in-depth databases to the severity of injuries suffered by the respective riders and passengers, it could be stated that in general injury severity decreases with increasing level of protection, see Table 4. However, this is not true for level 0 where only 27 cases were available.

For the three different speed bands the rider and passenger related injuries have been further investigated and classified by means of the Abbreviated Injury Scale (AIS) coding. At speeds up to 35km/h, it was noted that only the head sustained severe injuries (AIS 3+) according to the NL-MAIDS and GIDAS 2002 data. From the COST 327 information, it was clear that the thorax and abdomen also sustained severe, critical or maximum injuries. Additionally, with an increase of impact speed, other body regions were severely injured. Particularly the spine and neck injuries were already at a critical level for the speed band of 36-70km/h. The pelvis as well as the upper extremities sustained severe injuries when the impact speed exceeded 35km/h. For the impact speed band of 36-70km/h, the corresponding impact points struck by the riders and passengers as recorded in the NL-MAIDS and the GIDAS 2002 database are shown in Figure 9. In most body regions, impact with the ground or road as well as impact against an unspecified object were considered to be responsible for the injuries. Regarding pelvic injuries it is worth mentioning that often the PTW itself (e.g. the fuel tank, handlebar, etc.) was the object responsible for causing injury.

The body regions suffering injury have been analysed separately. For the head, helmeted and un-helmeted riders and passengers have been compared in order to identify possible protection effects. Different helmet types such as full-face helmet, jet helmet and half-shell helmet have been analysed within the three impact speed bands. The data showed that a significant number of riders did not use a helmet. This is due to the fact that in the Netherlands a helmet is not compulsory for low-speed mopeds. Compared to the un-helmeted PTW users those wearing a helmet suffered lower injury severity levels. This is true for all impact velocities. For impact speed values up to 35km/h, the helmet was effective in preventing severe injuries while, as soon as the impact speed values increased, the number and the severity of different types of injuries increased too. Additionally the helmet situation was split into 18 sectors and the damage to each of

Protection Level	Clothing combination	Protection Level	Clothing combination
0	No protection	1	Helmet
	Jacket		Helmet and boots
	Trousers		Helmet and gloves
	Jacket and trousers		Helmet and trousers
	Jacket, trousers and boots		
2	Helmet, gloves and boots	3	All the body covered
	Helmet, jacket and boots		Helmet, jacket and trousers
	Helmet, jacket and gloves		Helmet, jacket, trousers and boots
	Helmet, jacket, gloves and boots		Helmet, jacket, trousers and gloves

Table 3: Protection levels and respective clothing combinations

Protection level	Number of cases	Not injured	Slightly injured	Severely injured	Killed
0	27	3.7%	55.6%	33.3%	7.4%
1	586	1.9%	19.6%	39.8%	33.3%
2	102	0.0%	31.4%	36.3%	32.4%
3	159	1.9%	37.1%	32.1%	28.9%

Table 4: Injury distribution in relation to protection level

those as well as the corresponding injuries were analysed. It was found out that the critical regions were the forehead and the rear part of the helmet. Loss of the helmet during the impact was found not to be an unusual event. Improvements to the strap and/or the fitting of the helmet to the head were classified as effective countermeasures.

For facial injuries only NL-MAIDS and GIDAS 2002 data were taken into account because in the COST 327 database these injuries are included in the head section. Here, too, the different helmet types and the impact speed ranges have been considered. Again, it was found that the helmet is capable of preventing injuries, although it was

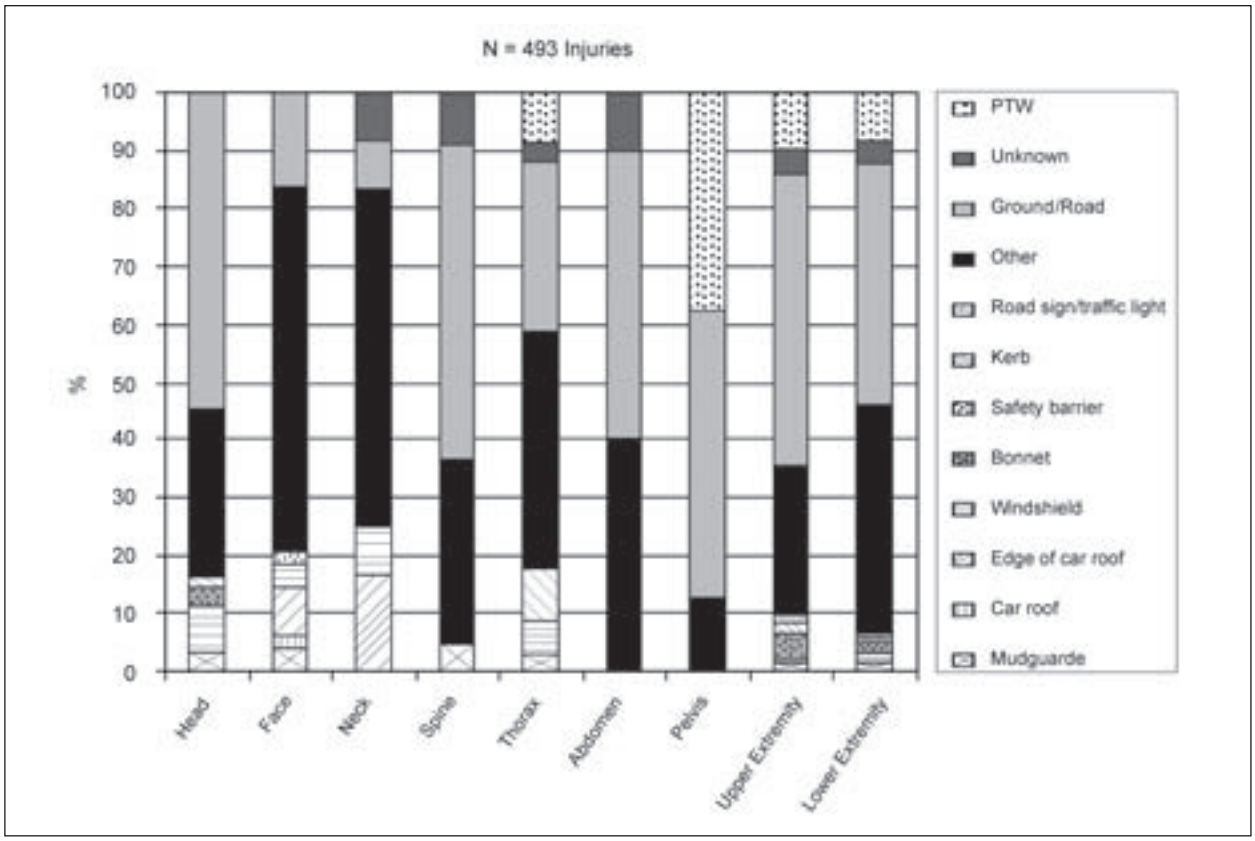

Figure 9: Spread of injuries and related impact locations for the impact speed band 36-70km/h, according to NL-MAIDS and GIDAS 2002 data

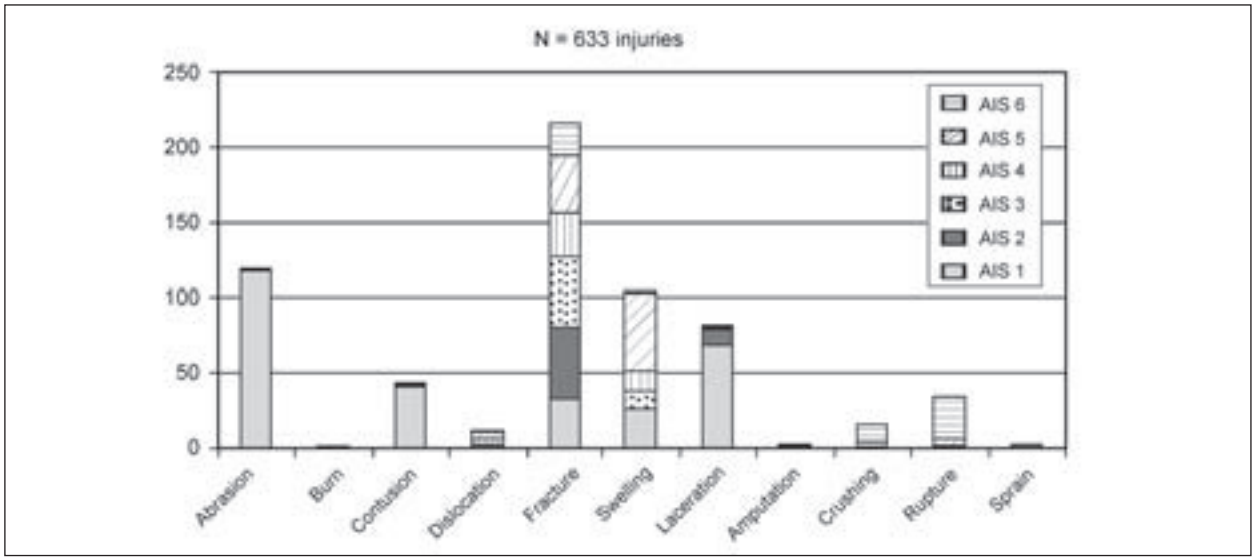

Figure 10: Injury types and severity levels for the neck, COST 327 database

noted that regardless of the impact speed the recorded AIS levels for the face were very low. They consisted mostly of abrasions, contusions and lacerations.

As far as the neck is concerned in NL-MAIDS and GIDAS 2002 databases, only the soft tissue injuries have been taken into account. The more severe skeletal injuries have been analysed separately in the spine section. Because of this, neck injury severity levels recorded in NL-MAIDS and GIDAS 2002 are lower than those found in COST 327 cases. The likelihood of soft tissue injuries in the neck is very low. In the case of COST 327 data where skeletal injuries were also included, the frequency and severity of neck injuries increased significantly for impact speeds higher than 35km/h. The different kind of injuries to the neck found in the COST 327 database are shown in Figure 10. Mostly AIS 1 injuries were recorded which normally refer to soft tissue injuries such as abrasions, lacerations or contusions. The severe neck injury types (AIS 3+) consisted of dislocations, fractures, swelling, crushing, and rupture.

Protected – meaning the wearing of leather clothes or heavy garments – and unprotected PTW casualties have been compared for their influence upon injury to the upper extremities. From the GIDAS 2002 and NL-MAIDS data, it can be seen that the frequency with which injuries to the upper extremities were sustained was reduced when protective clothing was worn, regardless of the impact speed. From the analysis of COST 327 data a similar situation is obtained, except for the impact speed band of 36km/h to 70km/h. No matter what impact speed or what database was taken into account, it can be stated that wearing protective clothing seemed to reduce the level of injuries. In fact, comparing casualties to injuries, 74 injuries were recorded for 51 harmed protected riders whereas 152 injuries emerged for 89 unprotected riders. The same analysis has been performed for the COST 327 data which respectively showed a total amount of 66 injuries for 46 injured protected riders against 169 injuries for 109 unprotected hurt riders. As far as the distribution of injury severity is concerned, it can be stated that the use of motorcyclist protective clothing had some benefits particularly at impact speeds up to 35km/h. The most common injury types were abrasions, fractures and contusions.

Almost the same conclusions could be drawn for the lower extremities as for the upper extremities. Wearing rider protective clothing significantly reduced the amount and the severity of injuries sustained at all impact speeds. For 49 wounded protected riders 85 injuries were recorded whereas for the unprotected riders 160 casualties with 331 injuries arose (NL-MAIDS and GIDAS 2002). The same trend was illustrated by the COST 327 data which showed a total of 59 injuries for 43 injured protected riders while 297 injuries were recorded for 161 unprotected harmed riders. The most frequent types of injuries were contusions, abrasions and fractures.

Analyses dealing with spinal injuries demonstrated that motorcyclist protective clothing is helpful in reducing the injury severity and the number of injuries in comparison to the number of casualties in all speed bands. Although there are not many cases available from GIDAS 2002 and Dutch MAIDS data, this trend could also be observed here – 18 injuries were recorded for 17 injured protected PTW users whereas 19 injuries were sustained by 14 harmed PTW users. The most frequent of the spinal injuries were fractures and distortions in the cervical spine area.

The data concerning thorax injuries confirmed that contusions and fractures in that order were the most frequent injuries. With regard to injury severity, damage to internal organs was the most critical aspect. From COST 327 data also, fracture was found to be one of the most severe types of injury but in this case, the data also included spinal injury and this affirmed the outcome of the previous section relating to the spine.

Summary and Future Steps Action

In order to reach the ambitious target to cut in half the number of road users killed every year by 2010 (based on the 2001 figures) for the EC-15 countries, special attention must also be paid to PTW accidents. Consequently, a sub-project dealing with motorcycle accidents was established within the APROSYS IP of the 6th Framework Programme of the EC. A two-step investigation of the PTW accident records has been completed. The National Statistics of four European countries for the years 2000–2002 have been analysed and found to show similar trends for the specific matters of concern which were examined. Seven main PTW accident scenarios were identified which have been further investigated via in-depth databases. The analyses of these scenarios have been conducted

by making use of the DEKRA PTW database, the GIDAS 2002 database, the COST 327 database and the Dutch element of the MAIDS database:

Urban – Moped – Car – Intersection.

Urban – Moped – Car – Straight road.

Urban – Motorcycle – Car – Intersection.

Urban – Motorcycle – Car – Straight road.

Non-urban – Motorcycle – Single vehicle accident.

Non-urban – Motorcycle – Car – Straight road.

Non-urban – Motorcycle – Car – Intersection.

In a subsequent step, three different tasks have been set up dealing with PTW-to-car accidents, PTW collisions with infrastructure features and the performance of rider protective devices. For the PTW–car accidents it was found that the outcomes of former studies in the field could be endorsed. Most PTW-to-car accidents resulted from a perception failure. As far as the ISO 13232 impact constellations are concerned, it was possible to confirm front-front and front-side impacts of the PTW with the car as being the most frequent. Accident avoidance manoeuvres on the part of the PTW were sometimes accomplished through braking and/or swerving but with little success. On average, injuries suffered by the PTW users were more severe when caused by contact with the car. In the case of PTW collisions with infrastructure features the most significant obstacles involved in accidents with a particularly severe outcome were trees/poles, roadside barriers and road infrastructure features in general including pavement. Frequently the collision with a road infrastructure feature constituted the primary impact. Roadside barriers appeared to cause particularly severe injuries when struck, a noteworthy point here being that the impact angles were rather shallow. Obstacle impacts led to head injuries particularly often and the lower extremities were injured nearly as often as the head. For the determination of the effectiveness of protective devices used by PTW drivers, a paired comparison between protected and unprotected casualties has been carried out in which four protection levels were defined. The analyses were focused on the impact speed bands of 0-35km/h, 36-70km/h and exceeding 70km/h. Even at velocities up to 35km/h, it was noted that the head, thorax, pelvis, abdomen and the upper extremities sustained severe, critical or maximum injuries. Analyses of spinal injuries demonstrated that motorcyclist protective clothing is helpful in reducing both the injury severity level and the number of injuries which are sustained in accidents occurring in all speed bands.

In the next stage of the project which deals mainly with PTW collisions with infrastructure features and the evaluation of rider protective devices, in-depth data as well as real crash test data will be further investigated. In particular, rider and PTW kinematics prior to, at the time of and after the collision are to be determined. Parameters such as impact angles, trajectories, POI-to-POR distance etc. will be gathered on a case-specific basis in order to define a model scenario. This model scenario will be reconstructed and visualized using multi-body simulation tools. Injuries will be simulated via human body models such as PAM Crash and RADIOSS. The output of the simulations will then be compared with the real accident data sets so as to validate the fitness of the simulations. Furthermore, a proposal for a test procedure to evaluate metal barriers will be developed as well as a concept design for motorcyclist safety in the context of roadside infrastructure features. Additionally, the problem of providing improvements to motorcyclist safety helmets and protective clothing will be addressed. Data relating to vehicle motion and impact behaviour will be studied in order to define working and activation parameters for complementary safety devices.

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