Powered two wheelers accident investigation and reconstruction

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Abstract - One of the major problems of road safety in Europe is the powered two wheelers accidents. One of the European countries with one of the highest rates is Portugal where in 2006, mopeds and motorcycles fatalities represented 27% of all road users deaths. In this work, a deep analysis and overview of the current state of mopeds and motorcycles accidents for the 2004-2006 period is presented. Within this period 830 PTW occupants die, 2958 have been severely injured and 25000 suffer slight injuries. A detailed analysis of the conditions of these accidents has been carried out, using the data of the national accident database. This analysis provides global information, about geographic environmental conditions, driver's characteristics among others. From this data detailed information is obtained allowing to know when, where and who. In order to answer the question why more a widely collection of data has been collect for 70 accidents. The data has been collected using OECD methodology. For these accidents a detailed reconstruction has been carried out, what is especially important for fatal accidents where for instance speed in an important factor. From these collection and analysis of data a wider overview of facts and measures are extracted. Among them, some are emphasized such as that the quality and non-use of helmets plays an important role in severe and fatal accidents especially for accidents involving moped vehicles, or speed is the most important factor in fatal accidents involving motorcycles.

Concerning motorcycle accident reconstruction, different tools can be used depending of the accident scenario and complexity. For simple cases, with specific characteristics, analytical formulation based in vehicle crash dynamics can be use in order to determine the impact speed of the vehicles impact, analysing the skid marks, deformations, victims rest position and considering parameters (EES, vehicle deceleration, etc). Aspects such as the energy absorption capability of motorcycles are also discussed. In the general cases the accident reconstruction software Pc-Crash has been used for the reconstruction of the accident. In very complex cases, has for instance the impact between motorcyclist and barriers, Madymo software is used especially to determine speed from injuries. An example of the impact of a motorcyclist and a motorcyclist-friendly barrier is present to illustrate the benefits and limitations of such systems.

NOTATION

MT1 Motorcycle type 1
MT2 Motorcycle type 2
MT3 Motorcycle type 3
PTW Powered two wheels
TWV Two wheels vehicles
VCL Vehicle control loss

INTRODUCTION

Portugal is one of the countries with one of the highest rates of accidents involving PTW in Europe. According to the Portuguese accident database in the 2004-2006 period, 28730 accidents with injuries occurred, 830 persons died (within the 30 days: correction factor= 1.14), 2958 severe and 24942 slight injuries occurred (Table 1).
Despite the fact that the PTW only represent 9,3% of the total vehicle in circulation in Portugal, it represents 27% of all road users deaths. This numbers are unacceptable, having a high impact in the country, generating implications in a social point of view and a socio-economical cost for the country, leading to an alarming situation, in which the number of fatalities per 1000 vehicles in circulation concerning the PTW overcomes the light vehicles and heavy trucks fatalities (Figure 1), and that's why it is highly recomendable the in-depth study of all road accidents in order to trace a strategy which the main goal is to reduce the number of fatalities and accidents involving PTW, and subsequently reduce the socio-economical cost for the country.

Table 1. Road injuries in Portugal 2004-2006 [1]

	Injuries								
	Fatal(*)			Serious			Slight		
Year	2004	2005	2006	2004	2005	2006	2004	2005	2006
PTW	302	294	234	1092	985	881	9072	8308	7562
Pedestrians	232	214	156	766	714	617	5849	5568	5612
Light Vehicles	644	620	477	2097	1830	1754	30381	28969	27955
Heavy Trucks	31	33	19	70	66	66	974	1071	909
Others	84	86	83	165	167	165	1543	1571	1616
Total	1293	1247	969	4190	3762	3483	47819	45487	43654

(*) Fatalities on accident scene applying the corrective factor 1,14.

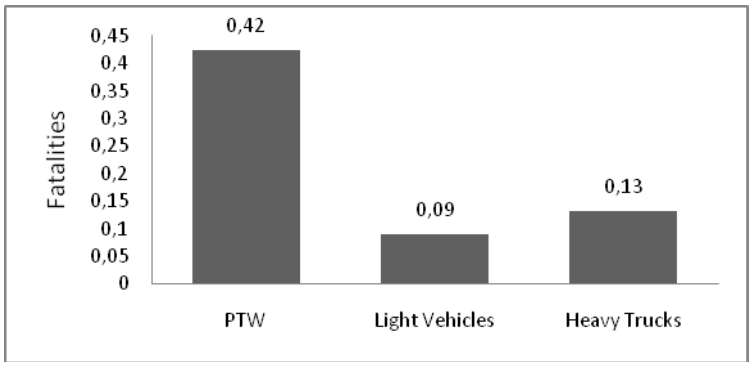


Figure 1. Fatalities per 1000 vehicles in circulation on Portugal, 2006.

The reduction of the Portuguese road fatalities, involves between others, countermeasures like campaigns providing PTW safety information, law enforcement, skills training and incremental technological advances such as ABS. Despite these efforts devising effective countermeasures requires comprehensive research into current causes of PTW crashes and defining aspects related to the population at risk. Making an effort all can help to accomplish much more towards improving the PTW safety, and it is necessary to remember that European harmonization requires homogenous definitions to establish meaningful comparisons.

The work presented hereunder is part of the in-depth research project of accidents involving PTW pedestrian accidents and that has the objective of understanding what are the factors responsible for the high number of injuries and fatalities in Portugal. Also the development of models for accident reconstruction of such accidents is an objective of this project.

VEHICLE FACTORS

In Portugal there are 4 types of PTW, mopeds and 3 different classifications of motorcycles, which are presented in Table 2. Each of those types of PTW, have different contributions concerning the number of accidents, and in the type of injuries that result from those accidents.

In Figure 2 is presented the percentage of accidents with injuries for 2004-2006, in which it can be concluded that mopeds are the major problem, when we talk about the high number of accident involving injuries, followed by the motorcycle type 3, that is capable of achieve the highest speeds, and acceleration.

The conclusion is obvious, mopeds are the type of PTW more involved in accidents with injuries in Portugal, and however are mopeds the most dangerous category of PTW in Portugal? According with the number of accidents in the period of 2005-2006 the answer is no, and it is based in Figure 3 and in Figure 4.

Table 2. PTW categories in Portugal

	**Moped:** Motor vehicle with two wheels, with an engine size of less than 50 cc. Design speed between 25 km/h and 50 km/h. One or two seats.
	**Motorcycle type 1:** Motor vehicle with two, three or four wheels, with an engine size of 50 cc. With a trailer possible. With a sidecar possible.
	**Motorcycle type 2:** Motor vehicle with two, three or four wheels, with an engine size of more than 50 cc but less than 25 kW of power. With a trailer possible. With a sidecar possible.
	**Motorcycle type 3:** Motor vehicle with two, three or four wheels, with an engine size of more than 50 cc and more than 25 kW of power. With a trailer possible. With a sidecar possible.

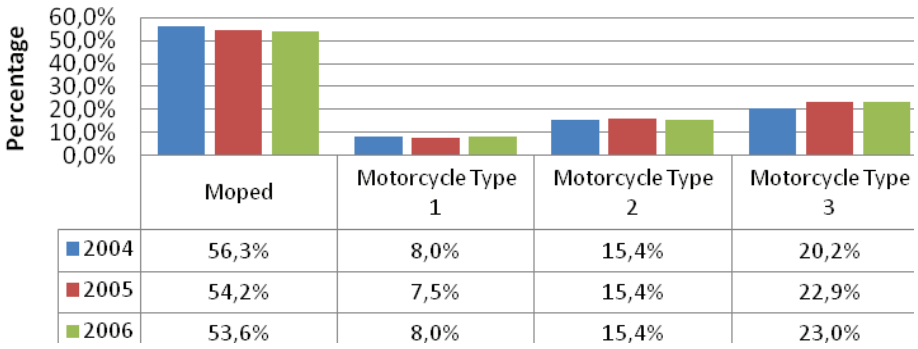


Figure 2. Percentage of accidents involving injuries with PTW in Portugal, 2004-2006.

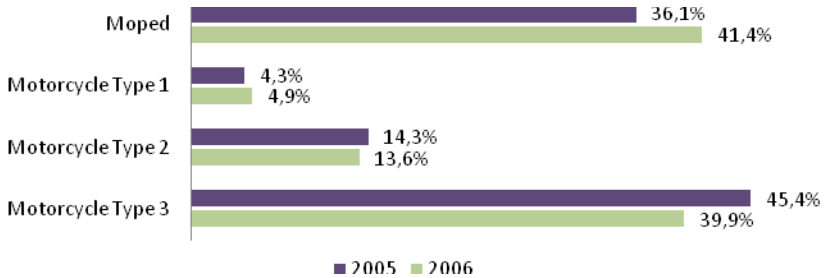


Figure 3. Fatal injury percentage per type of PTW in Portugal, 2005-2006.

Once again it is evidenced that mopeds are a category involved in a high number of accidents and consequently they produce a high number of fatal accidents. But also motorcycle type 3 produce a high number of fatal injuries, and it is the PTW category that is more dangerous in Portugal (motorcycle type 3), which produce the highest number of fatal injuries per 100 accidents involving injuries. Despite the low number of accidents that involve injuries that this category, motorcycle type 3, presents when compared with mopeds, they cause more deaths.

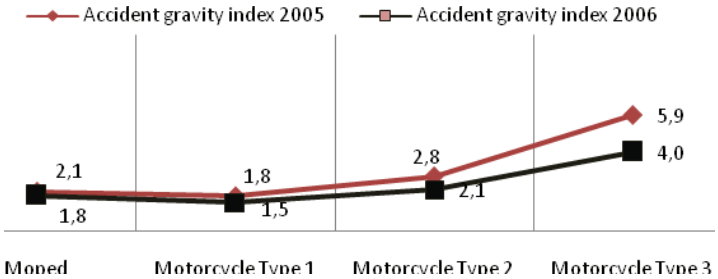


Figure 4. Accident gravity index of PTW in Portugal, 2005-2006.

It is important to understand which is the most common accident configuration. The statistical data for the configuration of accidents with injuries involving PTW in Portugal is presented in tables 3 to 5. In highlight there is the most frequent configuration of accidents with injuries involving PTW, and the most common in the period of 2004-2006 are, the lateral collision with another moving vehicle, followed by vehicle control loss, and at last the frontal collisions.

Table 3. Configuration of accidents with injuries involving PTW in Portugal, 2004.

Accident configuration	Moped	MT1	MT2	MT2
Running over animals	0,0%	0,0%	0,0%	0,0%
Running over of laborers	2,6%	3,8%	3,9%	4,3%
Lateral collision with another moving vehicle	36,8%	43,6%	36,7%	34,6%
Chain collision	0,1%	0,1%	0,2%	0,2%
Runaway collision	1,5%	1,7%	0,9%	0,9%
Back collision with another moving vehicle	8,9%	8,8%	8,1%	11,7%
Frontal collision	15,9%	15,2%	17,2%	12,9%
Collision with other situations	1,6%	1,5%	2,0%	1,4%
Collision with obstacle or vehicle in road	4,4%	3,6%	3,1%	3,3%
VCL with rollover	1,8%	0,8%	1,4%	1,5%
VCL with collision with immobilized vehicle or obstacle	3,0%	2,3%	4,3%	4,2%
VCL without road barrier	1,7%	1,3%	1,9%	1,5%
VCL with road barrier	0,2%	0,5%	0,4%	1,3%
VCL with runaway	0,1%	0,6%	0,3%	0,4%
VCL with transposition of the road barrier	0,1%	0,1%	0,4%	0,9%
Simple VCL (Vehicle Control Loss)	21,5%	16,0%	19,2%	21,0%

Table 4. Configuration of accidents with injuries involving PTW in Portugal, 2005.

Accident configuration	Moped	MT1	MT2	MT2
Running over animals	0,7%	0,0%	1,2%	0,7%
Running over pedestrians	2,9%	3,1%	4,0%	3,8%
Lateral collision with another moving vehicle	34,5%	41,2%	38,2%	36,0%
Chain collision	0,1%	0,3%	0,3%	0,3%
Runaway collision	1,6%	1,3%	1,6%	1,6%
Back collision with another moving vehicle	9,5%	9,2%	9,4%	8,6%
Frontal collision	15,1%	17,8%	13,7%	11,1%
Collision with other situations	1,9%	1,9%	2,1%	2,0%
Collision with obstacle or vehicle immobilized in road	4,4%	3,0%	2,4%	4,4%
VCL with rollover	1,3%	0,7%	1,9%	1,3%
VCL with collision with immobilized vehicle or obstacle	3,2%	3,4%	2,6%	3,7%
VCL without road barrier	2,2%	1,0%	1,4%	1,5%
VCL with road barrier	0,3%	0,1%	0,4%	1,1%
VCL with runaway	0,3%	0,1%	0,2%	0,3%
VCL with transposition of the road barrier	0,3%	0,0%	0,1%	0,8%
Simple VCL	21,6%	16,6%	20,3%	22,6%

Table 5. Configuration of accidents with injuries involving PTW in Portugal, 2006.

Accident configuration	Moped	MT1	MT2	MT2
Running over animals	0,6%	0,8%	0,9%	0,5%
Running over pedestrians	2,8%	2,1%	4,2%	3,1%
Lateral collision with another moving vehicle	34,4%	38,1%	35,7%	34,5%
Chain collision	0,2%	0,2%	0,2%	0,4%
Runaway collision	1,5%	0,8%	1,1%	1,3%
Back collision with another moving vehicle	9,2%	10,8%	7,9%	10,3%
Frontal collision	13,8%	15,8%	14,7%	11,1%
Collision with other situations	2,5%	1,8%	2,6%	3,2%
Collision with obstacle or vehicle immobilized in road	3,9%	4,5%	2,9%	3,4%
VCL with rollover	1,6%	1,2%	1,8%	1,5%
VCL with collision with immobilized vehicle or obstacle	2,7%	3,2%	3,5%	4,6%
VCL without road barrier	2,3%	1,8%	3,1%	2,3%
VCL with road barrier	0,5%	0,6%	0,5%	0,8%
VCL with runaway	0,3%	0,6%	0,2%	0,1%
VCL with transposition of the road barrier	0,2%	0,0%	0,3%	0,7%
Simple VCL	23,6%	17,9%	20,5%	22,2%

The main causes and problems behind lateral collision with another moving vehicle are bad conspicuity and visibility in junctions and the difficult of PTW being noticed by other vehicles in road, disrespect of priority rule, and inappropriate speed for the circulation conditions. Concerning the simple vehicle control loss, the main causes are high speed, poor driving skills, and deficient road construction and maintenance.
In Portugal the most critical types of PTW are the mopeds had to the high number of vehicles in circulation, and the motorcycles type 3, had to the fact of being extremely powerful and capable of very high acceleration and speed.

ENVIRONMENTAL FACTORS

The environmental and conditions in which the PTW are subjected in Portugal, is another important issue with direct influence in accidents with injuries involving PTW. The statistical data present in figure 5 demystifies the general idea that the majority of the accidents involving PTW occur in bad weather conditions, in fact it is in the optimum conditions that the majority of accidents happens, and this conclusion is also in conformity with the data present in figures 6 in which it is shown the distribution of accidents with injuries with PTW per month.

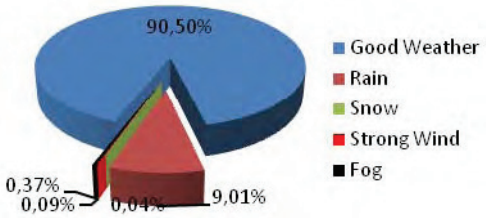


Figure 5. Weather conditions in accidents with injuries involving PTW in Portugal.

The months of June, July and August, which are the months with better weather conditions, this results have reveal that in those months there are more PTW in circulation, but also that when drivers are confronted with adverse conditions they tend to be more awareness of possible dangerous. Another aspect related with the road configuration, that is, if it is a straight road or bend, and in which more accidents occur. In figure 9 it is present the percentage of accidents that occurred without direct intervention of other vehicles, and the results show that for each accident in which the driver loses control of the vehicle in a bend configuration road, there are three that occur in a straight road configuration.

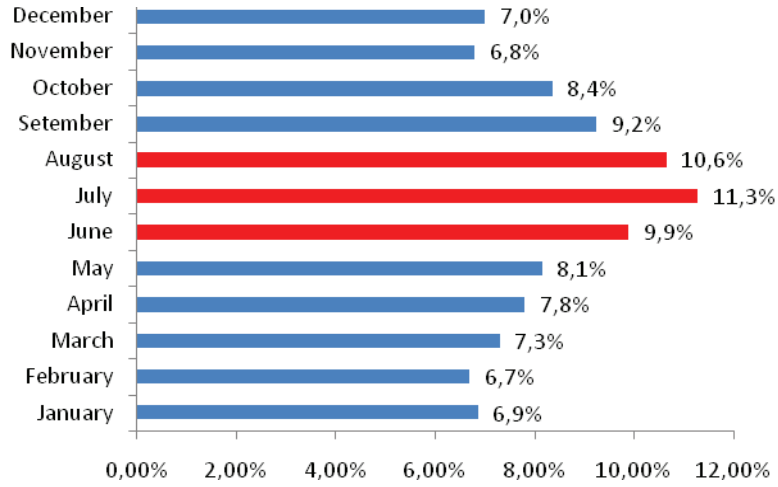


Figure 6. Accident with injuries involving PTW distribution per month in Portugal, 2005

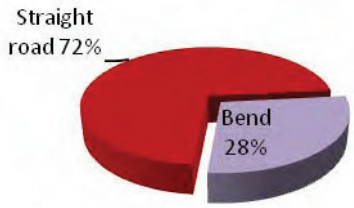


Figure 7. Simple vehicle control loss accidents with injuries involving PTW, according to road configuration in Portugal.

Those results only corroborate the previous statements, in which speed is a key issue but speed isn't an external factor that cannot be controlled or avoided, by the drivers of the PTW, and that's why human factors have a decisive contribution in road safety.

HUMAN FACTORS

There are some causes of PTW accidents that cannot be avoid by the driver of those vehicles, like in other category of vehicles, however PTW had to its features do not offer great conditions of safety for those who circulate in this type of vehicle, and that's why the driver must be aware and conscientious of the type of driving that he practices. It is imperative to study and specify behaviors of PTW drivers in order to improve their skills, make more efficient law enforcement, and trace the right path to a better national road safety strategy in Portugal.

In figure 10, it is shown that female drivers suffer more slight injuries compared to male drivers, however the male drivers suffer more serious and fatal injuries, this statistics reveal that in Portugal the PTW female drivers are more aware, and circulate more carefully and adequate speed when compared to the male drivers.

It is also important to filter the age interval in which occur more fatalities involving PTW, analyzing the data present in figure 11, it is evidenced that for less power PTW (moped, motorcycle type 1 and motorcycle type 2) the peak of fatalities is situated in an interval of ages between 16 years old and 21 years old, and for the most powerful type of PTW, motorcycle type 3, an interval between 21 years old and 30 years old, that correspond at the first years of licensing for each of those vehicles. According to this numbers the lack of driver skills, which a driver faces in his first years driving PTW, is an important factor, to have in consideration.

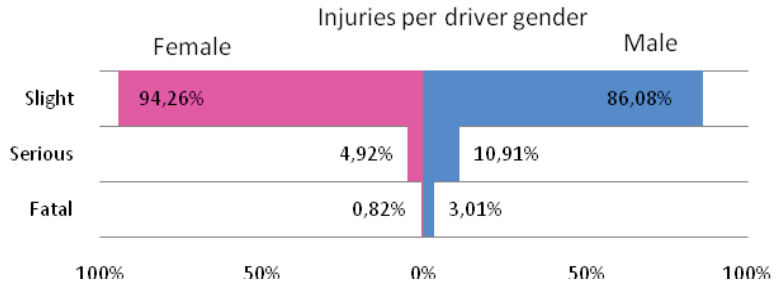


Figure 8. Injuries per driver gender involving PTW in Portugal.

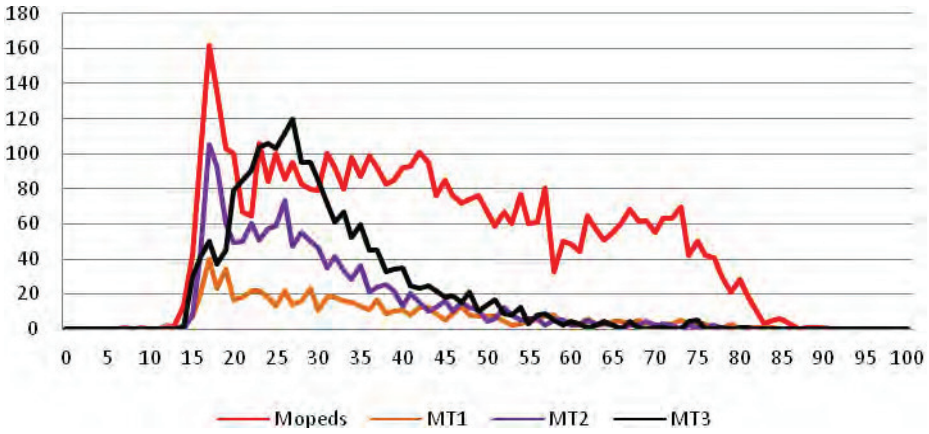


Figure 9. Drivers' age in fatal accidents.

It is also necessary to train drivers for the known problem that is alcohol, impairment by alcohol is an important factor influencing both the risk of a road accident, the severity of the injuries, as well post-crash outcome of injuries, even with a maximum legal blood alcohol content of 0,05g/l (in Portugal), in inexperienced young adults it represents 2,5 times the risk of involving in a road accident compared with more experienced drivers [3]. Through the graphic representation (figure 12), it is reveal that from all the drivers of PTW, who were involved in accidents with injuries, which had been submitted to blood alcohol test, and reveal a alcohol blood concentration greater than the legal 0,05g/l, 72% presented a alcohol blood concentration greater than 1,2g/l, running a risk of fatal injury accident 16 times when compared with a driver with zero alcohol blood concentration. However the number of drivers with alcohol above the limit is about 8%, which however is a very concerning number. This is an alarming situation and requires drastic measures (severe law enforcement) to avoid this kind of situations in the near future.

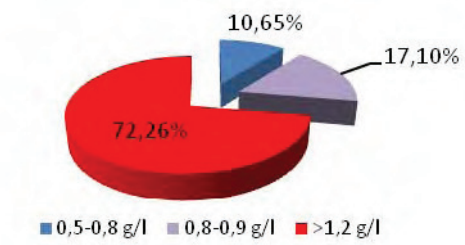


Figure 10. Alcohol test results in drivers involved in PTW accidents with injuries in Portugal.

Another situation that occur in Portugal, despite the use of helmet to be mandatory in Portugal, still many exist that don't use the helmet, this is a situation that requires a special attention on the part of

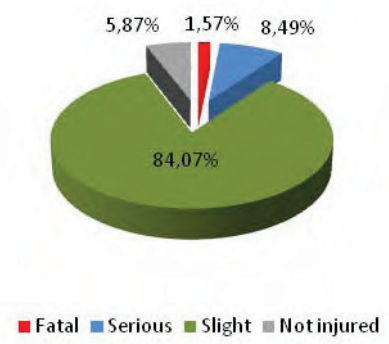
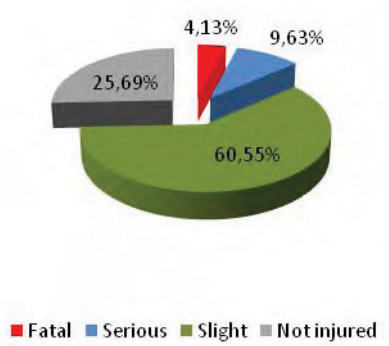
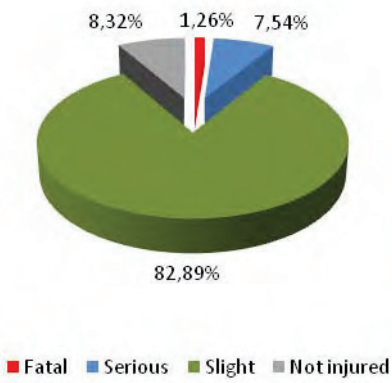
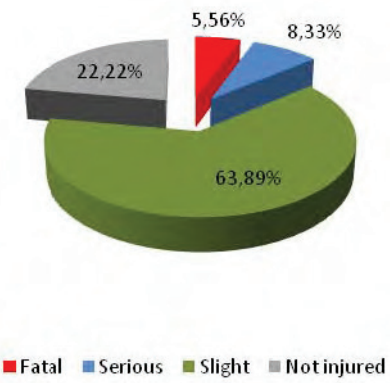
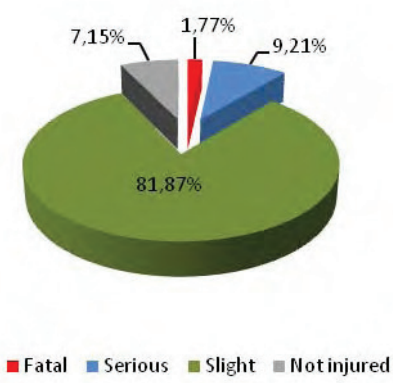
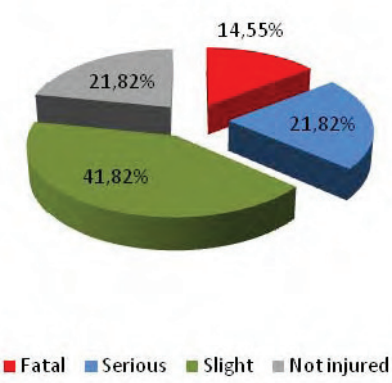
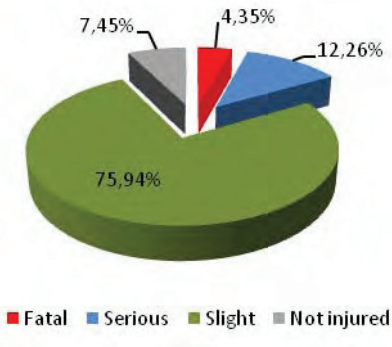
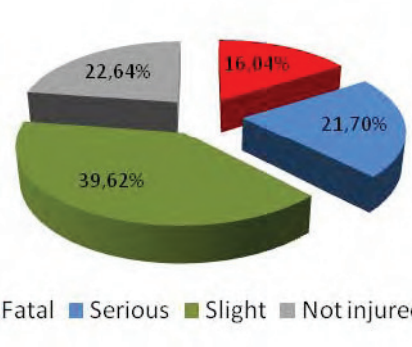
the authorities. Some drivers believe that the use of a helmet is inefficacious in possible crash-injury situation and it's a waste of money, but they couldn't be more wrong, helmets work, helmet effectiveness has been confirmed in studies, and in real life situations. Safety conscious riders should wear helmets by deliberate choice every time they ride, but sadly this is not the situation present in Portugal. The statistic data present in table 6, only confirms the helmet safety effectiveness, in each of PTW category in Portugal, the use of helmet has at least saved three times more riders from fatal injuries, compared with the ones who weren't using helmet, and drastically raise the percentage of not injured riders. Helmets saves lives, it is simply the best protective gear that a rider can use while riding a PTW, and a helmet makes riding a PTW more fun, due to comfort, the cut of noise, wind blast, deflects bugs among other features. Some of the solutions may pass for better PTW helmets, more attractive prices, campaigns, law enforcement, but the truth is that riders must be a responsible community and approach this problem in a very serious way, and then the solution will be simple: always wear a helmet when riding PTW.

Riders should have in mind that it´s impossible to predict when or what kind they will be, but crashes happen…

METHODOLOGIES

The methodologies for the study of accidents involving motorcycle, presented hereunder, are based on the on-scene in-depth motorcycle accident investigations methodology by the OECD [10]. The starting point is the information from the police reports that includes the more relevant data including diagrams and other information required for the reconstruction. The information contained in the Police reports is sometimes incomplete, and one of the aims of this undergoing work is also to collaborate with the police and traffic authorities in order to improve the quality and the quantity of the data collected at the crash scene. Next when some information is missing or some questions arise, the vehicle (if still available) has been mechanically inspected in order to detect mechanical failures or malfunctions as also evidences related with the contact between vehicles or vehicle and road users. From these data, a 3D accident reconstruction has been performed, as in the cases presented hereunder using the software PC-Crash [9]. All the data resulting from the reports and accident reconstruction is included in a Microsoft Access Database. Of course a detailed 3D accident reconstruction is almost impracticable to do for all the accidents occurred. In the future also non-accident population is to be included. For now the non-accident population is rather obtained from the statistical data.

Table 6. PTW rider injury related with use of helmet in Portugal.

PTW	Use of helmet	Non-use of helmet
Mopeds		
MT1		
MT2		
MT3		

ACCIDENT RECONSTRUCTION

In opposition to automotive vehicles where the pre and post crash movement is in the majority of the cases planar, motorcycles have frequently three-dimensional motion and sliding/skidding during fall down. Due to these three-dimensional motions the classical accident reconstruction techniques based on deformation or speed from skid and sliding marks can lead to erroneous results. Also the estimation of speed from skid marks should be used carefully because a significant number of the drivers in an emergency situation only use the rear brake. One example of a motorcycle accident form the in-depth database is presented in Figure 11. In Figure 12 some frames of the reconstructions are presented. This is an example in which the accurate estimation of the energy absorbed by the vehicles play an important role. Motorcycles are not designed for crashworthiness, and, in general, in collision with other vehicles, the larger amount of energy is absorbed by the other vehicle.

Figure 11. Vehicles' damage

a) Impact b) Rest Positions

Figure 12. Reconstruction of an accident involving a moped vehicle.

The accurate reconstruction of accidents involving motorcyclists and pedestrians requires, in general, the use of three-dimensional models. These models are necessary to reproduce the motion of the vehicles as also to estimate the injuries in pedestrians and to correlate them with the medical reports in order to allow the determination of the vehicle' speeds.
Multibody dynamics models are used in many fields, from vehicle dynamics, human body models and crashworthiness. These models are to be adapted to accident reconstruction of motorcycle accidents, giving a more reliable description of the vehicles' pre and post crash dynamics, and will include also models for occupants such as the Madymo models [11]. Scientific visualization tools or even CAD 3D models can be used to illustrate these aspects of the accident, as indicated in Figure 13.

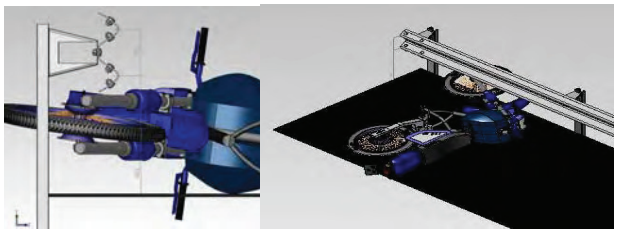


Figure 13. CAD 3D models for accident visualization and modeling.

The reconstruction of motorcycle accidents is a difficult task. The information about crash-tests is limited and the commercial accident reconstructions available sometimes have some difficulties dealing with some accident scenarios. In addition to the necessary crash data, multibody dynamics models can give an important contribution providing a more accurate modeling of the pre and post crash dynamics of the vehicle as also to include crashworthiness description. One of the methods to accurately develop safer hardware road structures as also to evaluate the biomechanical injuries for motorcyclists is the development of combined CAD+Finite elements+multibody models. In Figure 14 these models developed by Silva [13] are presented.

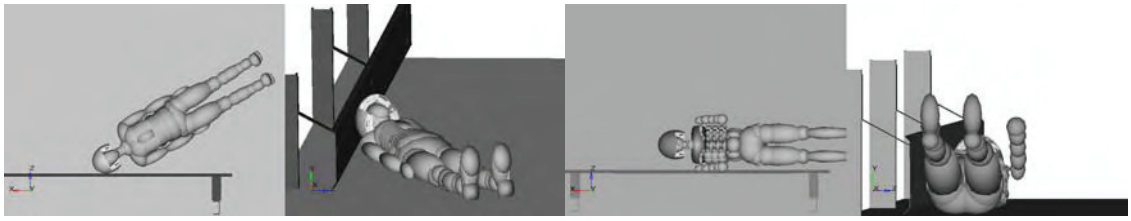


Figure 14. Guard rail models for motorcyclist protection.

These models combine CAD and finite elements models of the structures, and anthropomorphic models of the human body. The CAD models have been developed with commercial software Soli Works, the migrated to finite elements commercial software Ansys where the meshes are generated, and the integrated with the anthropomorphic models in Madymo where the simulations are performed. With these models the deformation of the structures is taken into account, and these can be used not only to develop safer structures but also to evaluate the injuries, and correlate them with medical data. With this approach complex accident can be reconstructed more accurately.

MOTORCYCLE ACCIDENTS: IN-DEPTH INVESTIGATION OF MOTORCYCLE ACCIDENTS

For now about 70 in-depth motorcycle accidents investigations have been carried out using the OECD and Maids methodology. Due to the complexity of such task, that involves a fully reconstruction of the accident this work is still ongoing. The accident reconstruction has been carried out using three-dimensional reconstruction techniques that have been briefly described in previous section. The determination of the impact speed and the pre-impact direction of the vehicles is a crucial point that is request by courts. In the data presented, it can be observed that only in one case no helmet use is observed. This agrees with the Portuguese statistics that reveals that the helmets use is greater than 90%. Alcohol use is considered one of the major causes of accidents. Even if the primary contribution for the accident is the other vehicle driver, speed plays a crucial role in the severity of the accident. For the fatal accidents speeds is the primary contribution factor for motorcycles (MT2 and MT3). In addition concerning motorcycles the typical driver characteristics is 20-30 year old male. Because of this the enforcement of speed and impaired driving laws becomes difficult. The behavior of those which breaks the traffic rules is an element of risk causing road traffic accidents [12]. For

PTW, the primary contribution of the accidents is an action of the Other Driver. This aspect has a very extensive contribution in accident involving moped vehicles or motorcycles MT1.
About 80% of all accidents occurred at good weather and light conditions.
The in-depth mechanical inspection of the vehicles is very important. Some details are not registered in the police reports but sometimes they play a crucial role for the determination of the accident' causes. Traffic police reports usually don't contain detailed information to fully understand the causes of the motorcycles accidents. Detailed photographs are in the majority of the cases absent and also mechanical inspection of the vehicles is not performed.

CONCLUSIONS

In this work an overview of the work carried out concerning PTW safety and methodologies for motorcycle accident reconstruction have been presented. Pedestrians and motorcyclists are worldwide two groups of risk. However in Portugal, the contribution of these groups for the overall injuries is much higher than the European average. From the accidents already analyzed especially involving motorcycles, the problems of conspicuity of PTW are a problem for the accidents in general, and the fact that the motorcyclist is not protected by any safety cage have a decisive contribution for the injuries. Speed has an important contribution in fatal accidents, especially for young drivers driving a sport motorcycle. Several tools can be used for motorcycle accident reconstruction, as speed form skid marks, Pc-Crash or Madymo models.

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