Powered Two Wheelers Road Accidents:

Identification of Risk Factors and Development of Computational Models for Scientific Reconstruction

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Abstract

Over 1.2 million lives are lost every year worldwide due to road traffic accidents. When comparing with car occupants, PTW (Powered Two Wheelers) occupants have 30 times more chances of dying in a traffic accident. Measures should be taken to lower the number of accidents as well as their severity because of the vulnerability of PTW users.

With a statistic descriptive analysis to all the PTW accidents with victims in Portugal between 2010 and 2015, and applying an ordered logistic regression to that dataset of accidents, the risk factors related to the increase on the severity of the injuries were determined.

Excess of alcohol, driving between 20h00 and 5h59, and in work days represent some of the risks in the increase of the severity of the injuries in PTW occupants in case of accident. More attention by the police should be taken for these problems.

With a literature review the coefficients of friction involved in a PTW accident reconstruction were analyzed. Depending on the motorcyclists clothes and the road surface the coefficient of friction between the motorcyclist and the ground can vary but a value of 0.64 was estimated. A range from 0.2 to 1.1 was estimated for the coefficient of friction between a sliding motorcycle and the road surface as it depends on the motorcycle type, the surface and the sliding distance.

A multibody model of a helmet was created to study the influence of its projection in crash simulations. The helmet turned out to be an important factor to help determining the accident dynamics.

Keywords: Power Two Wheeler, Ordered Logistic Regression, Accident Reconstruction, Crash Simulation, Friction Coefficient, Helmet multibody model.

1 Introduction

Motorcycle drivers and passengers are 30 times more likely to die in a traffic accident in comparison with car occupants (Lin and Kraus, 2008). The fact that a motorcycle is a vehicle without a rigid structure involving the occupants makes the occupants of this kind of vehicle more vulnerable in case of an accident.

Vulnerable road users, that are pedestrians, cyclists and power two wheeler (PTW) occupants, represent nearly half of the fatalities on the world's roads. One million and a quarter people die each year on the world's road due to road traffic accidents (WHO,2016).

Road traffic accidents represent the eighth cause of death globally and the leading cause of death for young people aged between 15 and 29

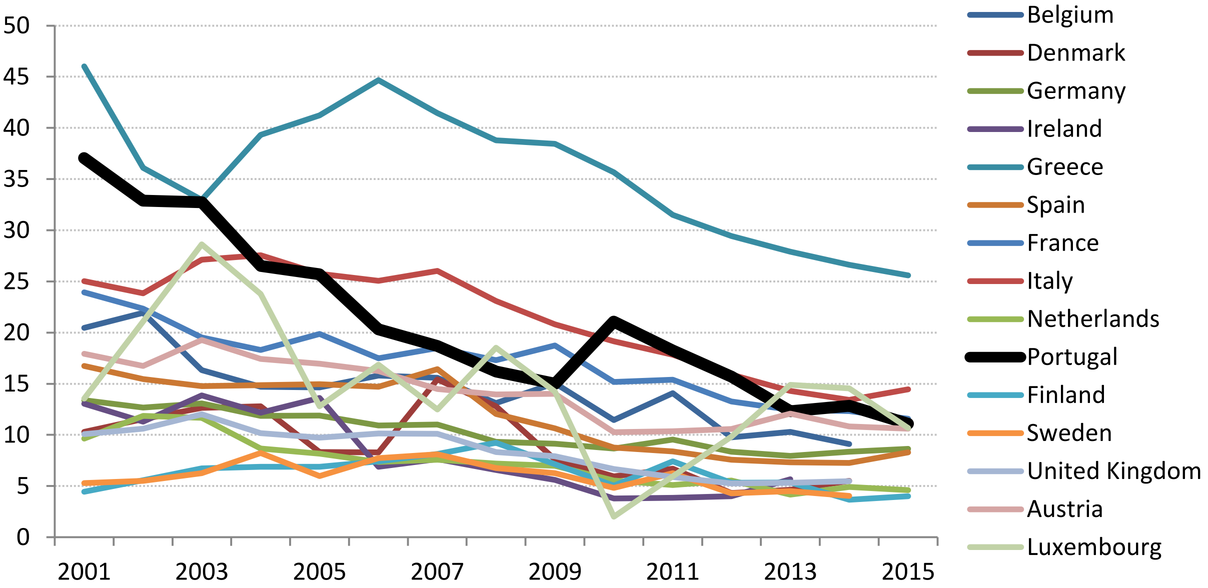


Figure 1 - Number of fatalities in PTW accidents per 1 million habitants from 2001 to 2015.

years old. This problem is evolving so fast that by 2030 road traffic fatalities are estimated to become the fifth leading cause of death worldwide unless urgent action is taken (WHO, 2013).

In Figure 1 is represented the evolution of the number of fatalities in PTW accidents in the European Union with 15 Member States from 2001 to 2015 through CARE database statistics. Despite the positive tendency in the considered set of 15 countries, this perspective of PTW accident injuries reveals that Portugal, in 2015, is still in the top levels of fatalities with only Greece and Italy with higher rates. Despite the reduction in the fatality rate, the numbers in Portugal are still alarmingly high and an increase of this number occurred in the years of 2010 and 2014.

In 2015 alone happened 41549 road accidents in Portugal with victims and, despite the decline of 30.9% since 1998, the number of victims increased by 5.5% in relation to 2013. However, the number of fatalities in 2015 in Portugal was the lowest since 2010. From the 593 fatalities in 2015, 19.4% belonged to PTW accidents (ANSR, 2015).

Among the years prior to 2015, in Portugal, PTW accidents represent a problem in terms of fatalities and so, measures should be taken in order to get results closer to the other European countries with better statistics

2 Statistical Analysis of PTW Accidents

With data provided by ANSR a retrospective analysis was done to the victims of accidents involving PTW in Portugal since 1998, taking special attention to the years of 2010 throughout to 2015.

With descriptive statistic it was made an analysis of vehicle factors, human factors, environmental and geographic distribution and finally the accident type in order to visualize the factors associated to the increase of the number of victims of accident as well as the increase of the severity of the injuries involved in the accident.

Using the statistical analysis software *IBM Statistics SPSS,* it was applied an ordered logistic regression to the ANSR data set to determine the risk factors associated to the increase or decrease of the severity of the injuries in the PTW drivers involved in accidents..

2.1 PTW Accidents in Portugal (2010 to 2015)

The number of fatalities per 100 accidents with victims is not the greatest for PTW compared with bicycles and heavy vehicles in some years. However, both motorcycles and mopeds take the top position between 2010 and 2015 for more fatalities and more severe injuries in road accidents per 1000 vehicles in circulation.

In terms of severity and number of victims, motorcycles represent the most critical vehicle in PTW with higher numbers of fatalities, severe injuries and severity indexes (number of fatalities per 100 accidents).

Between 2010 and 2015 the severity indexes of male PTW accidents can be higher from 2 to 6 times compared with female PTW accidents. In these years the average number of fatalities per age range is between 25 and 34 years old for motorcycle drivers and older than 60 years old for moped drivers. In terms of severity indexes the peaks are concentrated in the ages of 50 to for motorcycle drivers and in the ages of over 65 for moped drivers.

The severity index for drivers that not wear a helmet in PTW accidents is at least four times higher compared with drivers that wear a helmet.

The concentration of the total number of victims and fatalities between 18 and 19 o’clock is not a good indicator if it is actually at that time of the day that the injuries are more severe. Actually, between 2010 and 2015, for both motorcycle and moped accidents, the highest severity indexes are concentrated between 2 and 6 o’clock.

There is a uniform distribution with short variations of 4% of the number of victims in PTW accidents per day of the week. On the other hand the highest number of fatalities and the highest severity indexes are concentrated in the weekends, especially on Sundays.

Regarding the different months of the year from 2010 to 2015, it is in the period between July and September when most motorcycle accidents with victims occurred. The same happen with victims of moped accidents. This is connected that most of the PTW accidents with victims occurred under good weather conditions.

More than 80% of the PTW accidents with victims occurred inside towns. However the severity indexes are higher outside towns.

To conclude the analysis of PTW accidents with victims in Portugal it is necessary to study what is the main type of accident. Along the years, collisions are the type of accident with more victims among PTW drivers and passengers, followed by single vehicle accidents and finally run over pedestrians. In the case of severity indexes, between 2010 and 2015, in motorcycle accidents the highest values are in the run over of pedestrians. In moped accidents that value varies with the collision type and single vehicle accident type.

2.2 Risk Factors in the Severity of the Injuries on PTW Accidents

Descriptive statistics as done before is a primary and important way to evaluate data in terms of frequencies. To model the relation between variable there are regression models which are very important tools in data analysis.

The regression model where the response variable is categorical rather than continuous is the logistic regression. An ordered logistic model analyzes the relation between a multilevel ordinal dependent variable and one or more explanatory variables. In this case the dependent variable presents three different increasing degrees of severity of the injuries: minor, severe and fatal. All the theory associated to regression models, and in this particular case for the ordered logistic regression, is described in more detail in Lemeshow et al. (2000) and Norusis (2004).

The odd ratio (OD) is an association between the independent variables and the dependent variable that allows describing the association between the variables with a confidence interval of 95%. The statistical significance ($p<0,05$) of the results was given by the associated p-value. The following results presented in Table 1 are related to the PTW driver injuries severity.

When a moped is involved in the accident instead of a motorcycle, there is a 31.61% (OR=0,684; p=0,000) decrease in the odds of giving a response that indicates higher levels of the injuries severity.

When the accident happens in a rest day, there is a decrease of 19.53% (OR=0,805; p=0,000) in the odds of giving a response that indicates higher levels of the injuries severity when compared with work days.

Regarding the hour of the day and comparing with the period between 6h and 10h (period of the day to go to work), there is an increase of 55.41% (OR=1,554; p=0,000) in the odds of giving a response that indicates higher levels of the injuries severity for the period between midnight and 5h.

When comparing other road conditions with when the road is clean and dry, there is a decrease of 19.70% (OR=0,803; p=0,000) in the odds of giving a response that indicates higher levels of the injuries severit. This way, the severity of the injuries is highest for good weather conditions and for dry and clean roads.

With regard to location of the accident, inside or outside of a urban area, the results indicate that when the accident occurs inside the town there is a 24.82% (OR=0,752; p=0,000) decrease in the odds of giving response that indicates higher levels of the injuries severity when compared to accidents occurring inside urban areas.

The results indicate that when the PTW is not using a helmet there is an increase of 345.93% (OR=4,459; p=0,000) in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when compared to PTW drivers wearing helmet

In regards to drivers blood alcohol content (BAC), when comparing to a level below 0.2 g/L, all the other groups of drivers blood alcohol content shows an increase in the odds of giving a response that indicates higher levels of the injuries severity.

With regards to gender of the PTW driver, in comparison to males, the results shows that there is a 51.01% (OR=0, 490; p=0,000) decrease in the odds of giving a response that indicates higher levels of the injuries severity.

In respect to the category of the other vehicle when there is one involved in the accident, the results indicate that when there is a truck involved in the accident there is an increase of 191.86% (OR=2,919; p=0,000) in the odds of giving a response that indicates higher levels of the injuries severity when compared to a car involved in the accident.

When another vehicle is involved in the accident there is an increase in the severity of the injuries if the other vehicle driver is harmed.

More results were achieved but they have not statistical significance. These results are now presented.

Regarding the accident type, collisions and run over pedestrians have the lowest chances of more severe injuries compared with single vehicle accidents.

In respect to the month of the year, in comparison to summer months, June to August, the results shows that there is a 8.40% increase, the highest increase, of the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when the accident happen in the winter time, December to February.

Regarding 3 periods for a month, the period between the first and the eleventh day of the month has the highest chance of more severe injuries.

Regarding the different administrative regions of Portugal, it was found that there are fewer chances of more severe injuries in the more populated regions with the biggest cities, Lisboa and Porto, than in the less populated regions.

The severity of the injuries is highest for good weather conditions.

When a road is bended there is an increase of 9.82% increase in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when compared with straight roads.

All the road types have higher probability of higher injuries severity compared with streets but national road are the ones with the highest chances (67.97% more).

Overtaking is the action with highest chance of more severe injuries with an increase of 16.98% in the odds compared with regular driving.

Older people were found to be related to higher chances of having more severe injuries when involved in a PTW accident.

Table 1 – Results from the ordered regression (OR (CI of 95%) and statistical significance).

Variables	**Classes**	**OR**	**Confidence interval of 95%**	**P-value**
PTW category	Moped	0,684	0,750 - 0,624	,000
	Motorcycle (Reference)			
Accident type	Run over pedestrians	0,859	1,235 - 0,597	,411
	Collision	0,917	1,133 - 0,741	,421
	Single vehicle accident (Reference)			
Month	December, January and February	1,084	1,217 - 0,966	,172
	September, October and November	1,083	1,200 - 0,977	,129
	March, April and May	1,026	1,138 - 0,925	,622
	June, July and August (Reference)			
Day of the month	1 to 10	1,063	1,168 - 0,968	,200
	21 to 31	0,997	1,096 - 0,908	,958
	11 to 20 (Reference)			
Work day or rest day	Rest day	0,805	0,874 - 0,741	,000
	Work day (Reference)			
Hour	00 - 05h59	1,554	1,880 - 1,284	,000
	20 - 23h59	1,208	1,408 - 1,037	,016
	10 - 15h59	1,005	1,152 - 0,878	,937
	16 - 19h59	1,084	1,241 - 0,946	,246
	06 - 09h59 (Reference)			
Grip	Other road conditions	0,803	0,908 - 0,710	,000
	Clean and dry road (Reference)			
Administrative regions	Évora, Beja, Faro and Portalegre	1,602	1,822 - 1,410	,000
	Castelo Branco, Leiria, Setúbal and Santarém	1,929	2,185 - 1,704	,000
	Bragança, Coimbra, Guarda, Viseu and Vila Real	1,311	1,524 - 1,128	,000
	Braga and Viana Castelo	3,736	5,332 - 2,617	,000
	Aveiro	1,078	1,279 - 0,909	,388
	Porto	0,971	1,125 - 0,839	,699
	Lisboa (Reference)			
Wheather	Other weather coditions	0,895	1,060 - 0,755	,199
	Good weather (Reference)			
Location	Inside urban area	0,752	0,848 - 0,667	,000
	Outside urban area (Reference)			
Segment type 1	Bended	1,098	1,196 - 1,008	,031
	Straight (Reference)			
Road type	Other typed of roads	1,429	1,649 - 1,239	,000
	Highways and Freeways	1,569	1,920 - 1,281	,000
	National road	1,680	1,868 - 1,510	,000
	Street (Reference)			

Continuation Table 1 – Results from the ordered regression (OR (CI of 95%) and statistical significance).

PTW driver's age	>= 76	1,254	1,642 - 0,958	,099
	<= 15	0,803	1,550 - 0,416	,514
	60 -75	0,886	1,108 - 0,710	,289
	50 - 59	1,070	1,322 - 0,866	,531
	40 - 49	0,890	1,092 - 0,726	,265
	16 - 18	0,894	1,145 - 0,698	,376
	30 - 39	1,002	1,223 - 0,821	,986
	22 - 29	1,094	1,345 - 0,890	,393
	18 - 21 (Reference)			
PTW driver's gender	Female	0,490	0,592 - 0,405	,000
	Male (Reference)			
PTW driver's action	Other actions	1,117	1,293 - 0,965	,137
	Overtaking	1,170	1,388 - 0,986	,072
	Change of direction	0,971	1,171 - 0,806	,760
	Regular driving (Reference)			
PTW driver's safety accessories	Without helmet	4,459	5,545 - 3,586	,000
	With helmet (Reference)			
PTW driver's alcohol	Not tested	16,290	17,895 - 14,829	0,000
	>= 1.2 g/L	3,894	4,507 - 3,365	,000
	0.8 - 1.2 g/L	4,609	5,857 - 3,626	,000
	0.5 - 0.8 g/L	4,824	6,390 - 3,642	,000
	0.2 - 0.5 g/L	2,222	2,902 - 1,702	,000
	<= 0.2 g/L (Reference)			
Other vehicle category	Without other vehicle involved	1,565	2,505 - 0,978	,062
	Other type of vehicles	1,162	2,019 - 0,668	,596
	Bicycle and bicycle with motor	0,077	0,234 - 0,026	,000
	Moped	0,158	0,299 - 0,083	,000
	Motorcycle	0,185	0,334 - 0,102	,000
	Truck	2,919	3,618 - 2,354	,000
	Car (Reference)			
Other vehicle driver's injuries	Without other vehicle involved	0,691	1,368 - 0,349	,289
	Fatality	10,876	31,020 - 3,813	,000
	Severe injury	15,344	28,792 - 8,177	,000
	Minor injury	4,308	5,278 - 3,517	,000
	Unharmed (Reference)			

3 Accident Reconstruction of PTW Road Accidents

Statistical analysis is important to evaluate the evolution of road accidents in the past years and the impact of the measures taken along those years. Besides this analysis, the police report from the accident also has a rather high importance. These reports have the advantage of being done in the accident’s location and moments after it happens but have the disadvantage of the normal infield limitations. Pre impact velocities and position of the impact are parameters with a huge importance in order to define who is to blame in a car accident and who is not.

In deep investigation of PTW accidents the MAIDS methodology (ACEM, 2003) can be used. After the accident, a team specialized in road accidents do not go immediately to the local as the accident reconstruction is only realized when asked. The methodology used is a process of parameter optimization, pre-impact velocity and point of impact. The process begins with the analysis of the data given by the police, such as the sketch of the accident, photos of the local of the accident and the damage vehicles and the report of the injuries involved, followed by the construction of the scenario and the simulations of the accident. Then it can be estimated precisely the pre-impact conditions, such as speed, position and course of the vehicles.

The simulations are based on a dynamic analysis of the trajectories of the vehicles after the impact and by using the software *PC Crash*. Some parameters can be ajusted to obtain different pre and post impact results. The software is recognized and accepted in literature as a tool for accident reconstruction, using models of vehicles with characteristics close to reality and multibody systems for motorcycles and people.

3.1 Friction Coefficients for Accident Reconstruction

The friction coefficient expresses the resistance to motion between two surfaces. For accident reconstruction a parameter that always needs to be set is the coefficient of friction between the road surface and the tires of the vehicles. When dealing with PTW accidents, two additional friction coefficients are involved: the one between a motorcyclist body and the road surface and the one between a motorcycle and the road surface.

3.1.1 Coefficient of Friction between a Motorcyclist and the Road Surface

When dealing with accidents involving PTW it is necessary to take into account the behavior of the vehicle as well as the behavior of its rider and occupant. This way an important parameter to know is the coefficient of friction between a motorcyclist and the road surface. The calculation of a correct coefficient of friction between the motorcyclist body and the ground is based on the movement of the body on the road surface which can be sliding, tumbling or even both. Depending on the motorcyclists clothes and the road surface the coefficient of friction between the motorcyclist and the ground can be estimated.

A wide range of values for the coefficient of friction can be found in different sources throughout the literature. Completing the work done by Wicher (2016) it is possible to join the conclusions of 23 authors between the years of 1966 and 2008. Considering the variations in the coefficient of friction due to the road surface and the motorcyclist's clothes, an average of the values of all the authors can be performed and a value of 0.64 can be used for this coefficient. With information of the clothes and injuries of the PTW driver this value can be adjusted.

3.1.2 Coefficient of Friction between a Motorcycle and the Road Surface

According to Wood et al. (2008) there are three phases associated to a motorcycle falling to the ground: loss of control, impact with the ground and finally, stabilized sliding (Figure 2). To determine the coefficient of friction between a motorcycle and the ground, the phase of interest is the last one although the other two phases have a huge impact on the results depending on the sliding distance.

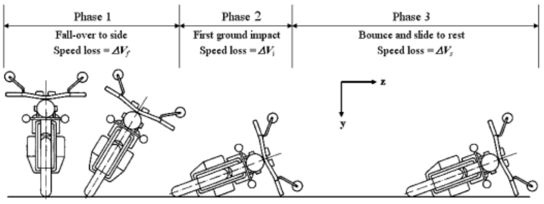


Figure 2 - Three phases of motorcycle fall.

The different sources, which can be found in the literature, show a big range of coefficients of friction. For example, Day and Smith (1984) conducted a series of sliding tests which proved the friction factors between the motorcycle and the road differed in the range of 0.45 to 0.58 on asphalt and in the range of 0.68 to 0.79 on gravel. Lynch (1984) determined friction coefficients from 0.38 to 0.55 with tests that dropped the motorcycle sideways from a towed trailer or pushed on its side. Medwell et al. (1997) determined, for a sport motorcycle equipped with a full coverage fairing, a sliding friction factor on asphalt in the range of 0.29 to 0.45. Lin et al. (2012) obtained, through tests in which a motorcycle was released from a pickup truck in an upright position and so it fell onto its side before it star sliding, an average friction coefficient of 0.428 for dry asphalt and an average coefficient of friction on wet asphalt of 0.340. The friction coefficient on dry and wet asphalt was in the range of 0.36 to 0.53, and 0.29 to 0.40, respectively.

Many more sources can be found on the literature but all of the previous studies just take into account the sliding phase but due to McNally and Bartlett (2007) attention needs to be taken to the sliding distance as the coefficient of friction can be higher for short sliding distances.

McNally and Bartlett (2007) realized tests with two different motorcycles, one with plastic bodyworks and other with crash bars. After making the first contact with the pavement the motorcycle decelerates more than in the later sliding so the deceleration rate is higher in the initial interactions with the road. Lambourn (1991) determined that, for shorter slides, this difference in the decelerations have more influence than for longer slides. For longer slides the initial impact phase has a short duration compared with the slide and so the overall average deceleration is less affected. Due to this it is not recommended to use the average coefficient of friction of the two phases (McNally and Bartlett, 2007). After stabilizing, McNally and Bartlett (2007) determined friction coefficients between 0.41 to 0.48. That study concluded that, for shorter sliding distances, higher coefficients of friction should be used and, therefore, for the impact phase of short duration slides, it should be from 0.75 to 1.0. Higher coefficients of friction are related to greater degrees of scraping or gouging on the roadway (McNally, 2006).

3.2 Multibody Helmet for accident reconstruction

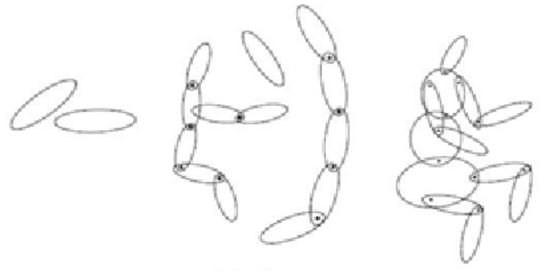
In accident reconstruction a parameter called EES, Energy equivalent Speed, can be introduced. This parameter represents the speed of a vehicle that would have certain damage if it crashed into a rigid barrier. This way, EES is not the real impact velocity but the necessary speed to produce a certain amount of damage colliding against a rigid barrier. This parameter is usually obtained with crash tests of vehicles. In other words, the energy lost in the collision due to damage is expressed in terms of kinetic energy of a vehicle with a virtual velocity, EES, in a collision of a vehicle with a rigid barrier.

This parameter is really important to determine the accident dynamics. For example, for an accident reconstruction of an accident between two passenger cars, two or more solutions can be found to reach the correct final positions of the vehicles and to have compatibility of the damages. However, only one solution will have the correct EES's for both vehicles and that the solution represents the real scenario.

To introduce a motorcycle and its occupant into a crash simulation, a multibody model needs to be used. The problem is that for multibody models the EES cannot be introduced in the crash simulation software, *PC-Crash.* This way the projection of a helmet in a PTW accident may be an important factor to the crash simulation when it occurs. To consider the helmet in the accident reconstruction, the introduction of a multibody helmet model is necessary.

3.2.1 Multibody helmet model

A multibody is a system of rigid and individual bodies which can be interconnected by different types of joints. These joints can be fully locked, fully free or can have stiffness applied around a direction. This way, a multibody system can be just one or several bodies connected to each other like the examples on Figure 3. Kinematics describes the absolute motion of mechanical systems, namely position, velocity and acceleration.



Two systems
System 1: 1 body
System 2: 1 body

Three systems
System 1: 7 bodies
System 2: 1 bodies
System 3: 5 bodies

One system
System 1: 12 bodies

Figure 3 – Multibody systems.

In computational accident reconstruction with multibody systems, each body is represented by an ellipsoid with the following properties: mass, moments of inertia, stiffness (used to calculate contact forces), restitution, two friction coefficients (multibody-vehicle and multibody- ground which is the same as multibody-multibody) and finally the friction in the joints (is determined depending the type of joint as a force).

The theory of multibody dynamics is explained in detail in Nikravesh (1988) and its implementation in the software *PC Crash* in the respective operating and technical manual (Datentechnik, 2016).

3.2.2 Multibody Helmet Model

For a more precise result in accident reconstruction for accidents with PTW involved, the final position of the helmet can be considered when it is projected after the crash. In order to consider the helmet in the reconstruction of the accident, a multibody model can de be introduced in the motorcyclist in the software *PC-Crash*.

Figure 4 shows some examples of helmets that can be projected after a crash when the helmet buckle is not tight or breaks.

Figure 4 – Examples of helmets

To create a multibody helmet the dimensions of the head of the motorcyclist need to be taken into account and they change as the height and weight of the motorcyclist change. For this purpose, a multibody system of 4 individual bodies are going to be considered and they are going to cover the head of a motorcyclist on the top, back, left and right sides. The helmet is fully fixed with rigid connections so its individual bodies can stay together.

Figure 5 illustrate the multibody helmet model created in the software *PC Crash*. As a standard helmet of this type its weight is 2 Kg.

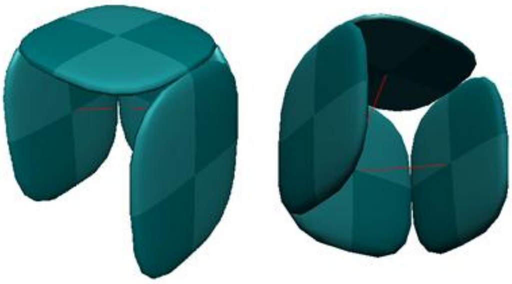
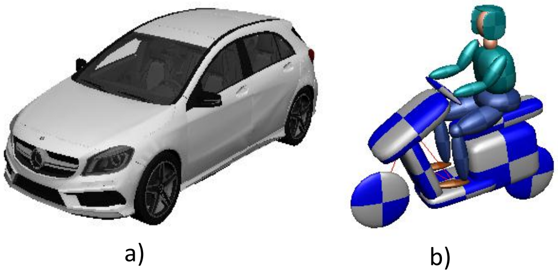


Figure 5 - Multibody helmet model (3D view).

3.2.3 Rear collision between a motorcycle and a passenger car with helmet projection

The multibody helmet model presented before is going to be used in the crash simulations. When the helmet buckle is not tight or breaks its projection will happen after a crash. The crash simulations that are going to be presented next will demonstrate the different distances of projections for different impact velocities.

A rear collision between a scooter and a passenger car was simulated in order to demonstrate the importance of the helmet in accident reconstruction. Figure 6 represents the motorcycle, Keeway ARN125, and the passenger car Mercedes-Benz A45 Amg from 2014, which were used in the crash simulations. A motorcyclist with 1,75m and 70 Kg was considered as well as a passenger car driver with 80 Kg.



a) b)

Figure 6 - model of the passenger car a), b) multibody model of the scooter and driver used in crash simulations.

Figure 7 represents the point of impact that was considered in the crash simulations. The passenger car is stationary and the motorcycle will crash against its rear side with different velocities.

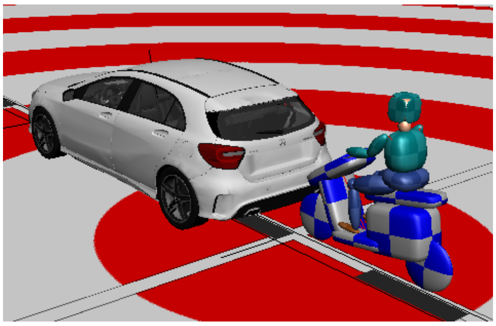


Figure 7 - Point of impact considered in the crash simulation: a) 2D view, b) 3D view.

In Table 2 can be seen the results of the crash simulations.

Table 2 – Results of the crash simulations for differents motorcycle crash velocities.

Motorcycle velocity (km/h)	Helmet hit the ground (m)	Total projection of the helmet (m)	Total motorcyclist projection (m)
80	14	36	5
70	12,5	28	top of the passenger car
60	10	20	0
50	9	14	0
40	7	8	0
30	4	5	0
20	0	0	0

The scooter's final position in all the crash simulations suffered very little changes as it remained in the back of the car. This way, the scooter's final position would not help in determination of the dynamics of an accident of this type. The motorcyclist body, on the other hand, was the same for scooter impact velocities from 20 to 60 Km/h. Therefore, for this impact velocities and taking into account that the scooter final position did not change either, it is not possible to determine the real velocity of a collision of this type if only the final positions of the scooter and motorcyclist are considered. However, and as expect if the helmet is projected, its projection differs for different scooter impact velocities. This way, in the range of 20 to 60 Km/h, the final position of the helmet must be a factor to take into account in the crash simulations. To conclude, the helmet final position in a PTW accident, when its projection occurs, can help to determine the accident dynamics.

3.3 Real PTW accidents studied

The computational simulations of two real accidents studied are briefly described.

3.3.1 Accident I

A scientifically detailed study was performed regarding a collision between the left-front area of a passenger car and the right-front area of a moped (Figure 8 and Figure 9). Involved in the accident were a passenger car Mercedes-Benz E-Class and a moped Casal K181. The accident happened in an intersection where the passenger car had priority in the road. In the crash simulation the moped has a velocity of 42 Km/h and the passenger car a velocity of 99,5 Km/h. As the speed limit was of 90 Km/h in that road, the passenger car was travelling over the speed limit even considering an error margin for the simulation. The moped had a relative position of 55° relatively to the passenger car in the crash simulation, considering the position of the passenger car was 0° as it was aligned with the road. Due to the angle of the moped, there are two options: either the moped wanted turn left in the intersection or it wanted to cross the intersection, moving forward. For each option and because of its velocity the moped did not stop in the intersection as it should. The passenger car driver had visibility to the road where the moped was driving but he could not predict that the moped was not going to stop in the intersection as it was obliged. The accident could not be avoided by the passenger car driver, even if he was driving within the speed limit.

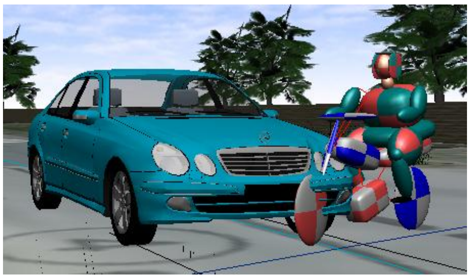


Figure 8 - t = 0.00s Starting positions.

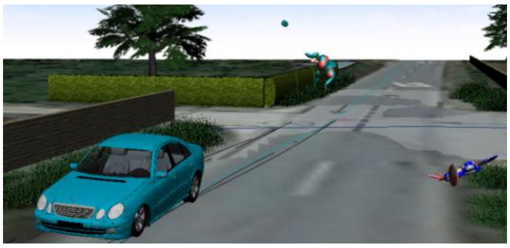


Figure 9 - t = 0.740s Projection of the motorcyclist and helmet. Moped sliding.

3.3.2 Accident II

A scientific study was developed regarding a first front collision in a straight road between a moped, Famel Zundapp 3, and a passenger car, BMW 316, followed by a second collision between the same passenger car and a bus, Mercedes-Benz O345, located approximately 14 meters after the first location (Figure 10 and Figure 11).

Figure 10 - t = 0.00s Fist collision.

Figure 11 - t = 0.95s Second collision.

As the moped wanted to turn left, it did not wait for the passenger car to pass or the passenger car was speeding. In the moment of the impact the passenger car had a velocity of 85 km/h and that result in a velocity of 95 km/h before breaking. As the speed limit in that road was of 50 km/h, even with a 10% error margin the passenger car was speeding. As the velocity of the moped when crossing the intersection was in the order of 13 km/h it is expected that it had slowed down when reaching the intersection. When the moped reached the intersection the passenger car was approximately 84 meters away and took 2.871 seconds to get there at that velocity. It was concluded that the accident was due to human factors, namely speeding of the passenger car. If the passenger car was driving within the speed limit the accident would not happen.

3.4 Helmet Projection in a Real PTW Accident

In accident I that was analyzed before occurred helmet projection as it was not fasten to the drivers head. For this accident were realized two different crash simulations. What these simulations have in common is the final positions of the vehicles, motorcyclist body and damage compatibility between vehicles. However for one simulation the passenger car was driving at 99.5 km/h and in the other it was driving at 73 km/h. As two different velocities were determined to the passenger car, two conclusions for the same accident could be made as the speed limit in the local of the accident was 90 km/h. These two different speeds were achieved with two different braking factors.

As occurred helmet projection, it was introduced the multibody model of a helmet to decide what simulation was closer to reality. Through Figure 12 and Figure 13 it is easy to conclude that the velocity of the passenger car was 99.5 km/h and not 73 km/h as the correct final position of the helmet after projection correspond to the first velocity. The projection of the helmet was an essential element for the determination of the dynamics of this accident and the pre impact parameters. To take this conclusion other pre impact parameters were analyzed as the conclusion was not taken just by the final position of the helmet.

Figure 12 - Helmet final position (99.5 km/h).

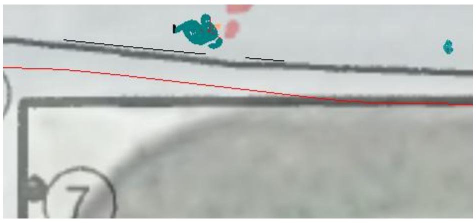


Figure 13 - Helmet final position (73 km/h).

4 Conclusions

Throughout the application of an ordered logistic regression in a data set from ANSR regarding PTW accidents, it was determined several risk factors that influence the severity of the injuries in the PTW drivers victims of accidents. The following risk factor were determined for the analyzed variables: motorcycle (PTW category), single vehicle accidents (accident type), September to February (month), work day (work day or rest day), 20h to 5h59 (hour of the day), clean and dry roads (grip conditions), Branga and Viana do Castelo (administrative regions), good weather (weather conditions), outside of urban areas (location), bended roads (segment type), national roads, highways and freeways (road types), 22 to 29 and over 76 years older (PTW driver’s age), male (PTW driver’s gender), overtaking (PTW driver's action), without helmet (PTW driver's safety accessories), 0,5 - 0,8 g/L (PTW driver's blood alcohol content), a truck involved (other vehicle category) and finally, other driver harmed (other vehicle driver's injuries).

The coefficients of friction between the ground and the motorcyclist and the ground and the motorcycle were discussed. For the coefficient of friction between the ground and the motorcyclist body the value of 0.64 is going to be used. The coefficient of friction between the ground and the motorcycle needs some attention to be chosen as it may needs to be adjusted taking into account the sliding distance and the motorcycle damages.

A multibody model of a helmet revealed to be an important factor in accident reconstruction when the projection of the helmet occurs due to the crash.

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