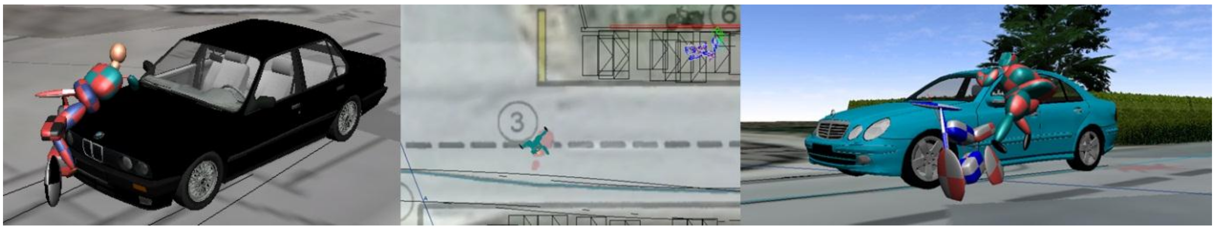

Powered Two Wheelers Road Accidents

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

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À minha mãe,
ao meu pai,
ao meu irmão…

por tudo.

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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.

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 for general cases. 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 determine the accident dynamics.

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.

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

Resumo

Mais de 1.2 milhões de vidas são perdidas todos os anos devido a acidentes de viação. Em Portugal em 2015, por 1000 veículos em circulação há 9.5 vezes mais mortes em acidentes com VDRM (Veículos de Duas Rodas Motorizados) do que com veículos ligeiros. Medidas devem ser tomadas de modo a reduzir o número de acidentes e a severidade dos mesmos.

Com uma análise de estatística descritiva a todos os acidentes com vítimas de VDRM que ocorreram em Portugal entre 2010 e 2015, e aplicando uma regressão logística ordinal a esse conjunto de acidentes determinaram-se os factores de risco que aumentam a severidade das lesões.

Com uma análise da literatura avaliaram-se os coeficientes de atrito utilizados na reconstituição de acidentes de VDRM. Dependendo das roupas do motociclista e do piso da estrada, o coeficiente de atrito entre o solo e o motociclista pode variar mas o valor de 0,64 foi estimado para casos gerais. Um intervalo de 0.2 a 1.1 foi determinado para o coeficiente de atrito entre um motociclo e o solo pois este coeficiente depende do tipo de motociclo, do tipo de solo e da distância de escorregamento do motociclo.

Um modelo de corpos múltiplos de um capacete foi criado para estudar a influência da sua projecção em simulações computacionais. O capacete revelou ser um factor importante na determinação da dinâmica de acidentes.

Excesso de álcool, conduzir entre as 20h e as 5h59, e em dias de trabalho representam alguns dos factores de risco associados ao aumento das lesões em acidentes envolvendo VDRM. Maior fiscalização por parte da polícia deverá ser feita para reduzir estes problemas.

Palavras-Chave: Veículos de Duas Rodas Motorizadas, Regressão Logística Ordinal, Reconstituição Computacional, Simulação de Acidentes, Coeficiente de Atrito, Modelo de corpos múltiplos de capacete.

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Glossary

ANSR – *Autoridade Nacional de Segurança Rodoviária* – National Road Safety Authority

BAC – Blood Alcohol Content

CARE – Community Road Accident Database

EES – Energy Equivalent Speed

EU – European Union

IRTAD – International Traffic Safety Data and Analysis Group

ITF – International Transport Forum

OECD – Organization for Economic Co-operation and Development

PTW – Power Two Wheeler (motorcycles and mopeds).

WHO – World Health Organization

Severity index - represents the number of fatalities per 100 accidents.

1 Introduction

Due to road traffic accidents, over 1.2 million lives are lost every year. Even more millions of people sustain serious injuries and live with long-term adverse health consequences (WHO, 2015). In the member states of the European Union in 2014 about 26000 people died in road traffic accidents (CARE, 2016). In Portugal 638 lives were claimed in 2014 as a result of road accidents (ANSR, 2015).

Worldwide, almost a quarter of all road traffic fatalities are among motorcyclists (WHO, 2015). In the European Union for the year of 2014, PTW (Power two wheelers that includes motorcycles and mopeds) fatalities represented about 17% of all people killed in road traffic accidents (CARE, 2016). In Portugal that number is about 21% (ANSR, 2015).

Despite the numbers in Europe been lowering in the previous years, the number of accidents with victims are still really high. The perspective in Portugal is not different and it actually takes a top four position in number of fatalities per million of inhabitants in power two wheelers (PTW) accidents (CARE, 2016). The number of PTW occupant fatalities remains high among the years and measures should be taken to lower this numbers.

This way it is important to understand this subject in order to reduce the number of victims of PTW accidents and to reduce it severity. Engineering takes a big role to develop better vehicle safety systems, road construction, among other factors to improve the safety conditions on the road. However, new regulations, education and enforcement issues have also a huge importance in this subject.

1.1 Motivation

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 if in this kind of vehicle more vulnerable in case of an accident. Other kinds of vehicles are equipped with passive safety systems that protect their occupants even more than just the shell around them. Passive safety systems like seatbelts and airbags are nowadays presented in all passenger cars. A power two wheeler occupant can only be protected by the helmet or some kind of protective clothes and boots, and fortunately the increase in the quality of this protective wearing have been huge in the past few years.

Vulnerable road users, that are pedestrians, cyclists and power two wheeler (PTW) occupants, represent nearly half of the fatalities on the world’s roads and one million and a quarter people die each year on the world’s road (WHO,2015). In the report of the World Health Organization of 2015 the number of fatalities in the world’s roads is unacceptably high and the injuries caused by the accidents take a huge damage on individuals, communities and national economies. Road traffic accidents represent the eighth cause of death globally and the leading cause of death for young people aged between 15 and 29 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, 2015).

In the 2016's Road Safety Annual Report of the International Traffic Safety Data and Analysis Group, IRTAD, it can be seen that since 1970 there has been a decline on the road deaths and between 2010 and 2014 the fatalities fell by 8.8%. In 2014, countries like Portugal, Canada and Italy had shown the lowest values in fatalities in the last 50 years. However this positive result changed in 2015 where the number of road deaths increased in, at least, 19 countries of the 32 IRTAD member countries and only 9 countries still manage to stabilize or reduce the number of fatalities in the roads (OECD/ITF, 2016).

In Portugal, between 1970 and 1989, there was an average increase in road deaths of 3.5%, followed by steady decrease in the number of fatalities or injuries from 1990 and forward. Actually, since 2000, the rate of decline had improved a lot with an average annual decrease of 8.3% between 2000 and 2013 and with stagnated results in 2014. About the vulnerable road users between 1990 and 2014, it was verified a decrease in the number of road fatalities in pedestrians, cyclists, moped users and motorcycle users with a decline of 80.5%, 70.8%, 94.5% and 14.2%, respectively. Despite that from 2013 to 2014, in relation to PTW, only the fatalities relative to moped users were reduced (15.7%) as motorcycle users had an increase of 16.7% (OECD/ITF, 2016).

For a deeper understanding of the evolution of the victims of accidents in Portugal and other countries in Europe, Community Road Accident Database (CARE) can be evaluated until the year of 2015. Eurostat provides data related to the population of each country and therefore it is presented in Figure 1.1 the evolution of fatalities in road accidents for PTW per million of inhabitants between 2001 and 2015 for countries that belong to EU 15.

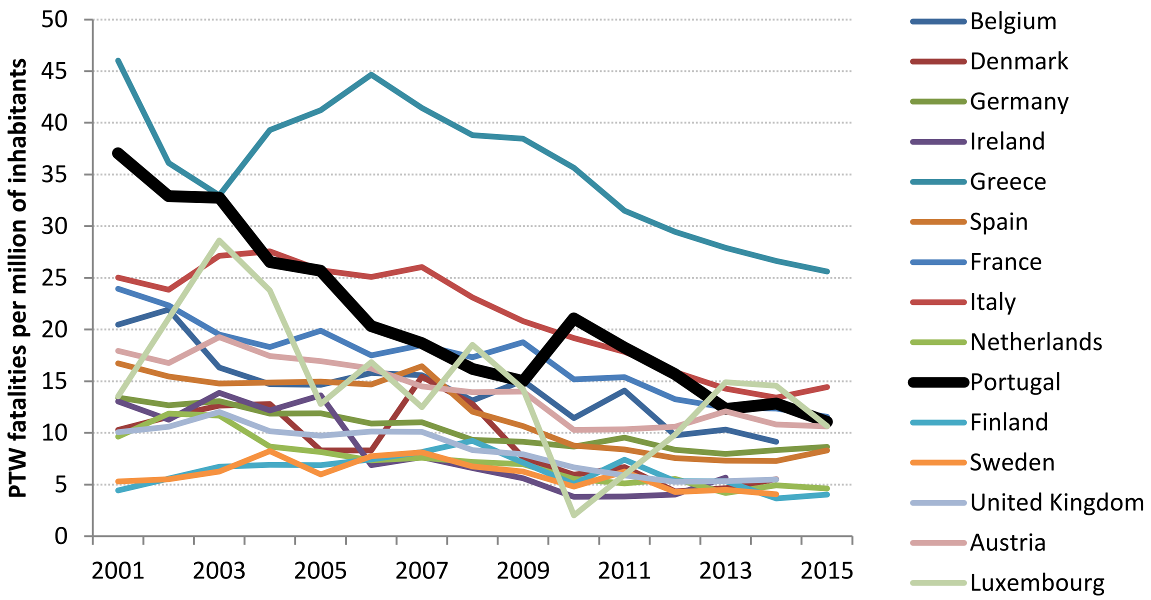


Figure 1.1- Number of PTW fatalities per million of habitants, 2001 - 2015.

Despite the positive tendency in the considered set of 15 countries, this new 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, 41549 road accidents with victims occurred and, despite the decline of 30.9% since 1998, the number of victims in 2015 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 due to road traffic accidents in 2015, 19.4% are PTW victims (ANSR, 2015).

Considering the data from ANSR (2015) it can be seen in Figure 1.2 the evolution of the number of victims of PTW road accidents from 1998 to 2015 in Portugal. Once again it is noticeable that the number of victims in general has been decreasing, especially for moped users. The advantages of driving PTW vehicles made them more and more popular throughout the time, particularly in the cities. Easy parking, time savings and lower costs with maintenance, fuel consumptions and vehicle itself are some of the reasons why motorcycles are being chosen over cars. The number of moped accidents' victims became lower than the number of victims of motorcycle accidents in 2010 and a reason why is due to the fact that since 2009 the car license allows drivers to ride motorcycles limited up to 125 cm^3 [Portuguese Law – DL 78/2009]. If only fatal victims are considered, the decreasing tendency is similar to Figure 1.2.

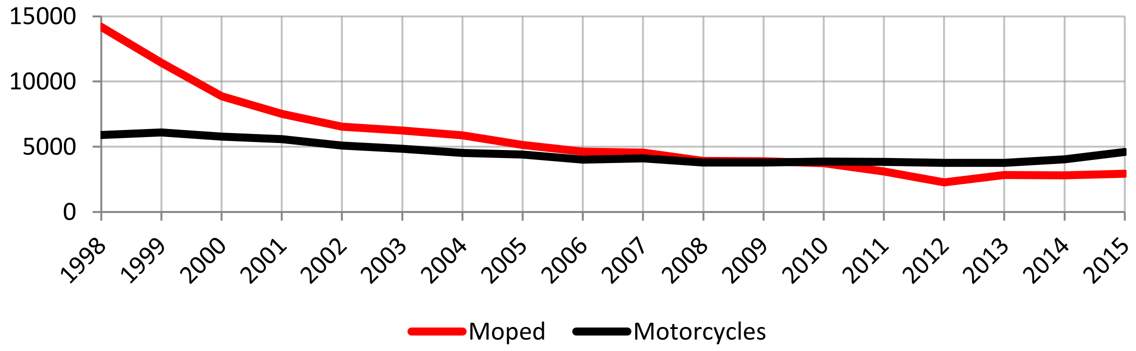


Figure 1.2 - Number of victims in PTW road accidents in Portugal.

As PTW occupants are included in the vulnerable road users more attention is required for this type of accidents. Figure 1.3 represents the comparison between the different ways of transportation for fatalities per 100 victims (ANSR, 2015). In 2015, trucks take the top position with 2.91 deaths per 100 victims of accidents involving this type of vehicle. The number of accidents with trucks is the lowest of them all however the number of fatalities is huge when compared with the number of accidents. In the year of 2015, only pedestrians surpass the PTW. Even though the results have not always been like this.

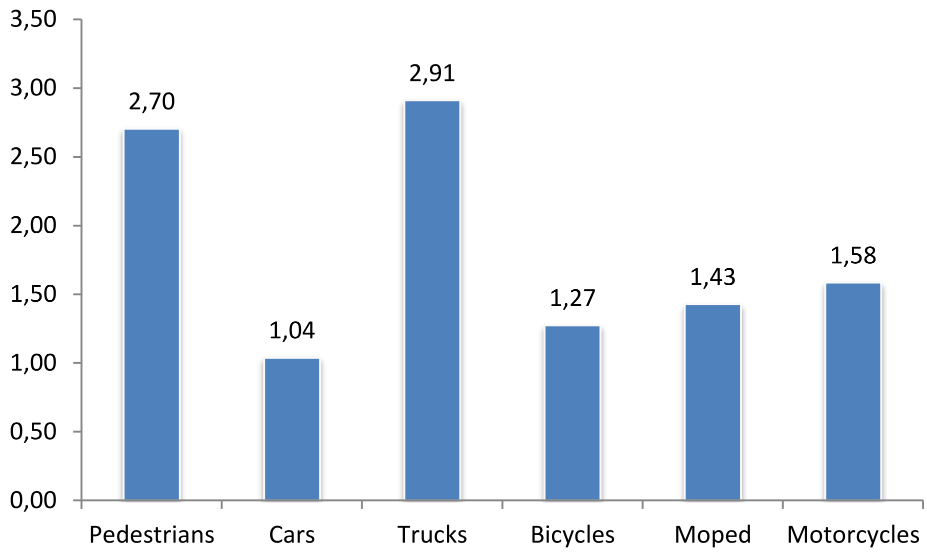


Figure 1.3 – Severity index by vehicle category in Portugal for 2015.

It can be seen in the Figure 1.4 (ANSR, 2015) that, among the years prior to 2015, 2010 was the one that presented the highest ratio between fatalities and accidents. Despite the improvements from 2010 to 2015, in relation to PTW fatalities, there is still a lot to overcome in order to achieve better numbers.

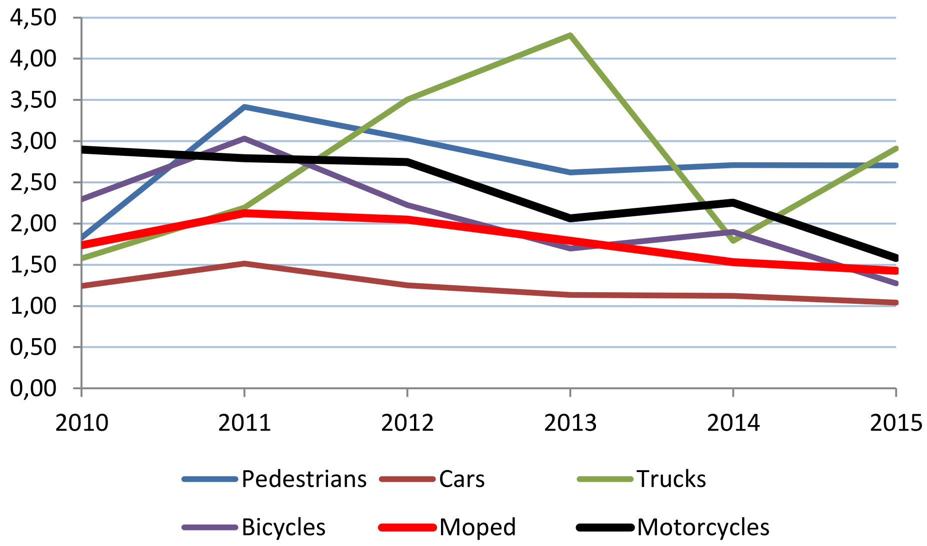


Figure 1.4 - Fatalities per 100 victims by vehicle category in Portugal, 2010 - 2015.

To conclude, the number of fatalities with PTW is a problem for most of the countries analyzed. In Portugal the numbers are really high in terms of fatalities and measures should be taken in order to get results closer to the other European countries with better statistics. Besides the lives that are lost and the decrease in quality of life of some of the other victims, road accidents have associated to them a huge social and economic cost. Donário and Santos (2012) released the most recent study about the costs involved in road accidents in Portugal between 1996 and 2010. There are some studies on this matter more recent than 2012 but none of them refer specific values of the costs. For Donário and Santos (2012) the average annual cost associated to road accidents between 1996 and 2010 was of

2503,3 million euros. However the costs associated with road accidents are not only money related as there is a lot of human resources too and this one does not have a solution.

1.2 Literature Review

The application of specialized statistical methods that analyze the factors that take influence in some phenomenon have been used by several scientific areas. In the case of accidents involving PTW, the determination of the risk factors associated to this kind of road accidents is an area of interest. Regarding Portugal there are three previous studies on this manner (Bernardo, 2012, Dias et al., 2014 and Ferreira et al., 2017) and one study related to road safety and not to the risk factors (Simão, 2010).

Simão (2010) evaluated the efficiency of Portugal's policies related to road safety for a period of 20 years, between 1987 and 2007, with a multiple linear regression. It was made an analysis of indicators and not of risk factors or injury severity.

Bernardo (2012) analyzed 24619 PTW road accidents with victims in Portugal between 2007 and 2010 with an ordinal logistic regression where, within the total of victims, 571 were fatalities and 2132 were seriously injured. In the following list are all the risk factors found in this work: motorcycle, gender, helmet usage, maneuvers, night time, months of July to September and weekends. For example, the fact of being a motorcycle involved in an accident increases 66.2% the chance of having more serious injuries compared with accidents with mopeds involved. When a female is involved in a motorcycle accident there is a chance of less 113% of occurring serious injuries compared with accidents with males involved. In the weekends it is 66.8% more likely of occurring serious injuries in an accident with PTW involved compared with accidents that happen during the week.

Dias et al. (2014) analyzed the PTW accidents that happened in Portugal between 2010 and 2012 using and ordered regression. The risk factors associated with the increase of the injuries of the PTW accident victims were determined. The results showed that there is a risk factor associated to the motorcycles compared with mopeds, the gender female is less likely to have more severe injuries than the gender male, not wearing a helmet is a risk factor. Accidents that happen at night, on weekends and outside urban areas are considered risk factors in the increase of the injuries too.

Ferreira et al. (2017) studied data from Porto's metropolitan area, Portugal, between 2006 and 2011, with a mixed logit model in order to understand the factors that contribute to the injury severity of traffic victims. Older people were associated with having higher risk of severe injuries when involved in a road accident. Regardless of the age, males have a higher probability of having serious injury compared to female. Driving under the influence of alcohol showed fixed results which were the increase of the probability of having serious injurious.

The main and most updated international studies regarding this field of work will be referenced throughout the next following paragraphs.

Chung et al. (2014) analyzed the injury severity of 792 vehicle-to-motorcycle crashes that occurred during delivery of parcels and food in the metropolitan area of Seul, Korea, between 2007 and 2009, with an ordered probit model. The main finding of this work was that risky behaviors, such as speeding, driving in opposite lanes, improper weaving and driving under the influence of alcohol, reflected in an increase of the crash severity.

A multinomial logit analysis was used by Çelik and Oktay (2014) to study 11771 traffic accidents between January 2008 and December 2013 in the Erzurum and Kars Provinces of Turkey with the goal of determining the risk factors affecting the severity of the traffic injuries. Fatal, injury and no injury were the three categories in which injury severity was divided. The following factors were determined to increase the probability of fatal injuries: drivers over the age of 65, primary-educated drivers, single-vehicle accidents, accidents occurring on state routes (highways or provincial roads) and the presence of pedestrians on crosswalks. The results also indicate that the presence of a car or a private vehicle, the presence of traffic lights, time of the day being the evening peak, the local being city streets or the accident occurred under clear weather conditions decrease the probability of fatal injuries.

Naqvi and Tiwari (2017) studied 1534 fatal crashes in three National Highways in India which occurred in five years using binomial logistic regression .Fatal crash patterns were analyzed in order to identify the factors contributing to motorcycle fatal crashes. It was concluded that the type of collision, the number of vehicles involved, the number of lanes and the time of crash were risk factors for fatalities in accidents that occur in Indian's highways. For example, the probability of a fatality in an accident with a single vehicle is three times higher than with two or more vehicles.

Cunto and Ferreira (2017) analyzed 3232 traffic accidents between 2004 and 2011 in Fortaleza, Brazil, in order to observe crash frequency and severity in motorcycle accidents. A categorical ordered logit model was developed to conclude that the use of helmet reduce by 9% the chance of suffering severe and fatal injuries after the crash. What is more, accidents during the daylight and on weekends decrease the chance of occulting a fatality. When motorcyclists are older than 61 years old, there is 22% more chances of severe injuries or fatalities compared to young drivers.

From two major urban arterials in the city of Athens, Greece, 527 accidents between 2006 and 2011 were analyzed by Athanasios and Yannis (2017). Due to the high number of candidates to risk factors, a random forest model was primarily applied. The potentially significant variables resulting from the previous model were used as an input to a Bayesian logistic regression model. As results of the analysis PTW have more chances of being involved in a multivehicle accident than in a single-vehicle accident. The results also showed that for more intense traffic flows and variations in speed the probability of a PTW being involved in an accident increases. On the other hand, weather was found to have no effect. Finally it was concluded that PTW are more prone to head-on, side and sideswipe collisions.

It is essential to be aware of the risk factors on the severity of the injuries of PTW users when performing an investigation of this type. This will allow to select the proper data for the statistical models and to validate or not the results obtained with the statistical analysis.

A road safety problem which is globally recognized is driving under the influence of alcohol and the reason why is because the human capabilities are compromised leading to a decrease in driving capacity concentration, visual field and reflexes, an increase in the reaction time and it is created a fake state of euphoria and capacity overvaluation (Behnood et al.,2014). Alcohol consumption increases the relation between impulsivity and risky behaviors (Jakubczyk et al., 2014). In the specific case of accidents involving motorcycles in Sao Paulo, Brazil, alcohol-positive drivers were three times more likely to be in an accident than alcohol-free drivers (Carvalho et al., 2015). Ouellet and Kasantikul (2006) detected that motorcycle drivers with a blood alcohol content (BAC) of 0.05g/dl are more likely of being involved in an accident and Creaser et al. (2009) concluded that, for the same value of BAC, the reaction time would increase. Different drugs have different effects on the brain. Marijuana can slow reaction time, impair judgment of time and distance, and decrease coordination. Drivers who have used cocaine or methamphetamine can be more aggressive and reckless when driving. Certain kinds of sedatives can cause dizziness and drowsiness. All of these impairments can lead to vehicle crashes (National Institute of Drug Abuse, 2016). In Carvalho et al. (2015) motorcycle drivers who consume drugs present a 1.7 higher culpability ratio on an accident than a drug-free driver however this result does not take into account the different types of drugs.

A high-risk group with regard to road traffic accidents is the young road users due to inexperience and abilities (Word Health Organization, 2013). Yet the lack of experience is not the only factor to be taken into account in young drivers as the personality of the driver has a big contribution in the driving behaviors and those behaviors are translated into risky driving in these ages. Wong, Chung and Huang, (2010) and Bina, Graziano e Bonino (2006) concluded that the excess of velocity is the main infraction committed by the studied adolescents motorcycle drivers. Crundall et al. (2012) and Underwood et al. (2012) considered perception of risk as the main difference between younger and older drivers and this is why for younger riders take more risks. Studies have identified that the level of risk-taking from late adolescence into early adulthood among drivers is stable (Moller and Haustein, 2013; Vassallo et al., 2014) as well as differences in risk-taking behaviors and attitudes among pre-licensed adolescents (Mann and Landsdown, 2009). Crundall et al. (2008) and Magazzú et al. (2006) concluded that car and motorcycle drivers with more experience have less probability of having an accident with motorcycles when driving a car. Young riders have a lighter tendency towards negligence of potential risk and motorcycle safety checks (Chang and Yeh, 2006).

Harris and Jenkins (2009) have determined differences related to the gender of the driver involved in an accident and women have bigger perception of risk and are involved in less dangerous maneuvers. Several studies have identified factors to explain gender differences among young drivers. Young men are involved in risky behaviors such as driving longer distances, driving over the speed limit, driving under the influence of alcohol or driving while speaking on a mobile phone (Ainy et al., 2011; Vardaki and Yannis, 2013), in addition to the lower use of safety devices among men, such as seat belts and helmets (Fernandes et al., 2010). In summary, young and male riders are more likely to disobey traffic regulations (Chang and Yeh, 2006). When it is a male as a car driver, motorcyclist, cyclist or pedestrian mortality is greater (Hanna et al., 2006; Stimpson et al., 2013; World Health Organization, 2013; Zhu et al., 2013). Female drivers are involved in less severe accidents than male drivers (Zhang and Yau, 2013).

For motorcyclists speed is a significant risk factor to take into account (Jevtic et al., 2014). Pang et al. (2000) described that, when it comes to high speed driving, there is a higher chance of occurring an accident and of higher severity. This way, with speed related to severity, motorcycles with higher power are connected to higher risk of death. According to the Serbian Traffic Safety Agency (ABS, 2013) speeding is the key factor in accidents of motorcycles and with excessive driving speed the extension of injuries grows (WHO, 2008; Lin et al., 2003). To summarize, motorcycle crash severity is greater for higher speeds (Shaheed and Gkritza, 2014)

The advantages of wearing a helmet when driving a motorcycle are enormous and can be associated with reduced risk of head, facial and traumatic brain injury and death (Olsen et al., 2016 and Keng, 2005). Rice et al. (2015) estimated that motorcyclists wearing a helmet are 37% less likely to suffer neck injury, head injury or fatality than riders without said safety device, after accounting for differences in rider age, sex, alcohol use and motorcycle speed. Using safety equipment while driving a car or a motorcycle will dramatically reduce head-face traumas resulting from accidents (Maghsoudi et al., 2016). Injuries to the body of the PTW drivers can be reduced or avoided when using protective equipment (Lin and Kraus, 2009).

Conspicuity is the state or quality of being clear or bright and in the case of PTW is their capability of being visible to the drivers of the others vehicles. The low conspicuity of PTW is an important factor why this type of vehicles are involved in traffic accidents (Wells et al., 2004) and the main reason is due to the size of a motorcycle, the irregular shape, the low contrast between the vehicle and the environment and the capability of PTW to circulate in unexpected places during traffics jams. Wearing reflective or fluorescent clothes, white or bright colors for the helmet and lights turned on during the day can dramatically reduce the severity and fatalities of motorcycle accidents. However for Gershon et al. (2012) the most important factor is the contrast between the motorcycle and the background and reflective and white clothing had advantages when the motorcyclist was far from the viewer. What is more, in normal conditions car drivers do not expect motorcycles on the road and this way is much harder for them to see the motorcyclist (Gershon et al., 2012).This way, low motorcycle conspicuity is a factor that increases motorcycle accidents severity (Haque et al., 2009).

1.3 Objectives

Significant improvements in road accident rates in the EU and even in Portugal happened in the last years however it stills remains very important to understand the origin of the high rate of PTW road accidents. As vulnerable users, identifying the risk factors and find the priority areas of action that minimize PTW occupants exposure to risk is the way to minimize the consequences of this accidents. The present study aims to find and understand factors that contribute to increase the severity of PTW occupant's injuries, focusing only on accidents with victims with this type of vehicles involved. An important topic on this subject is a crash simulation that allows understanding in what circumstances the accident happened. Developing models for the investigation and reconstruction for these accidents is extremely important too.

The outline of this thesis is as follows:

Chapter 2 – Statistical Analysis of PTW Accidents

In this chapter it was made a descriptive statistic of PTW accidents with victims in Portugal in the last years in order to understand the dimension of the problem. This analysis was done with data from ANSR witch has detailed information about the accident and the drivers involved. Secondly, it was applied an ordered logistic regression with the software *IBM Statistics SPSS* in order to determine the risk factors in the severity of the injuries of the PTW driver's involved in accidents between 2010 and 2015.

Chapter 3 – Accident Reconstruction of PTW Road Accidents

In this chapter are presented various themes related to accident reconstruction. The topics of this chapter are presented below.

In the topic 3.1, Methodology Applied in PTW Accident Reconstruction, is presented the methods applied for PTW accident reconstruction. These methods are applied in the software *PC Crash*.

In the topic 3.2, Friction Coefficients for Accident Reconstruction, are discussed the different friction coefficients that are presented in a PTW accident reconstruction. These parameters are essential to determine the dynamics of an accident. The coefficient of friction between the road surface and the vehicles, a motorcyclist and the road surface and the motorcycle and the road surface are discussed in this topic.

In the topic 3.3, Multibody Helmet for Accident Reconstruction, is presented how a multibody model works and its importance in accident reconstruction. A multibody model of a helmet is constructed to further use in crash simulations.

In the topic 3.4, Energy Equivalent Speed, EES, is presented the concept of energy equivalent speed, EES, in order to be discussed its importance in other topics. The multibody model of a helmet was created because the EES cannot be used in crash simulations with multibody models.

In the topic 3.5, Accident Reconstruction of Real PTW accidents, two real accidents that happen in Portugal are shown. With the software *PC Crash* its crash simulations are made and presented in this topic. With crash simulations pre impact velocities and pre impact positions can be determined.

In the topic 3.6, Influence of the Helmet in Accident Reconstruction, some PTW crash simulations are made with a multibody model of a helmet. It is discussed the importance of this model in crash simulations and why it needs to be used in some real cases.

Chapter 4 – Conclusions

In this final chapter are presented the main conclusions of all the work performed as well as the work that should be done in order to continue this thesis.

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. Starting with a descriptive statistical analysis in the first part and with previous similar works on this subject it was intended to determine the risk factors associated with the injuries suffered by PTW drivers in case of accident. Bernardo (2012) performed a similar analysis from 2007 to 2010, so this works continues that analysis.

2.1 PTW Accident Characteristics in Portugal

Between 1998 and 2015 the accidents involving cars had the highest number of victims within the national panorama as can be seen in Table 2.1 (ANSR, 2015).

Table 2.1- Victims in road accidents in Portugal, 1998 – 2015.

	1998	Variation 98 - 10	2010	Variation 10-13	2013	Variation 13-15	2015
Pedestrians	9052	-34,1%	5964	-7,8%	5499	-1,8%	5399
Cars	35624	-12,1%	31330	-22,2%	24364	4,2%	25398
Trucks	1464	-43,7%	824	-17,8%	677	-3,5%	653
Bicycles	1670	-26,9%	1220	40,0%	1708	14,9%	1963
Moped	14179	-73,6%	3739	-23,9%	2846	3,4%	2943
Motorcycles	5893	-34,4%	3864	-2,3%	3777	22,0%	4609
Others	586	-38,4%	361	43,5%	518	12,7%	584
TOTAL	68468	-30,9%	47302	-16,7%	39389	5,5%	41549

Through Table 2.1 it can also be seen that the highest reduction of victims of accident since 1998 belongs to mopeds with similar values of motorcycles in the year of 2010. The constant decrease in victims since 1998 untill 2010 changed and only accidents with cars experienced a higher reduction till 2013. From 2013 to 2015 the values had big variations in terms of victims in PTW accidents and instead of decreasing they experienced an increase of 3.4% and 22% in moped and motorcycle accidents respectively. However, higher numbers of total victims does not reveal the severity of the accidents as there can be more fatalities per number of accidents. This way, looking at Figure 2.1 (ANSR, 2015), that represents the number of fatalities per 100 accidents (severity index), it can be seen a different perspective of the numbers presented in Table 2.1. In 2010 the highest probability of death was connected to motorcyclists and there was expected that this numbers were maintained because of the previous years (Bernardo, 2012). However this number had a significant improvement from 2.90 fatalities per 100 accidents with motorcycles in 2010 to 1.58 in 2015. The highest rate of fatalities per 100 accidents belongs to trucks in 2015 followed by accidents with pedestrians involved. Since 2009 the severity index of moped accidents had been reducing. Despite the fact that cars have the highest number of victims of accident, the severity index has been the lowest throughout the years and therefore special attention needs to be taken in relation to the other types of vehicles.

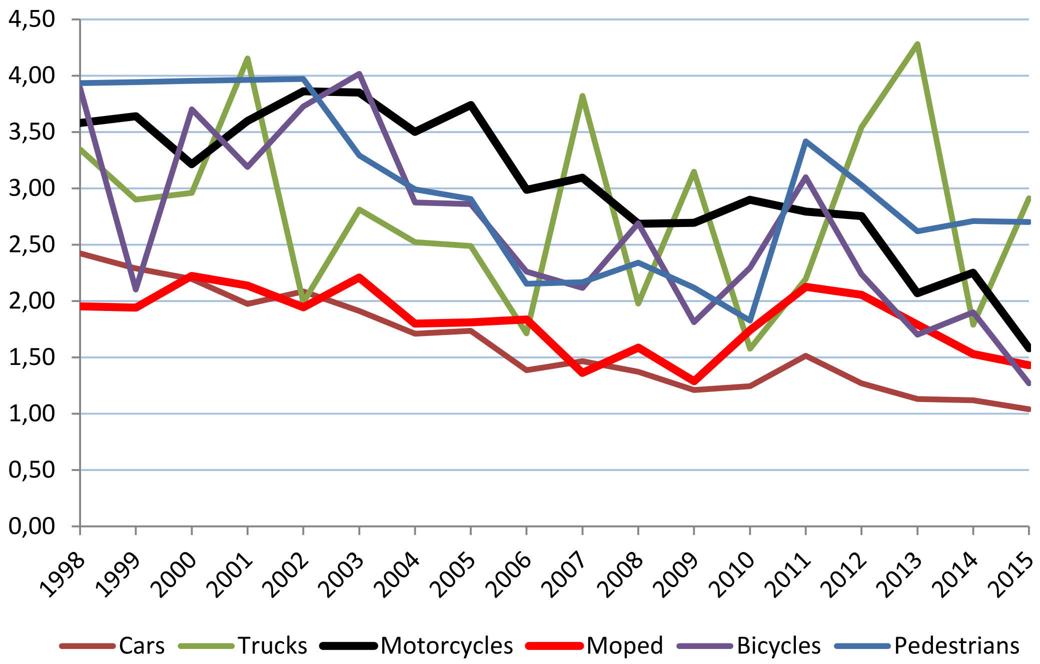


Figure 2.1- Severity index in road accidents with victims in Portugal, 1998 – 2015.

Despite the oscillatory behavior of the severity indexes, except for accidents involving pedestrians, the severity indexes are decreasing through the years in Portugal (Table 2.2).

Table 2.2 – Severity indexes in road accidents in Portugal, 1998 – 2015.

	1998	Variation 98 - 10	2010	Variation 10-13	2013	Variation 13-15	2015
Pedestrians	3,93	-53,5%	1,83	43,4%	2,62	3,1%	2,7
Cars	2,42	-48,6%	1,24	-9,2%	1,13	-8,0%	1,04
Trucks	3,35	-52,9%	1,58	171,3%	4,28	-32,0%	2,91
Bicycles	3,89	-41,0%	2,30	-25,9%	1,7	-25,3%	1,27
Moped	1,95	-11,0%	1,74	3,0%	1,79	-20,1%	1,43
Motorcycles	3,58	-19,0%	2,90	-28,6%	2,07	-23,7%	1,58

To get into the subject of PTW accidents with victims and to identify factors that have influence on the occurrence of the accidents it is going to be developed a study related to the years between 2010 and 2015 using the data from ANSR. This analysis is done discriminating the factors related to the vehicle, the human and, finally, environmental and geographic factors to establish what kind of accidents involving motorcycles and mopeds occurs the most and with highest severity indexes.

2.1.1 Vehicle Factors

From 2010 to 2015 the highest number of fatalities, severe injuries and minor injuries occurred in accidents involving cars due to high number of this type of vehicle. In the same years motorcycle accidents are the ones with more fatalities, after cars, followed by moped accidents with 12.3% and 7.1% of the fatalities in 2015 respectively. The same pattern is obtained for severe injuries and minor injuries (ANSR, 2015).

As the number of cars is much greater than the number of motorcycles, 5715760 versus 255865 in 2015, and with similar differences in the previous years, the number of fatalities and severe injuries can be compared per 1000 vehicles in circulation between 2010 and 2015. Motorcycles far exceed moped in terms of risk of occurring a fatality or a severe injury when involved in an accident. The probability of occurring a fatality or a severe injury in an accident with a motorcycle involved is the highest of all types of vehicles and motorcycles have the lowest number of vehicles in circulation right after trucks (ASF, 2015). Figure 2.2 represents the relation between fatalities and Figure 2.3 represents the relation between severe injuries in accidents per 1000 vehicles in circulation between 2010 and 2015, which were plotted using data from *Autoridade de Supervisão de Seguros e Fundos de Pensões* (ASF, 2015), as it is the closest indicator of the number of vehicles in circulation on the road, that was correlated with the data form ANSR). The figures also allow to see that between 2010 and 2015 the severity of the accidents related to the type of vehicle did not change much and only the trucks had more fluctuations. Therefore, the motorcycle is a vehicle that represents a high number of severity in the injuries. The analysis would present even worse results if the number of kilometers travelled by the vehicles was taken into account. The number of kilometers, although is estimated by no one but, is supposed to be way lower for PTW in comparison to light or trucks.

The other vehicles involve industrial vehicles as well as bicycles. The number of bicycles cannot be certain as they do not need insurance. This way is not possible to determine the number of bicycles in circulation. However, from surveys it was possible to determine that the number of bicycle users in Portugal. In 2009 nearly 25% of the people inquired ride regularly his bicycle but that number increased to almost 70% in 2015 (Dias et al., 2014). This increase in the number of bicycles users is related to the increase of the number of bicycle accidents.

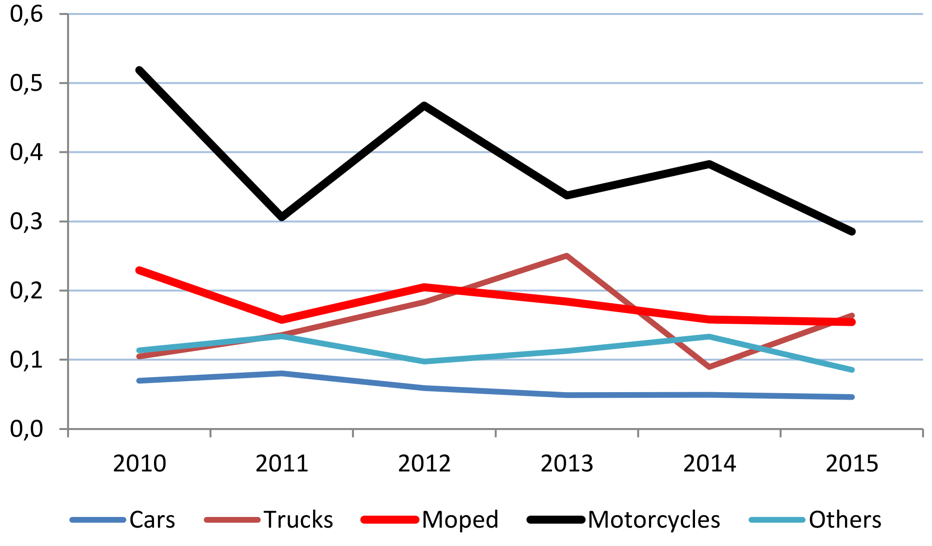


Figure 2.2 - Fatalities per 1000 vehicles in circulation, 2010-2015.

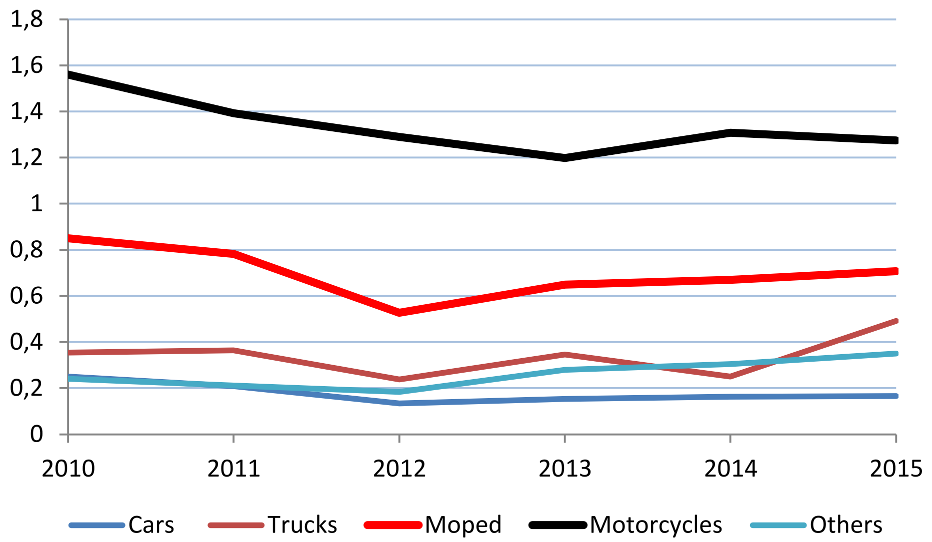


Figure 2.3 - Severe injuries per 1000 vehicles in circulation, 2010-2015.

Comparing all two wheeler vehicles (TW), motorcycles, moped and bicycles, it can be assessed by observation of Figure 2.4 that most of the victims correspond to motorcycle accidents followed by moped accidents and this distribution was obtained from 2010 to 2015. Since 2010 motorcycle accidents with victims, within TW accidents, had a variation from 57.7% in 2012 and 45.3% in 2013. Nearly half of the victims of TW accidents are from motorcycle accidents.

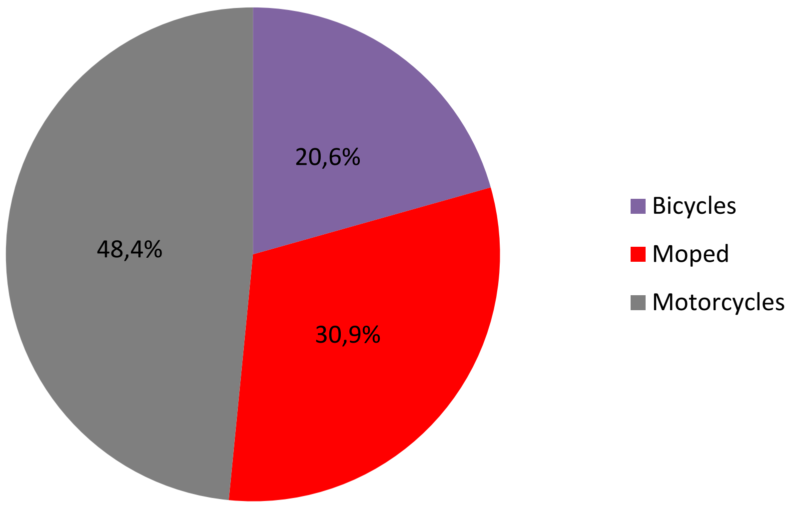


Figure 2.4 – Accident victims for TW categories in 2015.

From 2010 to 2013 the number of victims of motorcycle accidents had been stabilized around 3800 but in 2014 and 2015 that number increased reaching as high as 4609 victims. Figure 2.5 also shows that there was a tendency for the number of victims to decrease along the years. Despite the increase in the number of victims in bicycle accidents, this vehicle has yet the lowest value of victims in TW. The number of moped accidents victims became lower than the victims of motorcycle accidents in 2010 and a reason for this is because since 2009 the car license started to allow drivers to ride a motorcycle limited up to 125 cm^3 [Portuguese Law – DL 78/2009].

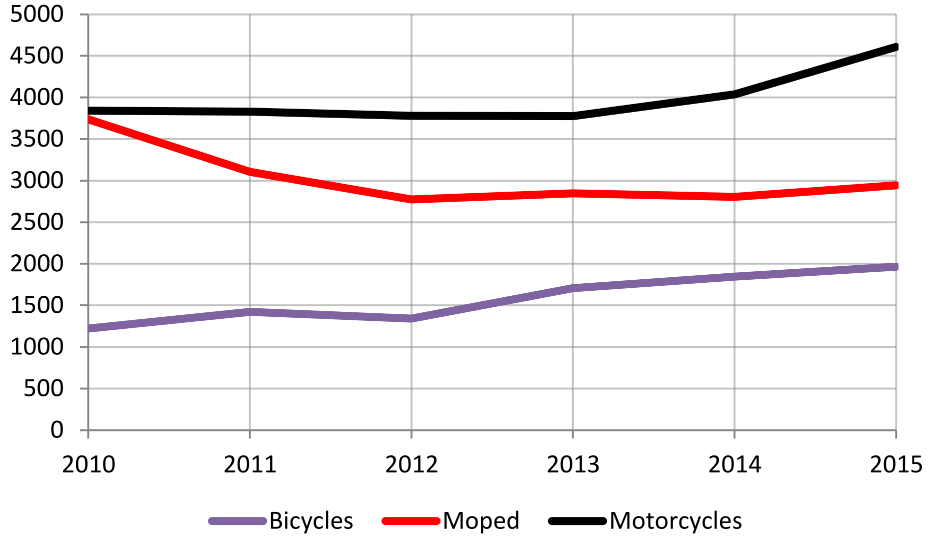


Figure 2.5 - Accident victims for TW categories, 2010 - 2015.

To evaluate the previous problem only PTW accidents are going to be taken into account and the number of fatalities and severe injuries in those accidents are represented in Figure 2.6. In the case of fatalities, 2015 had the lowest numbers since 2010 with 73 and 42 fatalities for motorcycle and moped accidents, respectively. However since 2012 the number of severe injuries has been increasing for PTW accidents.

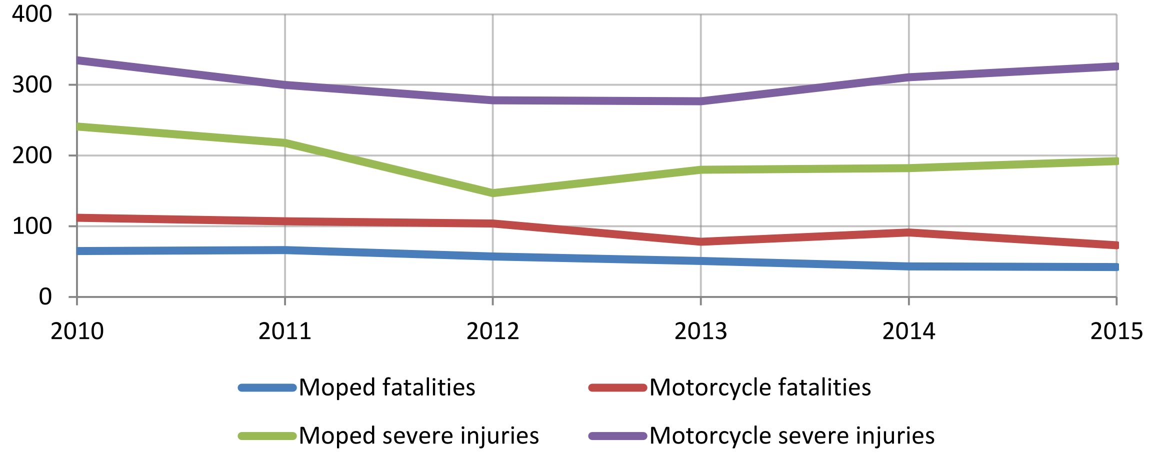


Figure 2.6 – PTW fatalities and severe injuries, 2010 - 2015.

Through Figure 2.7 it is visible that, since 2010, motorcycle accidents have always taken the highest position in terms of severity in the accident for PTW accidents. Despite the high number of mopped accidents, they represent less risk to their drivers and passengers. From 2009 to 2012 the severity index of moped accidents had been increasing but since 2013 that that effect was contradicted. Even though the severity of the accidents has been decreasing the number of victims has been increasing as shown in Figure 2.5 and that means that there were more victims, especially minor injuries, but less fatalities.

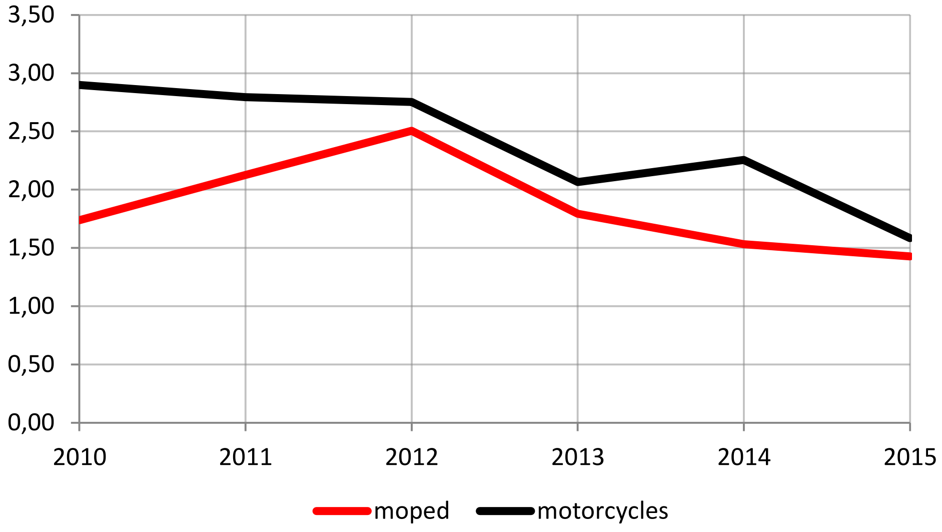


Figure 2.7 - Severity index for PTW accidents, 2010 - 2015.

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 and that is due to the possibility of reaching higher velocities than mopeds and so there is more energy involved in the impact. Nevertheless, mopeds are yet a reason to be concerned due to the increase of severe injuries in the last years.

2.1.2 Human Factors

The driver behavior has a crucial influence in the occurrence or avoidance of a road accident. The driver can submit himself to danger, by driving under the influence of alcohol or disrespecting the traffic laws, for example, or suffer from human mistakes and wrong evaluation of the danger. Several parameters that are in ANSR data base are going to be analyzed in order to relate the behaviors of the drivers that are involved in more severe accidents and the probability of occurring an accident. It is important to take into account the physical and mechanical properties of PTW in order to relate the topics as, for example, the high power and low stability of motorcycles.

Figure 2.8 represents the distribution of the PTW accident victims in 2015 and it can be verified that the majority of the victims suffer minor injuries. In the previous years the same pattern is visualized.

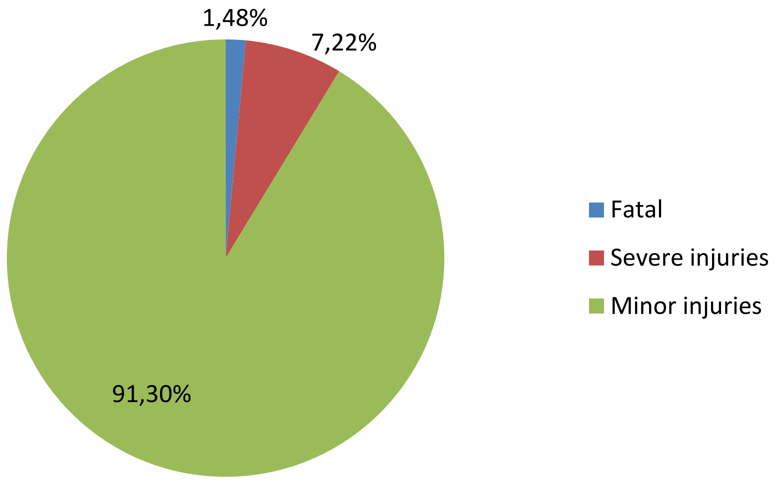


Figure 2.8 – PTW accident victims in 2015.

In PTW accidents there is a big discrepancy related to the gender of the driver as it can be seen in Figure 2.9 and Figure 2.10 which represent the distribution of the victims of accident by gender for motorcycle and moped drivers in the year of 2015. Empirically this can be justified by the reduced number of women driving PTW compared to men (Bernardo, 2012) and it is verified a proportion of 2 fatalities in women to 98 in men in PTW drivers victims of accident. If the number of PTW driving licenses in Portugal by gender were known it could be determined if the lower occurrence of accidents in female drivers is related to the fact that are few women driving this vehicles or if this number is related to the differences between women and men driving. Between 2010 and 2015 the severity indexes of male PTW accidents can be higher from 2 to 6 times compared with female PTW accidents.

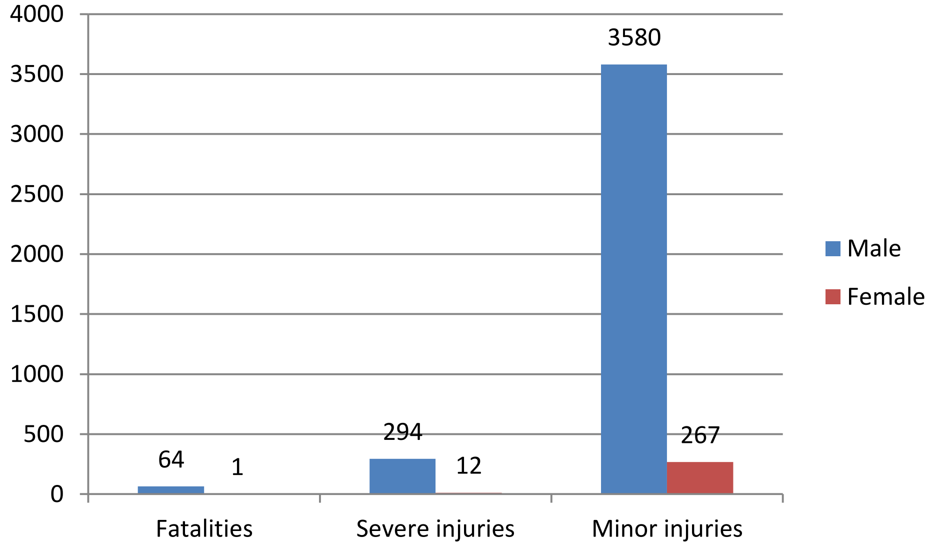


Figure 2.9 - Motorcycle drivers victims of accident by gender in 2015.

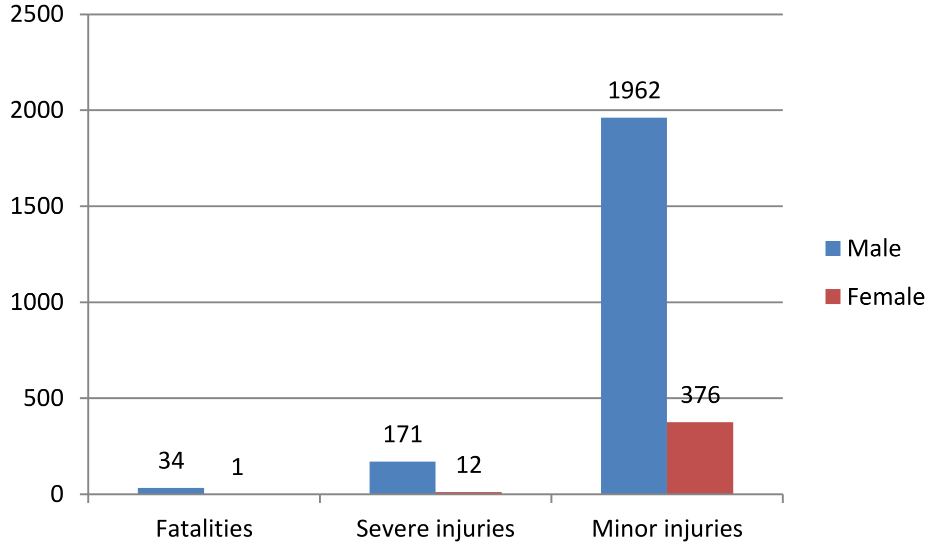


Figure 2.10 - Moped drivers victims of accident by gender in 2015.

By age group, the average number of fatalities between 2010 and 2015 in motorcycle and moped drivers can be seen in Figure 2.11. For motorcycle drivers, in general, a big group can be identified containing drivers between 25 and 34 years old and is characterized by the largest number of deaths between 2010 and 2014 with emphasis to the group from 30 to 34 years old. The age group where more fatalities occur has been changing as in the years of 2013 and 2014 it was from 30 to 39 years old while a new change occurred in 2015 where the previous group changed to 35 to 44 years. The lowest number of fatalities belongs to the age group under 25 years old. For the drivers of mopeds victims of accident it is clear that for ages above 65 years old there are more fatalities severe and minor injuries since 2010 until 2015. For ages under 64 years old, in terms of minor injuries, it can be seen that there are more victims under 19 years old. This vehicle was always associated with older people and in young ages it is used because people do not have yet the right age to drive a motorcycle. It is visible that the number of fatalities of moped drivers overcomes the number of fatalities of motorcycle drivers for ages between 50 and 55 years old.

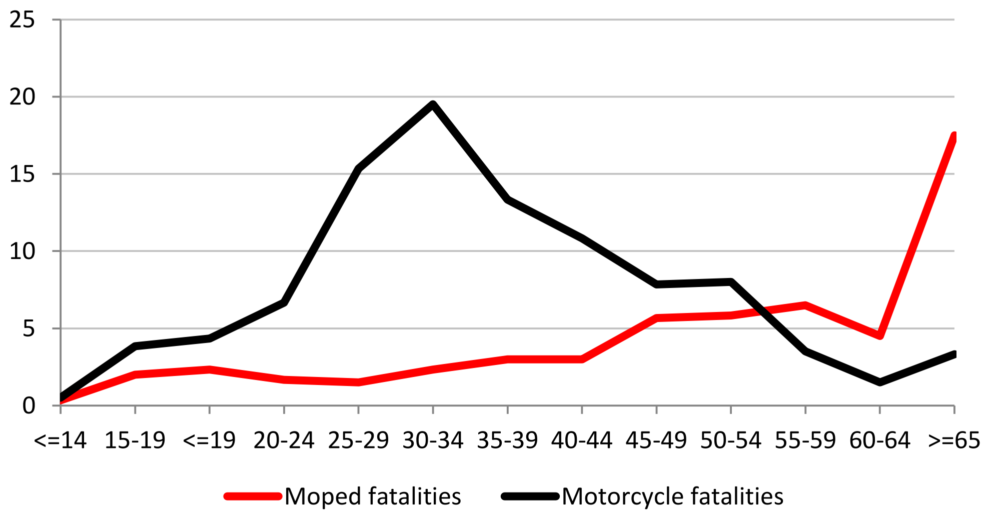


Figure 2.11 - Number of fatalities per age group for PTW drivers, 2010-2015.

Figure 2.12 shows the average number of severe injuries between 2010 and 2015 in motorcycle and moped drivers. Despite the decrease of the number of motorcycle severe injuries between 20010 and 2011, it was interrupted in 2013. From 2010 to 2012 the age group of 25 to 34 was the most affected of severe injuries in motorcycle accidents however from 2013 to 2015 it began to be the group of 30 to 39 years old. Between 2013 and 2015 the group that was more affected by fatalities and severe injuries in motorcycle accidents was the age group of 35 to 39 years old. It is visible that the number of severe injuries of moped drivers overcomes the number of severe injuries of motorcycle drivers for ages between 50 and 55 years old, once again.

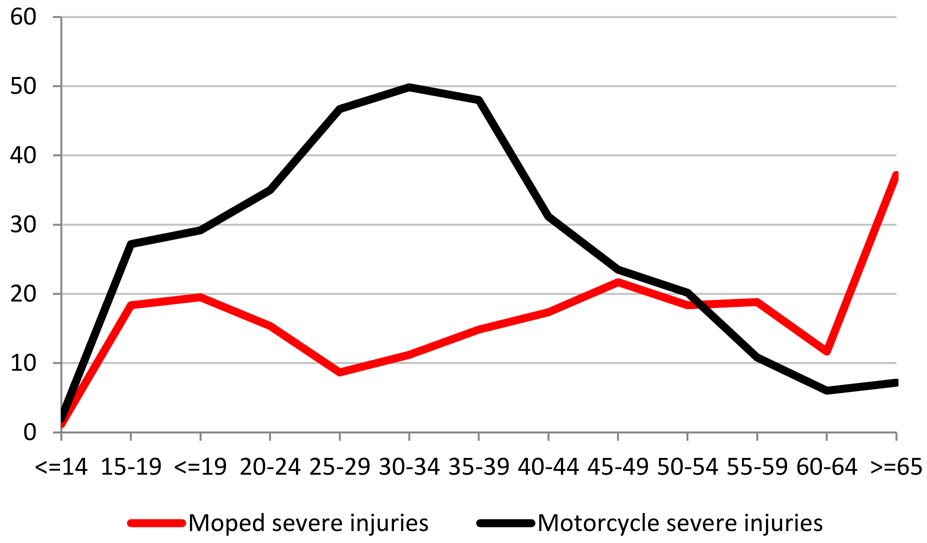


Figure 2.12 - Severe injuries per age group for PTW drivers, 2010-2015.

Figure 2.13 shows the average number of minor injuries between 2010 and 2015 in motorcycle and moped drivers. Regarding the minor injuries in motorcycle accidents the group of 25 to 34 years old was leading in number of injuries between 2007 and 2011. However in 2012 those groups changed to the 30 to 39 years old and remained until 2015. For ages greater than 35 years old there has been an increase number of minor injuries since 2007 to 2015. It is visible that the number of minor injuries of moped drivers overcomes the number of severe injuries of motorcycle drivers for ages above 45 years old.

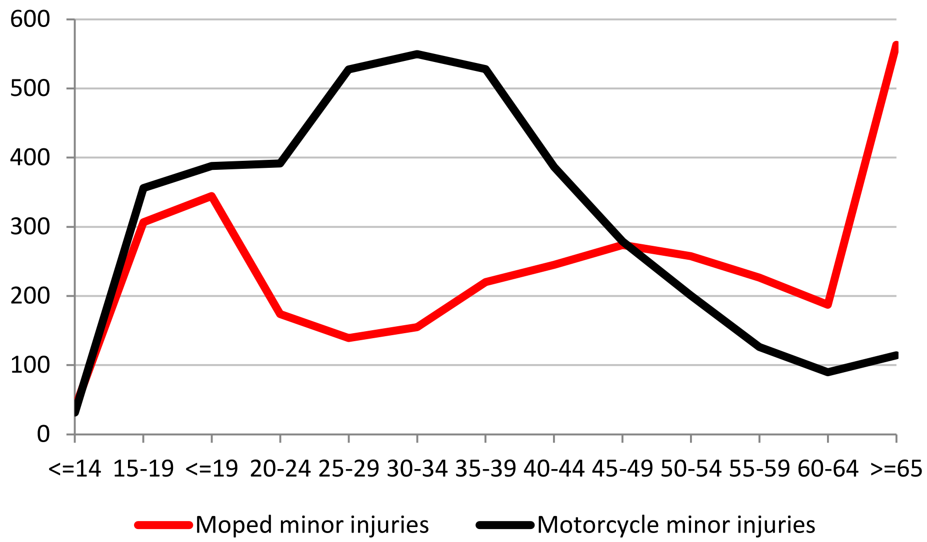


Figure 2.13 - Minor injuries per age group for PTW drivers, 2010-2015.

Through Figure 2.14 it is visible that the severity index is higher for motorcycle than for moped accidents for younger ages. However for older ages, after around 55 years old, moped accidents have the highest sever indexes compared with motorcycle accidents.

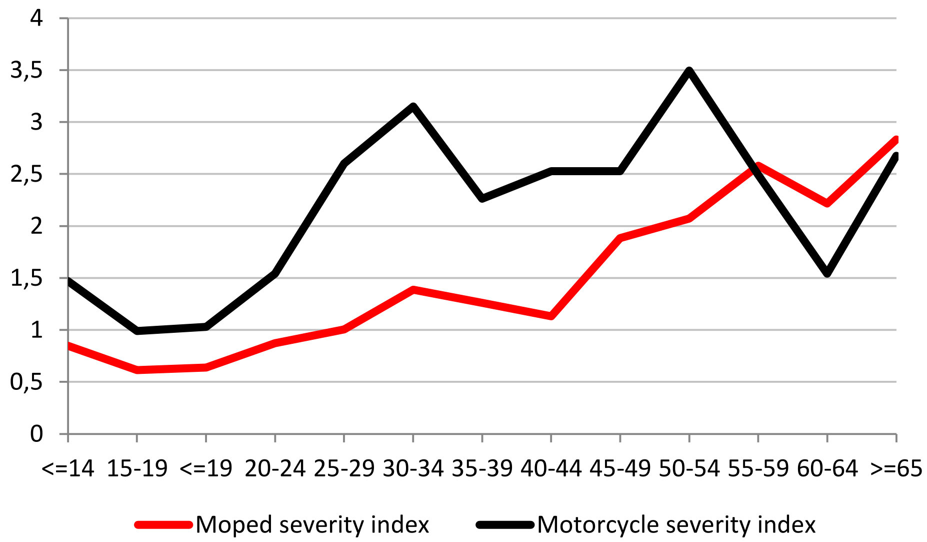


Figure 2.14 - Severity indexes per age group for PTW drivers, 2010-2015.

Moped drivers victim of accident belong to age groups superiors than motorcycle drivers, however in the last years there has been a general increase in the average age of the PTW driver in all kind of injuries as can be seen in Table 2.3.

Table 2.3 - Variation of the ages of PTW drivers victims of accidents, 2010-2015.

Vehicle	Injuries	2010	2011	2012	2013	2014	2015
Motorcycle	Fatal	36,8	36,1	37,1	36,3	39,1	39,6
	Severe	34,2	34,4	36,4	35,6	37,0	36,6
	Minor	34,9	35,2	36,2	35,9	36,0	36,6
Moped	Fatal	54,3	55,3	51,5	54,1	58,1	58,1
	Severe	47,1	45,7	46,7	46,7	48,0	48,9
	Minor	46,8	47,3	47,0	46,7	47,2	46,8

The age of the driver is not an indicator of his experience as a person can get a driver license in older ages. Actually the age of the victims of PTW accidents is getting higher as people are starting more often in older ages to driver PTW vehicles. To have an idea of the experience of the driver the years of the driving license of the driver can be analyzed. On Figure 2.15 it can be seen that motorcycle drivers with license under one year are the ones that contribute the less to the fatalities among this type of drivers. The results in this manner are stable. The top position had been changing through the years. In 2010, 2012 and 2015 driver licenses with 1 to 5 years were the range that contributes the most to motorcycle fatalities however in 2008, 2009, 2011 and 2013 it was driver licenses with 11 to 20 years. The year of 2014 was the only one since 2007 that driver licenses with 6 to 10 years contributed the most to the fatalities among motorcycle drivers.

For moped drivers the reality is different. There is a tendency for more fatalities as the number of years of the driving license increase. As a matter of fact, driving licenses with more than 20 years have always been the ones that contributed the most for fatalities in moped drivers in road accidents.

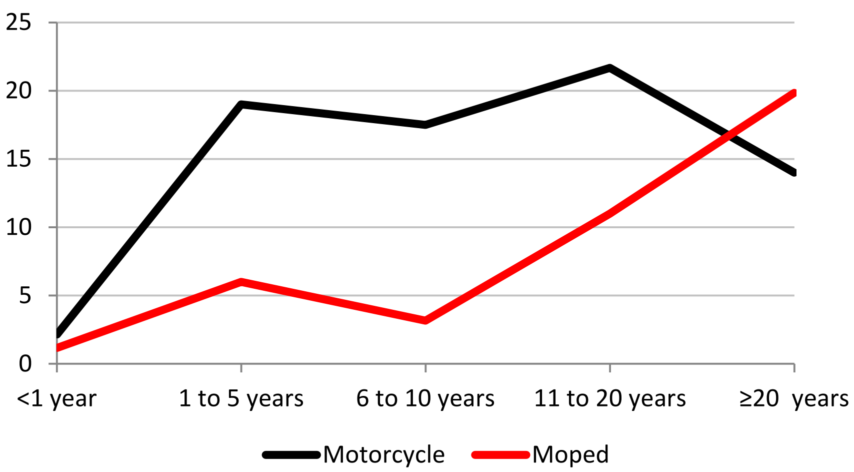


Figure 2.15 - Fatalities in PTW drivers per years of driving license, 2010-2015.

Analyzing just the number of PTW fatalities does not allow to take a conclusion if the experience of a driver have influence on the accident. Through Figure 2.16 is visible that most of the accident victims are concentrated for PTW drivers with driving license between 1 and 5 years and that include the drivers without experience. That group of drivers also includes drivers that start to think that they already have experience after driving license with 3 or 4 years. The most inexperienced drivers presents the lowest contribution for PTW accidents and that can be related with the fact that that drivers know that they are inexperienced and that way they drive very carefully. The second group that more contribute to PTW accidents is the group with driving license between 11 and 20 years and the third group is drivers with driving license with more than 20 years.

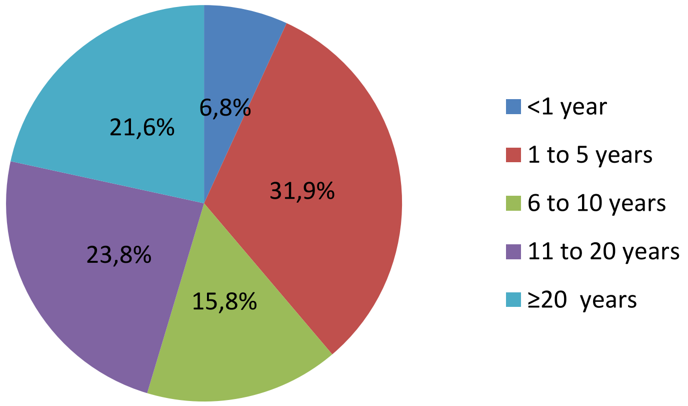


Figure 2.16 - Distribution of PTW victims per years of driving license, 2010 - 2015.

An accident does not only depend on the PTW driver as other vehicle can be involved. To have a better idea of the influence of the years of driving license the PTW accidents without other vehicles involved can be analyzed. Figure 2.17 shows the distribution of PTW single vehicle accidents. It is visible that the distribution is exactly the same as the distribution for all the accidents. This allows concluding that the experience of a driver is not related to other vehicles being involved in the accidents. An experience driver reveal its experience in all cases and not only when driving in the presence of other vehicles.

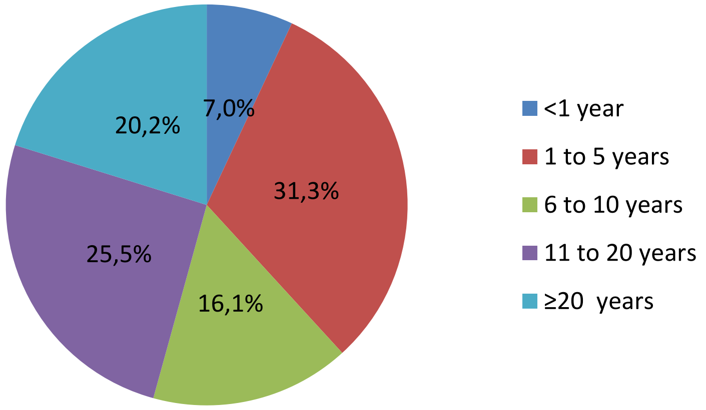


Figure 2.17 - Distribution of PTW victims per years of driving license in single vehicle accidents, 2010 - 2015.

The previous analysis goes against the idea that younger and inexperienced drivers contribute the most for the increase of the fatalities in PTW accidents. However drivers with driving license between 1 and 5 years are the ones that most contributes for PTW accidents. The reason why they contribute the most for the number of victims but not for the number of fatalities can be related to the fact that the majority of that drivers are young drivers and that way they have more resistance to injuries.

Before it was seen that drivers with driving licenses between 1 and 5 years are the ones that most contribute for PTW accidents. However in that analysis it was not considered the drivers without driving license. Table 2.4 represents the distribution of PTW drivers victims of accidents that have or not proper driving license.

Table 2.4 - Distribution of PTW victims drivers per property of driving license, 2010 - 2015.

	Without proper driving license	With proper driving license
Fatalities	12,5%	87,5%
Severe injuries	14,0%	86,0%
Minor injuries	6,1%	93,9%

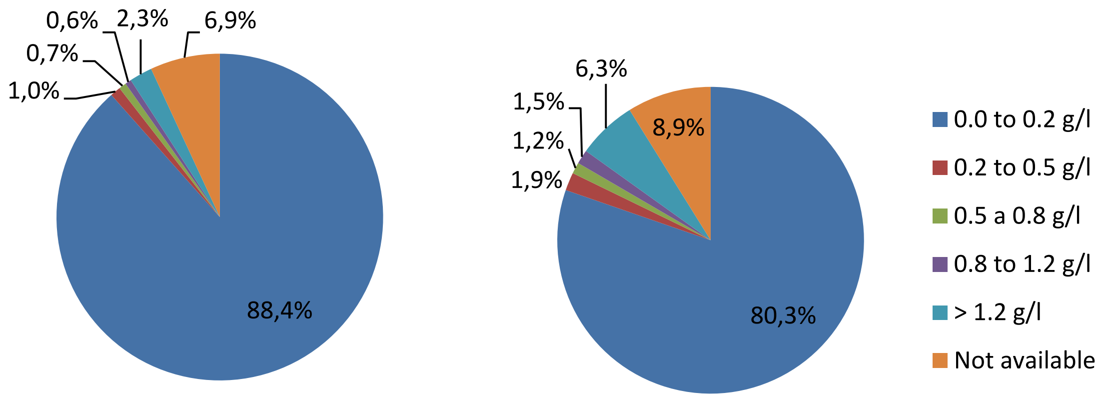
Among PTW drivers victim of accidents present in ANSR data base most of them had proper driving license for the vehicle they were driving. Since 2010 until 2015 the number of PTW drivers without proper driving license for the vehicle involved in accidents with victims had been decreasing. On the other hand the percentage of fatalities for drivers without proper driving license is too high. Actually, the severity index for 4.2 and for drivers with proper driving license is 2.1.

Alcohol consumption is considered one of the main causes of road accidents due to the effects it has on person who is drinking. In Table 2.5 it is represented the percentages of PTW drivers involved in accidents with victims between 2010 and 2015 in each category of blood alcohol content regarding the Portuguese legislation. When the alcohol content is inferior to 0.5 g/l it is not considered driving under the influence of alcohol.

Table 2.5 – Percentage of PTW drivers involved in accidents with victims, by blood alchool content, 2010 - 2015.

		0.0 to 0.2 g/l	0.2 to 0.5 g/l	0.5 a 0.8 g/l	0.8 to 1.2 g/l	> 1.2 g/l	Not available
Motorcycle	**2010**	84,4%	1,7%	0,7%	1,1%	3,3%	9,9%
	2011	87,4%	1,5%	1,0%	1,7%	3,1%	8,5%
	2012	84,7%	1,5%	0,6%	1,3%	3,4%	8,5%
	2013	87,1%	1,1%	0,8%	1,0%	2,4%	7,6%
	2014	88,0%	1,4%	0,4%	1,0%	2,6%	6,6%
	2015	88,4%	1,0%	0,7%	0,6%	2,3%	6,9%
Moped	**2010**	76,2%	2,4%	1,0%	1,7%	9,5%	9,2%
	2011	75,9%	2,1%	1,0%	1,4%	10,7%	8,9%
	2012	86,0%	2,0%	1,3%	1,9%	8,8%	9,7%
	2013	77,3%	1,9%	0,9%	1,4%	9,0%	9,6%
	2014	78,9%	1,9%	1,3%	1,1%	7,9%	8,9%
	2015	80,3%	1,9%	1,2%	1,5%	6,3%	8,9%

This way in 2015 most of the drivers did not drive under the influence of alcohol when having an accident (Figure 2.18). The drivers out of law in motorcycles exceeded in 7.2% the drivers of mopeds. Still in 2015, for 293 motorcycle drivers the result of an alcohol test is not available perhaps due to severe injuries in the accident or even in fatal cases.



a) **Motorcycles** **b) Mopeds**

Figure 2.18- BAC (g/l) in drivers involved in accidents with victims in 2015.

Table 2.6 gives the average numbers regarding the usage or not of a helmet, in the years from 2010 to 2015, among PTW drivers victims of accidents. In Portugal, in the year of 2015, 99.61% of the motorcycle drivers victims of road accidents were wearing a helmet and the rest 0.39% were not. Regarding moped drivers, of all the victims 98.91% were wearing helmet and 1.09% were not. Looking only to the number of fatalities in motorcycle accidents it was a difference of 64 to 1 fatality between the usage of helmet or not in motorcycle and moped drivers respectively.

Table 2.6 - Wearing of helmet in PTW drivers victims accident, 2010 - 2015.

		Minor injuries	Severe injuries	Fatalities	Severity index
Motorcycle	**With helmet**	90,0%	7,7%	2,3%	2,3
	Without helmet	54,9%	29,8%	15,3%	15,3
Moped	**With helmet**	92,0%	6,3%	1,7%	1,7
	Without helmet	71,0%	20,2%	8,8%	8,8

However if the number of accidents in the previous case is taken into account is easy to understand why wearing a helmet is so important in minimizing injuries suffered at a PTW accident. To sustain the previous result the percentages between fatalities wearing or not a helmet can be analyzed, concluding that for PTW drivers the severity of the injuries increase a lot when the driver is not wearing a helmet.

2.1.3 Environmental Factors and Geographic Distribution

Environmental factors consider the different luminosity and atmospheric conditions. As PTW drivers cannot control these parameters in the occurrence of a road accident all the victims (PTW drivers and passengers) are going to be taken into account.

From 2010 to 2015 most of the accidents occurred during daylight however the harshest injuries are divided between night and twilight. For instance, in 20015 occurred 3322 accidents during day light, 1008 during the night but only 127 during twilight. However the highest severity index is related to twilight despite the lowest number in accidents. For 2010 and 2014 the same distribution of number of accidents can be seen. For a more detailed analysis the night time can be divided into two categories: with and without street light. With this division the period of the night without street light is where the severity index is the highest for the considered years. The reason beyond this increase compared with only night time is because most of the accidents with victims that occur at night are in the presence of street light. This way it can be concluded that the highest risk of death in a motorcycle accident is associated with night time without illumination on the road. Regarding moped accidents with victims in 2013 and 2015, the results indicate that twilight is when the most severe cases happen. For 2011 and 2014 the result was not the same as there were no fatalities in that period making night the period with the highest severity index.Tthe highest severity index in the years of 2010 and 2012 was in night time.

Dividing the day per hours it can be seen in Figure 2.19 that it was in the period between 17 to 20 that occurred most of the accidents with victims among PTW's, between 2010 and 2015. Regarding moped accidents the time of the day with most victims was as before. To be more precise regarding motorcycle and moped accidents, the highest amount of victims was recorded to be between 17 and 19. Independently of the season of the year, the previous period corresponds to the end of the day, in particular the end of a work day. On the other hand is dawn, with the fewest victims regarding both PTW vehicles, followed by the beginning of the morning.

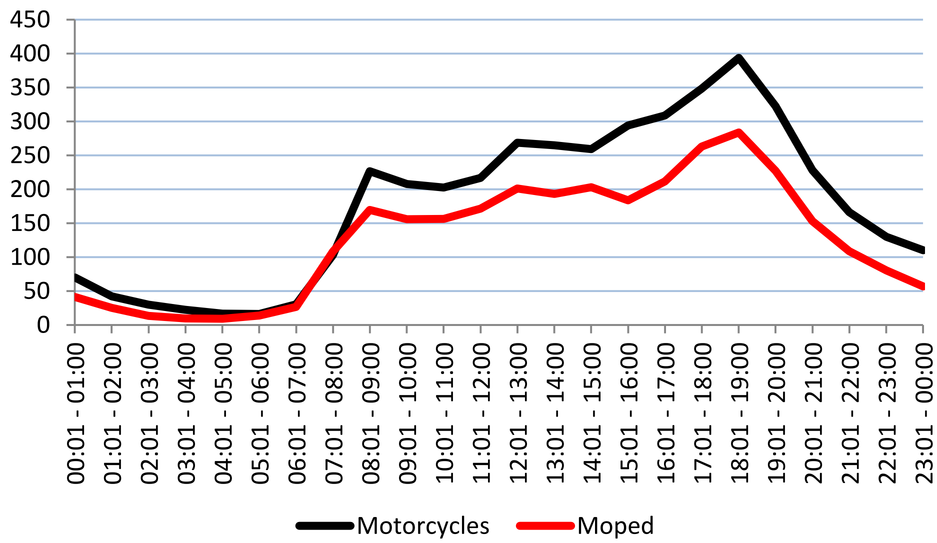


Figure 2.19 - PTW accident victims divided by hours of day, 2010 - 2015.

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. To do so the severity index can be analyzed from Figure 2.20. Between 2010 and 2015, for both motorcycle and moped accidents, the highest severity indexes are concentrated between 2 and 6.

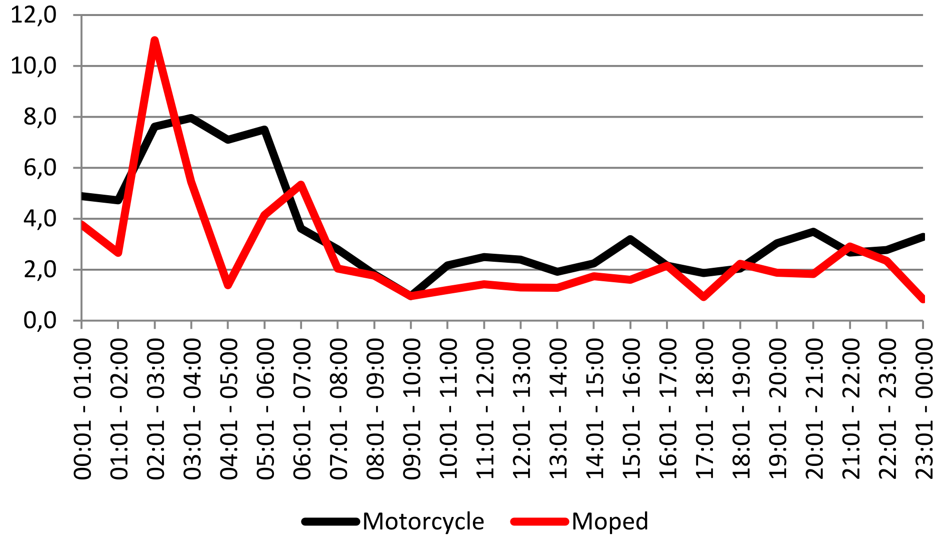


Figure 2.20 – Severity indexes for PTW accidents divided by hours of day, 2010 - 2015.

Still on the frequency of the occurrence of PTW accidents, the day of the week can be evaluated. From Figure 2.21 it is visible that between the years of 2010 and 2015 there a uniform distribution of the number of victims in PTW accidents short with variations between 12% and 16.

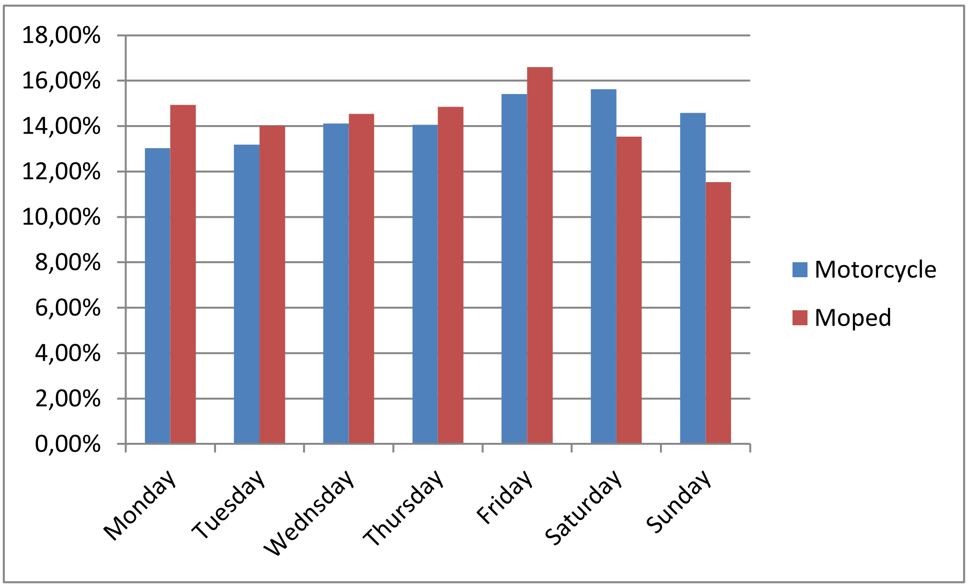


Figure 2.21 PTW victims per day of week, 2010 - 2015.

From Figure 2.22 it is visible that between 2010 and 2015 the highest number of fatalities is concentrated in the weekends.

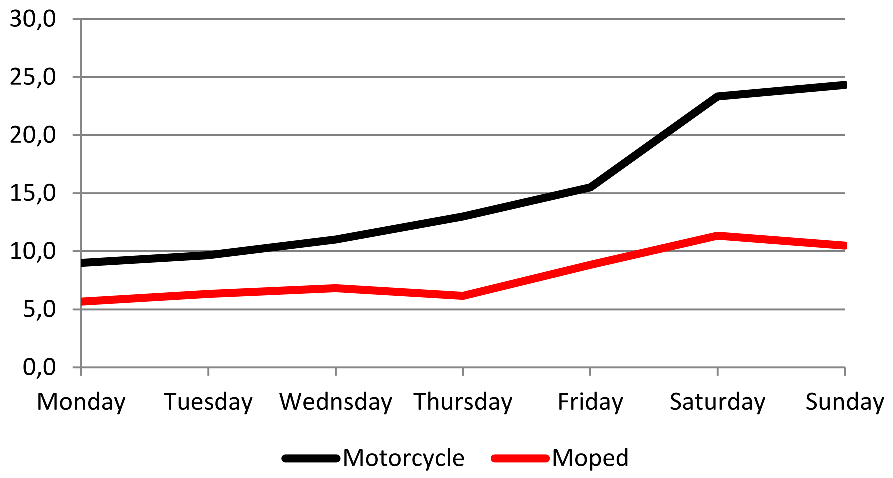


Figure 2.22 - Fatalities in PTW accidents per day of week, 2010 - 2015.

Highest number of fatalities is not a synonym for highest severity indexes but the weekends actually take those both positions (Figure 2.23). The day of the week where the injuries are more severe in PTW accidents is on Sundays.

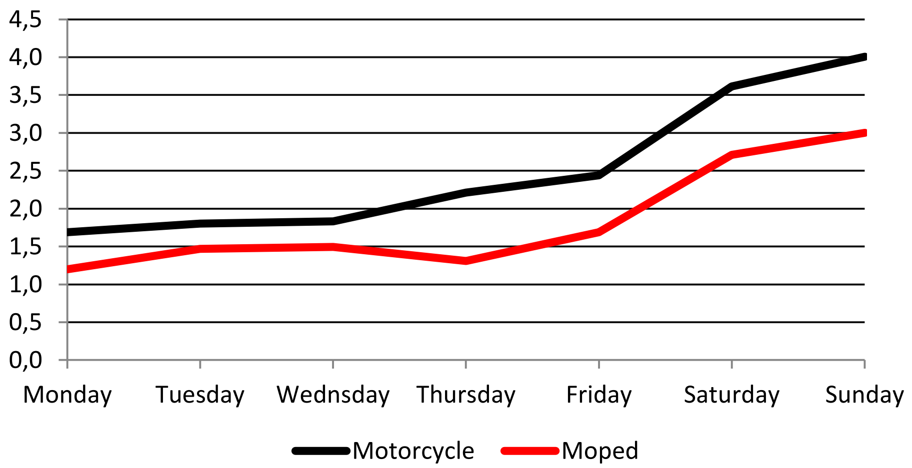


Figure 2.23 – Severity indexes in PTW accidents per day of week, 2010 - 2015.

Regarding the weather conditions, between 2010 and 2015 most of the PTW accidents with victims occurred under good weather conditions. In second place comes rainy days with more victims. Hail, snow, fog, smoke cloud and strong wind are associated with a very low number of victims in PTW accidents between 2010 and 2015. What can explain this is the fact that under these conditions there is a lower use of this type of vehicle because it is uncomfortable for the rider and when it is used the rider drives slower as the conditions of the road are weaker and as a result the probability of having an accident is reduced (Bernardo, 2012).

As weather conditions have a direct influence over the surface of the road conditions, between 2010 and 2015 the motorcycle accidents had mainly occurred during good weather with a severity index varying from 1.9 to 3.3 throughout the years. For moped accidents the severity indexes are higher in the case of good weather for the years of 2013 and 2014, however in the year of 2015, 2012, 2011 and 2010 the severity index for rain was higher than for good weather with a maximum value of

3.3. Higher number of victims for good weather conditions and higher severity indexes for the same conditions can be explained by the weather over the year in Portugal as it is a country with Mediterranean weather and lots of days without rain throughout the year.

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 validates the theory that PTW are used seasonally and specially in the period of spring and summer. The severity indexes for PTW accidents varied a lot between the months of the year as can be seen in Figure 2.24 for the case of motorcycle accidents. Looking to Figure 2.24 is difficult to conclude anything as in the 6 years in analysis there are huge variations.

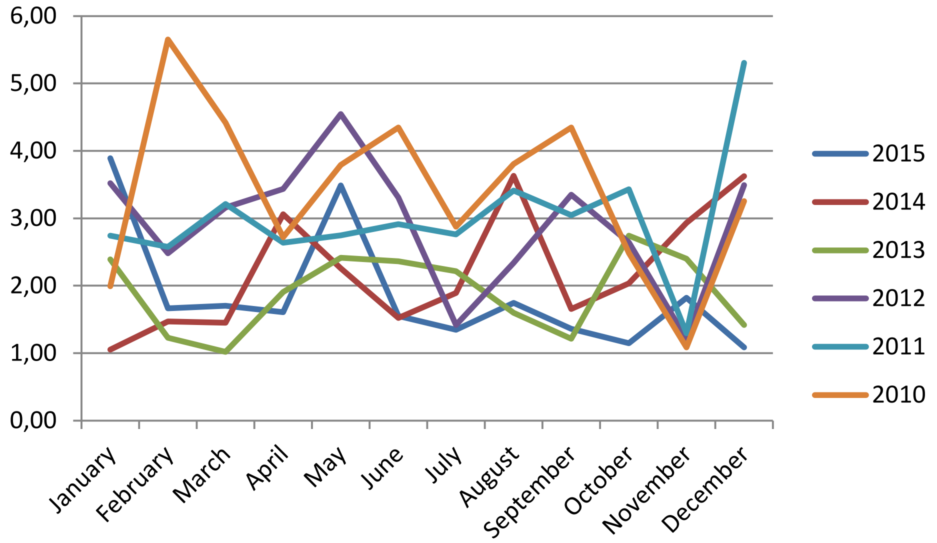


Figure 2.24 – Severity indexes of motorcycle accidents per months, 2010 - 2015.

An average of all the severity indexes for the 6 years in analysis is performed. That result is represented in Figure 2.25. The peak of the severity index is in the month of May. However in November the severity index begin to increase and in the winter months is higher than in the summer months.

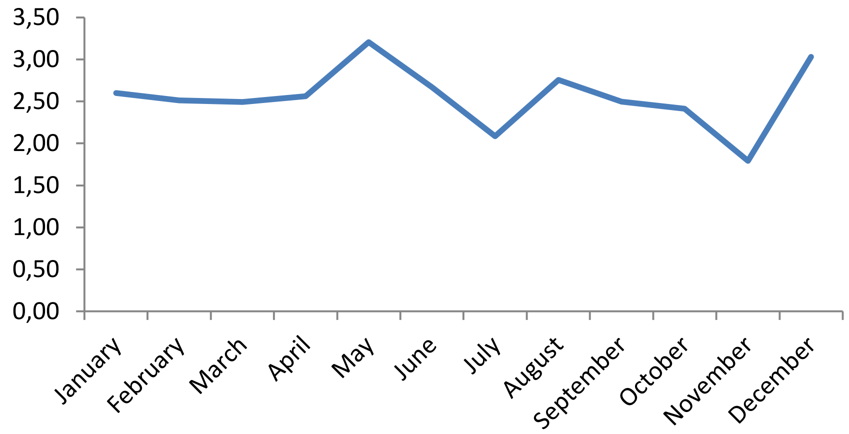


Figure 2.25 - Severity indexes average of motorcycle accidents per months, 2010 - 2015.

Data about the population of each administrative region of Portugal (INE, 2012) allows the construction of Figure 2.26 which will be used in the analysis of the different Portuguese administrative regions. This image represents the geographic distribution of fatalities per 100 000 inhabitants in each administrative region in the year of 2015 for motorcycle accidents with victims. Lisbon and Faro were the administrative regions with the highest values in 2015 with 78.8 and 67 fatalities per 100 000 inhabitants, respectively. Actually Lisbon and Faro had been leading that number since 2010. Regarding moped accidents with victims, Faro and Aveiro had the highest number of fatalities per 100 000 inhabitants from 2010 until 2015 with 73.4 and 65.2 fatalities per 100 000 inhabitants, respectively, in 2015 (Figure 2.27).

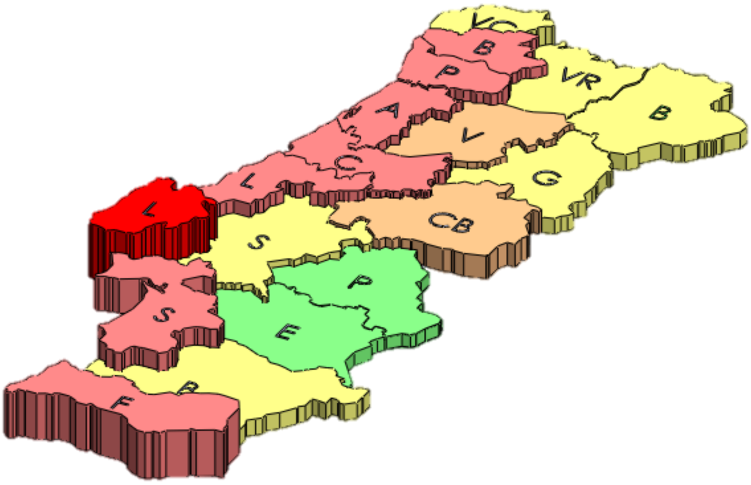


Figure 2.26 – Motorcycle fatalities per 100 000 habitants per regions in 2015.

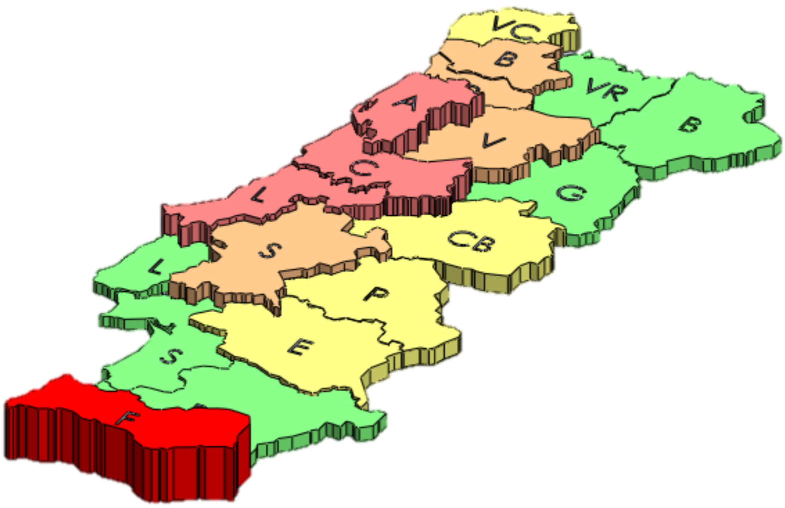


Figure 2.27 – Moped fatalities per 100 000 habitants per regions in 2015.

Considering the severity index for motorcycle accidents with victims, the two administrative regions with the highest severity index were not always the same from 2010 to 2015. The lowest results since 2010 were achieved in 2015, in which the top two positions were taken by Santarém and Aveiro (Figure 2.28) with 5.4 and 4.4, respectively. For moped accidents with victims in the year of 2015 the administrative regions of Beja and Viseu were the ones with highest severity indexes with 6.9 and 5.2, respectively. Beja has taken the top two positions in the years from 2010 to 2013. If an average of the years between 2010 and 2015 was considered the administrative regions of Viana do Castelo, Évora and Beja would be the ones with the highest severity indexes for motorcycle accidents and for moped accidents the administrative regions of Viseu, Beja and Portalegre would take the top positions in terms of severity indexes (Figure 2.29).

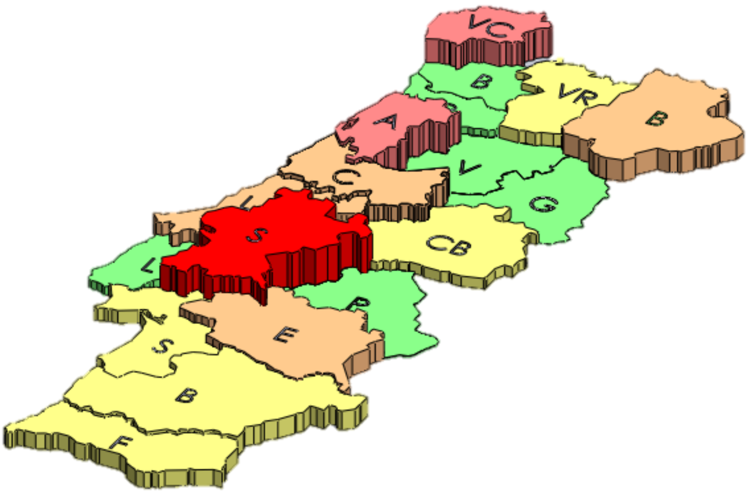


Figure 2.28 - Severity index in motorcycle accidents per regions in 2015.

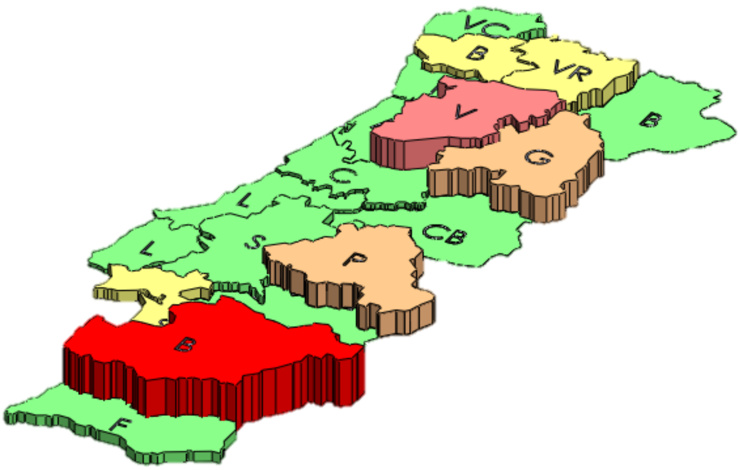


Figure 2.29 - Severity index in moped accidents per regions in 2015.

From 2010 to 2015, more than 80% of the PTW accidents with victims occurred inside urban areas. Despite the case of motorcycle accidents in 2015, with 42 fatalities inside urban area and 50 outside urban area, PTW accidents in the years between 2010 and 2015 had always had more fatalities inside urban area. However, and as seen before, more fatalities are not a synonym of higher severity. In PTW accidents the severity index tends to be higher outside (Figure 2.30).

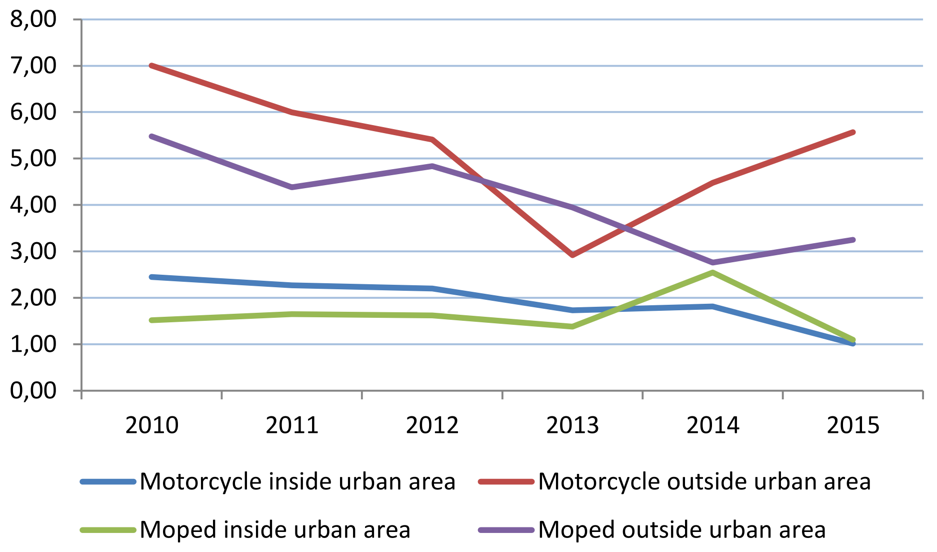


Figure 2.30 - Severity index in PTW accidents per regions, 2010 - 2015.

As the speed limits are higher outside urban areas, it is reasonable expected that the severe index is higher too. Despite the lower speed limits inside urban area, the number of intersections is larger and for that reason the likelihood of an accident between two crossing cars happening is higher.

2.1.4 Accident Type

To conclude the analysis of PTW accidents with victims in Portugal it is necessary to study what is the main type of accident. According to the data from ANSR there are three major accident variations: Run over pedestrians (ROP), collisions (COL) and single vehicle accident (SVA). From Table 2.7 it is easy to see that along the years collisions is the type of accident with more victims and fatalities among PTW drivers and passengers, followed by single vehicle accidents and finally run over pedestrians.

Table 2.7 - PTW accident victims, fatalities and severity indexes per accident type, 2010 - 2015.

		% of victims				% of fatalities				Severity index		
		ROP	**COL**	**SVA**		**ROP**	**COL**	**SVA**		**ROP**	**COL**	**SVA**
Motorcycle	**2010**	1,8	60,1	38,1		0,9	50,9	48,1		1,69	2,71	4,04
	2011	2,0	59,3	38,8		1,0	43,8	55,2		1,47	2,24	4,32
	2012	1,7	59,6	38,7		0,0	52,5	47,5		0,00	2,53	3,52
	2013	1,4	59,7	38,9		0,0	62,2	37,8		0,00	2,24	2,09
	2014	1,4	58,6	40,1		1,1	53,9	44,9		2,00	2,25	2,74
	2015	1,9	58,8	39,3		1,4	52,8	45,8		1,22	1,53	1,98
Moped	**2010**	1,2	60,8	38,0		0,0	59,2	40,8		0,00	2,22	2,45
	2011	1,2	58,1	40,7		0,0	57,4	42,6		0,00	2,15	2,28
	2012	1,8	58,9	39,3		0,0	50,0	50,0		0,00	1,91	2,86
	2013	1,5	55,9	42,6		0,0	53,1	46,9		0,00	1,79	2,08
	2014	1,8	54,7	43,5		0,0	63,2	36,8		0,00	1,72	1,26
	2015	1,6	55,5	42,9		0,0	52,4	47,6		0,00	1,48	1,73

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 in the collision type and single vehicle accident type. Globally, the severity of the injuries had been lowering passing the years.

As the number of run over pedestrians are really low can be made an analysis to the other two types of accident. In that case the concentration of fatalities and victims are in collisions but the highest severity index tends to be on single vehicle accidents.

In Table 2.8 is represented the distribution of victims as well as the severity indexes in single vehicle accidents for bended and straight roads and for location between 2010 and 2015. It is visible that the highest number of all type of victims is concentrated in the accidents that occur in straight roads. However the highest severity index is in single vehicle accidents in bended roads. This can be related to the fact that in a straight road the body id projected and slides in the road ground but in a bended road the body after its projection can slides for the outside of the road.

Table 2.8 – Single vehicle accidents , 2010 – 2015.

		Minor injuries	Severe injuries	Fatalities	Total	Severity index
SVA	**Bended roads**	5012	456	166	5634	2,9
	Straight roads	8484	669	233	9386	2,5
	Inside urban are	10900	761	249	11910	2,1
	Outside urban area	2649	364	148	3161	4,7

Inside urban areas are more PTW victims of single vehicle accidents. However the highest severity is in accidents that happen outside urban areas what can be related to the higher speeds in that kind of areas.

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

Descriptive statistics as done before in this work is a primary and important way to evaluate data in terms of frequencies. In Portugal where PTW accidents represents a problem with a significant importance and this way descriptive statistics is limited as it cannot relate variables and the causes of that relations. To model the relation between variable there are regression model which are very important tools in data analysis. In this type of models the objective is to relate a response variable or dependent variable with one or more independent variables that are also called predictors or explanatory variables.

An analysis for the PTW accidents and another analysis just for the motorcycle accidents were done. Both the analysis presented really close results as its going to be discusses later. Appendix A contains all the information about the data set provided by ANSR used for the analysis as well as all the important results.

2.2.1 Data

Data provided by ANSR have all the information about PTW accidents with victims occurred in Portugal between 2010 and 2015. Table 2.9 represents the number of the different types of victims of accidents in the two classes of PTW of the original data.

Table 2.9 - PTW accidents with victims, 2010-2015, original data.

2010 - 2015			
	Moped	**Motorcycle**	**Total**
Minor injuries	14866	19331	34197
Severe injuries	1051	1659	2710
Fatalities	317	545	862
Total	16234	21535	37769

The original data had 57 variables and each one of them was divided in different classes. There are variables related to the accident, to the PTW driver as well as to the other driver involved in the accident when there is one. In Table A.1 from Appendix A is represented all the variables and classes with the respective description of the original data.

2.2.2 Methodology

The objective of the following analysis is to identify, among the PTW drivers victims of accidents, the risk factors to then find the priority areas of action that minimize PTW occupant's exposure to risk.

2.2.2.1 Variables

To estimate the risk factors that have influence in the injuries of the PTW driver's, it is possible to build an ordinal variable that have the different levers of severity in the injuries, in the same way as done by Bernardo, 2012 and Sousa, 2017. This way, the dependent variable PTW driver's injuries contains three levels of severity in a crescent order: minor injury, severe injury and fatality.

The independent variables, also called predictors or explanatory variables, represent the potential risk factors in the severity of the injuries in the PTW driver's. They were selected from the original data considering the descriptive statistics and other studies presented in the literature review.

Table A.2 from Appendix A presents the classes of each variable, the number of observations and the marginal percentages of the discretized data. Those classes are going to be used in the statistical analysis. Table 2.10 represents the new number of the different types of victims of accidents in the two classes of PTW of the discretized data. The discretized data was obtained with the removal of some accidents with no information in some classes.

Table 2.10 - PTW accidents with victims, 2010-2015, discretized data.

2010 - 2015			
	Moped	**Motorcycle**	**Total**
Minor injuries	14510	18806	33316
Severe injuries	1022	1608	2630
Fatalities	305	527	832
Total	15837	20941	36778

In the discretized data, between 2010 and 2015, 36778 PTW accidents with victims happened in Portugal where 832 fatalities resulted. Almost 91% of the victims correspond to minor injuries.

2.2.2.2 Statistical Model

The selection of the proper statistical model depends on the hypothesis to test and the data to analyze. In the following analysis are going to be determined the risk factors, in the severity of the injuries of the PTW driver's, in the previous presented classes. In the conditions of the data the ordered logistic regression is the one that fits the best (Quddus et al., 2002, Bernardo, 2012, Dias et al., 2014, and Sousa, 2017).

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 type of regression the function logit is the most used and recommended when the ordinal dependent variable presents a distribution relatively even in its classes. If the function logit is applied then the ordered logistic regression, considering more than one independent variables, presents the following formulation:

$$f\left(\gamma_j(X)\right) = log\left(\frac{\gamma_j(X)}{1-\gamma_j(X)}\right) = log\left(\frac{P\{Y \leq y_j/X\}}{P\{Y > y_j/X\}}\right) = \alpha_j + \sum_{n=1}^{k} \beta_k X_k \text{ , } j = 1,2,\ldots,k-1 \qquad \textbf{(2.1)}$$

$$\gamma_j(X) = \frac{e^{\alpha_j + \beta X}}{1 + e^{\alpha_j + \beta X}} \qquad \textbf{(2.2)}$$

$f\left(\gamma_j(X)\right)$ gives the cumulative logit model with proportional odds and j represents the cut-off points for the dependent variable. Y is the response variable, which takes integer values between 1 and j. γ_j is the cumulative probability. X_k are the k-1 explanatory variables. α_j represents the limits for each cumulative probability. β_k are the regression coefficients of the independent variables.

To interpret the results from an ordered logistic regression, the main point is to analyze the regression coefficients of the independent variables as they indicate the effect of the independent variables in the cumulative probability of the ordinal response. In contrast to the classic Laplace's Law that gives the probability of a certain event as the quotient of the number of favorable cases and possible cases, the odds ratio (OR) represents the possibility of certain event of the group p_1 or p_0 and it is the ratio between the probability of the occurrence event in the group and the probability that the same event does not occur. The odd ratio (OR) in logistic regression is basically an association between the independent variables and the dependent variable in an ordered logistic regression.

$$\boldsymbol{OR} = \frac{\boldsymbol{p_1/(1-p_1)}}{\boldsymbol{p_0/(1-p_0)}} = \mathbf{e}^{-\beta} \qquad \textbf{(2.3)}$$

An OR bigger than 1 represents the addition in risk of occurring variables of minor order of the dependent variable compared with the risk of occurring variables of upper order. That previous comparison is related to variations in the classes of the independent variable in relation to the reference class in that variable.

An OR smaller than 1 represents the reduction of the risk of occurring variables of minor order of the dependent variable compared with the risk of occurring variables of upper order. That previous comparison is related to variations in the classes of the independent variable in relation to the reference class in that variable.

The OR of the reference class in an independent variable is equal to 1. If an OR is equal to 1 then there is the same risk of occurring variables of minor order of the dependent variable compared with the risk of occurring variables of upper order.

The OR has a minimum value of 0 but there is no maximum value.

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).

2.2.3 Results

The following analysis was made with the software IBM Statistics SPSS 22 and the main results for PTW accidents are presented in Table A.3 of the Appendix A. With the values from that table it is possible to determine the odds ratios. The values of odds ratio (OR) represents the increase (OR > 1) or decrease (OR < 1) in the odds between the classes of each variable. The lower bound (LB) and the upper bound (UP) are the limits of a confidence interval of 95% (CI95%) for rejecting the null hypothesis in the significance test. All the final calculations for PTW accidents are presented next. In the analysis there were 66.4% of cells with zero frequencies that is dependent levels without combination to predictors variables values. The same analysis was done just for motorcycle accidents and for this case the Table A.4 from Appendix A presents all the final calculations.

2.2.4 Discussion

The necessary results to take some conclusions about the risk factor that influence the increase of the severity of the injuries in PTW occupants when involved in accidents are presented below. All the odd ratios, confidence intervals of 95% and the p-values for each class of the data set are presented.

In Table 2.11 can be seen all the results related to vehicle factors.

Table 2.11 – PTW results for vehicle factors.

Variables	Classes	OR	Confidence interval of 95%	P-value
PTW category	Moped	0,684	0,750 - 0,624	,000
	Motorcycle (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)			

With regards to the PTW category the results indicate that when a moped is involved in the accident instead of a motorcycle, there is a 31.61% decrease in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver. Motorcycles can achieve higher speeds than mopeds. Hassan and Abdel-Aty (2013) and Ahmed et al (2012) concluded that speed variations affect the injuries in PTW accidents. What is more, it was determined in the descriptive statistic that the severity index is higher in motorcycle accidents than moped accidents.

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% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when compared to a car involved in the accident. An important result is that when is no other vehicle involved in the accident besides the PTW and comparing to PTW accidents with cars involved, there is an increase 56.54% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver. This way there are higher probabilities of having more severe injuries when the PTW is the only vehicle involved in the accident. This result can be related to a previous one when was concluded that single vehicle accidents was the type of accident with the highest probabilities of having more severe injuries.

When another vehicle is involved in the accident besides the PTW, there is an increase of the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when the driver of the other vehicle ends injured, compared to when the driver of the other vehicle ends unharmed.

In Table 2.12 can be seen all the results related to the accident type.

Table 2.12 - PTW results for accident type.

Variables	Classes	OR	Confidence interval of 95%	P-value
Accident type	Run over pedestrians	0,859	1,235 - 0,597	,411
	Collision	0,917	1,133 - 0,741	,421
	Single vehicle accident (Reference)			

Collisions and run over pedestrians have the lowest probabilities of more severe injuries compared with single vehicle accidents for the case of PTW accidents or just motorcycle accidents. This way, when the PTW accident does not involve other vehicles there are higher chances of severe injuries. If only the descriptive statistic was realized the conclusion would be that for motorcycle accidents the severity index is higher for run over of pedestrians. In the case of moped accidents the descriptive statistic concluded that the highest severity indexes are in collisions as in single vehicle accidents. However, the ordered logistic regression concluded that the risk factor is associated to single vehicle accidents.

In Table 2.13 can be seen all the results related to environmental factors and geographic distribution.

Table 2.13 - PTW results for environmental factors and geographic distribution.

Variables	Classes	OR	Confidence interval of 95%	P-value
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			
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)			
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)			

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. All the other months have higher odds when compared with the summer months. In fact, the period between September and February has the higher chances of severe injuries when a PTW accident happens. This result is opposite to the one determined by Bernardo (2012). This way the good weather in hot days in the summer, that can be connected to more people driving his PTW, is not related to the increase in the severity of the injuries. In the summer months there are actually more PTW accidents but the severity of them are lower comparing with the other months of the year.

Despite the lower odds for the summer months, when considering the weather conditions, the results indicate that when there is bad weather there is a decrease of 10.54% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when compared with good weather conditions. In Portugal, the winter months do not have to be directly related to bad weather conditions. With the descriptive statistic nothing was concluded analyzing the weather conditions as the severity indexes varied a lot between 2010 and 2015.

Good weather conditions are related to the grip of the road. Actually when comparing other road conditions with when the road is clean and dry, there is a decrease of 19.70% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver. This way, the severity of the injuries is highest for good weather conditions and for dry and clean roads. This odd sustain the previous result that good weather conditions are associated to higher severity indexes.

When the accident happens in a rest day, there is a decrease of 19.53% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver when compared with work days. This result is once again the opposite of the one determined by Bernardo (2012) and is opposite to the one discussed in the descriptive statistic.

Regarding 3 periods for a month, the period between the first and the eleventh day of the month has the highest chances of higher levels of the injuries severity in the PTW driver. This result can be related to salary pay day as people have more money in the beginning of the month and this way drive more often a PTW.

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% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver for the period between midnight and 5h. In fact, the period between 20h and 5h has the higher chances of severe injuries when a PTW accident happens. In the descriptive statistic it was concluded that most of the accidents happen 8h with the peak at 19h (when people are leaving work) but the highest severity indexes were concentrated in the dawn.

Regarding the different administrative regions of Portugal, it was found that there are fewer chances of severe injuries in the more populated regions with the biggest cities, Lisboa and Porto, than in the less populated regions. With the descriptive analysis it was difficult to conclude a region or a group of regions where the severity of the injuries would increase however with this new analysis the gropu of Braga and Viana do Castelo reaveled to have a 237.57% increase in the odds of giving response that indicates higher levels of the injuries severity in the PTW driver when compared to accidents occurring in Lisboa.

With regard to location of the accident, inside or outside of an urban area, the results indicate that when the accident occurs inside the urban area there is a 24.82% decrease in the odds of giving response that indicates higher levels of the injuries severity in the PTW driver when compared to accidents occurring inside the urban area. In this case there is a risk associated to accidents occurred outside a urban area and the same conclusion was taken in the descriptive statistic as the severity indexes were higher for PTW accidents outside urban area.

Road type is the only class where there are variations in results of PTW accidents or just motorcycle accidents. In respect to PTW accidents, all the road types have higher chances of higher injuries severity but national road are the ones with the highest chance, which is 67.97% more than compared with streets. In the case of motorcycle accidents the risk factor is associated to highways and freeways with an increase in the odds of having more severe injuries of 70.58% compared with accidents occurred in streets. On the other hand, the increase of the odds of accidents that happen in national roads is high to with a value of 68.65%. This way, for the general case of PTW, the risk factor is associated to national roads, highways and freeways.

Still related to the roads, 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.

In Table 2.14 can be seen all the results related to human factors.

Table 2.14 - PTW results for human factors.

Variables	Classes	OR	Confidence interval of 95%	P-value
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)			

Older people were found to be related to higher chances of having more severe injuries when involved in a PTW accident. Ferreira et al. (2017) and Carter et al. (2014) determined the same pattern. This conclusion can be related to older people being more fragile. Regarding the descriptive statistic it was expected that the risk group in motorcycle accidents would be in younger ages, 24 to 40 years old, as they have higher severity indexes. However, the group from 22 to 29 years old presented an increase in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver of 9.40% when compared to the group of 18 to 21 years old and this way there is actually a risk associated to younger ages. Larger than the 9.40%, ages superior to 76 years old presented an increase in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver of 25.44%.

With regards to gender of the PTW driver, in comparison to males, the results shows that there is a 51.01% % decrease in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver. This result is coherent with the results from other authors, for example Crundall et al. (2011) and Shankar and Varghese (2006).

Comparing with regular driving, overtaking presents an increase of 16.98% in the odds of giving a response that indicates higher levels of the injuries severity in the PTW driver. Overtaking is the action of a PTW driver with highest chance of more severe injuries.

The importance of the helmet was referred in the literature review and tis quite clear its advantages. The results indicate that when the PTW is not using a helmet there is an increase of 345.93% 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 the descriptive statistic the same result was achieved with higher severity indexes for PTW accidents were the driver was not wearing a 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 in the PTW driver. A BAC between 0.2 and 0.5 g/L represents the lowest increase of the odds and the highest odd is in BAC between 0.5 and 0.8 g/L. Right after this previous group there is a BAC between 0.8 g/L and 1.2 g/L. This way the highest risk of more severe injuries is associated to a BAC between 0.5 and 1.2 g/L. Ferreira et al. (2017) and Gómez-Restrepo et al. (2014) also concluded that alcohol was found to have a fixed result increasing the probability of serious injuries.

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 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.

Taking this into account, a deeper research by engineers has a big importance in PTW road accidents. After the accident a reconstruction of it can be made in order to know what happened and to unravel the cause of the accident. On a different point, safety measures can be taken as a way to reduce the risk of injuries or fatalities.

3.1 Methodology Applied in PTW Accident Reconstruction

In deep investigation of PTW accidents the MAIDS methodology (ACEM, 2003) is 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, as shown in the block diagram in Figure 3.1.

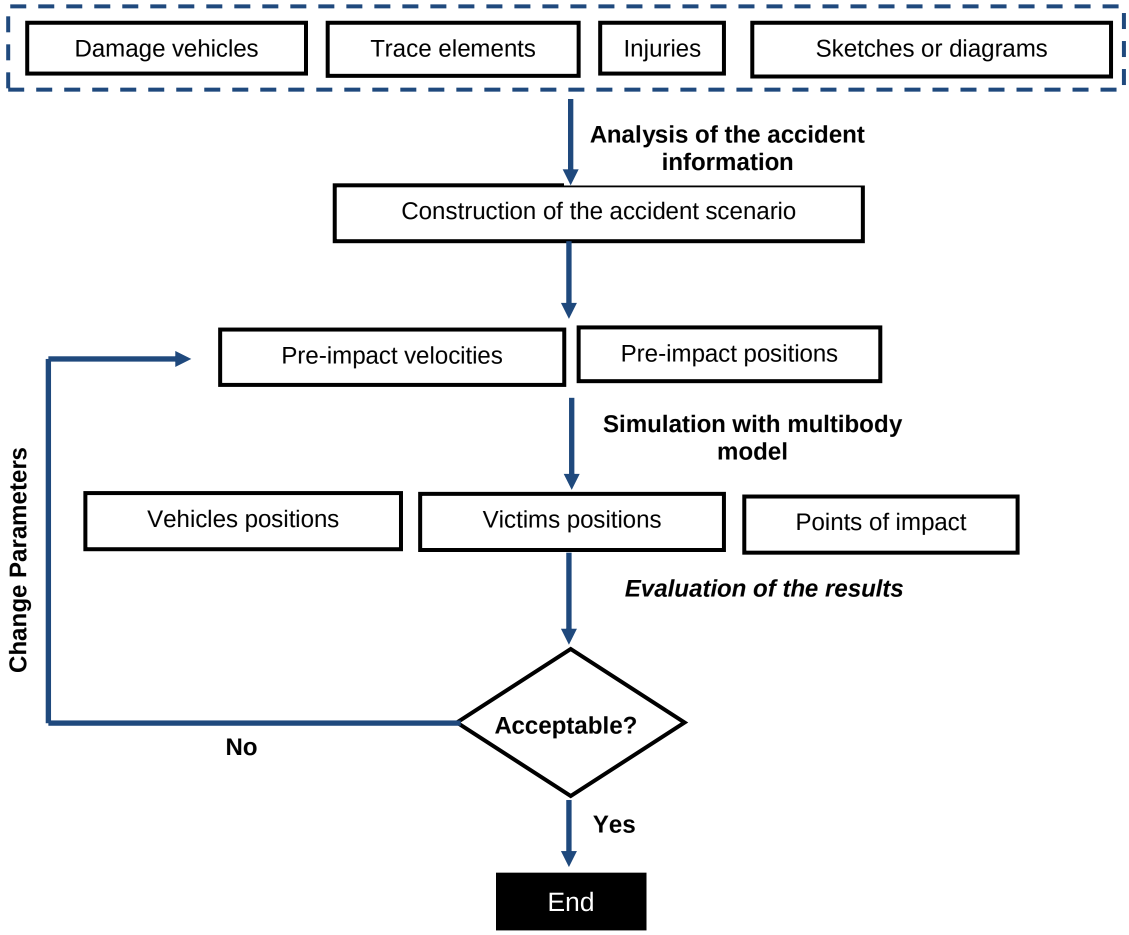


Figure 3.1 – Block diagram of the stages applied in accident reconstruction.

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.

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 among others. 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.

PTW accident reconstruction is pretty complex due to the geometry of the motorcycle and the motorcyclist as their movement after impact can suffer big changes for a small variation of the initial conditions, such as the point of impact, conact plane, restitution coefficient and velocities of the vehicles. As the projection of the motorcyclist is usual, biomechanical models are important to understand how the accident happens.

3.2 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. However, in some cases, more than one road surface is present in the environment of the accident and so special attention needs to be taken.

Moreover, when dealing with PTW accidents, two additional friction coefficients are involved: the one between a motorcyclist and the road surface and the one between a motorcycle and the road surface. The setbacks with the determination of these coefficients are the number of variables that can change and the effect on the value of the coefficient. In order to estimate acceptable values for the accident reconstructions a literature review was done.

3.2.1 Coefficient of Friction between the Road Surface and the Vehicles

The investigation on coefficients of friction in traffic accident reconstruction done by Fricke and Baker (1990) will be summarized below.

For the determination of the initial velocity of a vehicle after the deceleration phase data regarding distance that the vehicle decelerates, the vehicle's deceleration and the final velocity of the vehicle when it stops is needed. Normally, in accident reconstruction, the final position of the vehicle is known and its velocity is zero as it is stopped. However the deceleration of the vehicle needs to be determined, which can be achieved with the drag factor and the coefficient of friction. The drag factor is related to the reduction of speed of the whole vehicle and the coefficient of friction is related to the slowing force at the tire-road interface. Drag factor and coefficient of friction are usually similar for four-tired vehicles, however, in the case of motorcycles, that is not always true as motorcycles can only brake with the rear wheel, as the front wheel is rotating and not sliding, and this way the drag factor is going to be lower than the coefficient of friction.

The resistance to motion between two surfaces can be seen as friction but a more precise definition of the coefficient of friction says that it is the ratio of the tangential force (parallel to the surface) applied to an object sliding across a surface to the normal force (perpendicular to the surface). Figure 3.2 shows a typical diagram of the forces involved in the object sliding on a surface.

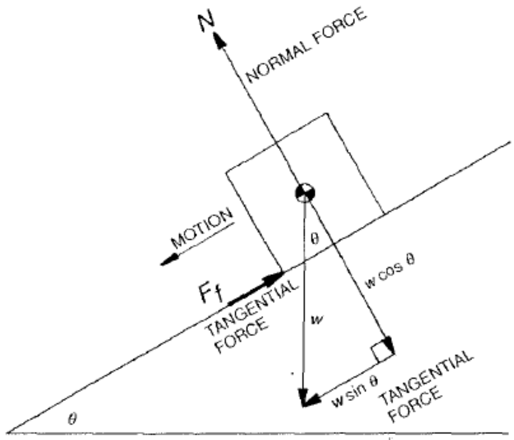


Figure 3.2 - Object sliding on a surface.

In accident reconstruction, three types of friction are considered: static friction, when the sliding is about to start and more force is required for the movement, dynamic friction, when the object is already sliding and so the force is less than the previous one, and rolling friction, which refers to the resisting forces of a vehicle that rolls without braking. Lower speeds are associated with higher coefficients of frictions. Values higher than 0.90 and up to 1.20 are rarely experienced and with these values the tire suffers a great deal of abrasion.

Table 3.1 and

Table 3.2 are presented in Fricke and Baker (1990).

Table 3.1 - Typical values of friction coefficients for various roadway surfaces.

DESCRIPTION OF ROAD SURFACE	DRY				WET			
	Less than 48 Km/h		More than 48 Km/h		Less than 48 Km/h		More than 48 Km/h	
	From	To	From	To	From	To	From	To
PORTLAND CEMENT								
New, Sharp	0,80	1,20	0,70	1,00	0,50	0,80	0,40	0,75
Traveled	0,60	0,80	0,60	0,75	0,45	0,70	0,45	0,65
Traffic Polished	0,55	0,75	0,50	0,65	0,45	0,65	0,45	0,60
ASPHALT or TARMAC								
New, Sharp	0,80	1,20	0,65	1,00	0,50	0,80	0,45	0,75
Traveled	0,60	0,80	0,55	0,70	0,45	0,70	0,40	0,65
Traffic Polished	0,55	0,75	0,45	0,65	0,45	0,65	0,40	0,60
Excess Tarmac	0,50	0,60	0,35	0,60	0,30	0,60	0,25	0,55
GRAVEL								
Packed, Oiled	0,55	0,85	0,50	0,80	0,40	0,80	0,40	0,60
Loose	0,40	0,70	0,40	0,70	0,45	0,75	0,45	0,75
CINDERS								
Packed	0,50	0,70	0,50	0,70	0,65	0,75	0,65	0,75
ROCK								
Crushed	0,55	0,75	0,55	0,75	0,55	0,75	0,55	0,75
ICE								
Smooth	0,10	0,25	0,07	0,20	0,05	0,10	0,05	0,10
SNOW								
Packed	0,30	0,55	0,35	0,55	0,30	0,60	0,30	0,60
Loose	0,10	0,25	0,10	0,20	0,30	0,60	0,30	0,60

Table 3.2 - Values of friction coefficients for various roadway surfaces for Automobile and truck tires.

Description of road surface	Automobile tire	Truck tire
Dry concrete	0,85	0,65
Dry asphalt	0,80	0,60
Wet concrete	0,70 - 0,80	0,50
Wet asphalt	0,45 - 0,80	0,30
Packed snow	0,15	0,15
Ice	0,05	0,11 (dry)
		0,07 (wet)
Dry dirt	0,65	
Mud	0,40 - 0,50	
Gravel or sand	0,55	
Wet, olly, mooth concrete		0,25
Hard-packed snow with chains		0,60
Dry ice with chains		0,25

3.2.1.1 Flat Tire or Under Inflated Tire Effect in the Coefficient of Friction

An impact between two or more vehicles results in damage in all of them and a tire can blow. This can change the friction coefficient between the car and the road surface. Even if a tire does not blow after the impact, the pressure of the tire could drop below normal which will also influence the value of the coefficient of friction.

Warner et al. (1983) published empirical values for a correction factor for the adhesion coefficient due to rolling resistance. For a normal inflation of the tire, partial inflation and flat tire, this coefficient would change.

In the literature only one experimental study was found on this subject. Grover et al. (2007) investigated the effects that tire type, surface condition, inflation pressure and speed have on the friction between the road surface and the tire. Normal inflation with variation of approximately 30% were experienced for normal tires, low profile tires and run flat tires for wet and dry surfaces. Despite the tests realized and the results obtained in these experiments, a general conclusion cannot be taken on the variations that should be done on the coefficient of friction. What is more, the results of this study are not appropriated when only a tire is under inflated or flat.

3.2.2 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 occupants. This way an important parameter to know is the coefficient of friction between a motorcyclist and the road surface (μ). Several authors studied this matter in pedestrian thrown across the road so some studies will be analyzed in order to estimate a value of this coefficient of friction.

In Figure 3.3 (Wicher, 2016) it is represented the three different phases involved in the pedestrian throw: impact, flight and movement on the road surface. Only the last phase is going to be taken into account because it is in this part of the trajectory that the pedestrian is in contact with the ground. The coefficient of friction between the pedestrian's clothes and the road surface is really difficult to estimate but this parameter is fundamental for the reconstruction of a vehicle/pedestrian collision accident.

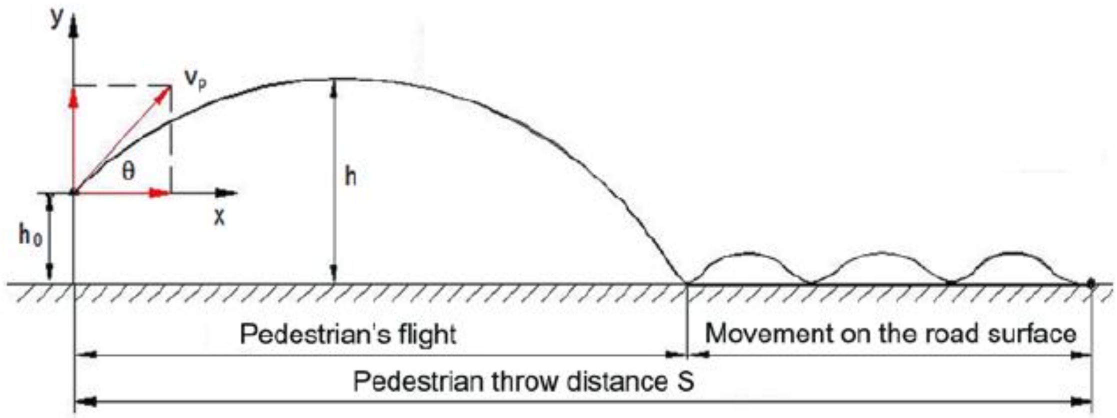


Figure 3.3 - Schematic diagram of the pedestrian throw process.

The calculation of a correct coefficient of friction between the pedestrian and the ground is based on the movement of the pedestrian on the road surface which can be sliding, tumbling or even both. Sliding is when the body is moving in constant contact with the ground. Tumbling can occur when after the first contact of the body with the ground it is tossed to the air in some short phases.

In Wicher (2016) is presented a range of $0.1 \leq \mu \leq 1.2$ in relation to pedestrian launch velocity and the coefficient of friction for 4 different mathematical models from different sources. With a sensitivity function, Wicher concluded that the effect of the coefficient of friction on pedestrian launch velocity is lower by almost a half in the interval $0.5 \leq \mu \leq 1.2$ that within the interval of $0.1 \leq \mu \leq 0.5$. This result can only be applied to the mathematical models described by Searl, J.A; Searl, A (1983), Searl, J. (1993), Aronberg, R. (1990) and Wood, D. P. (1991).

A wide range of values for the coefficient of friction can be found in different sources throughout the literature. These values were used to build Table 3.3 (based on Wicher (2016)). Looking at the table it is easy to see that the divergence between the values obtained by the different authors making it a more of a challenge to pick one of them.

In Cheng et al. (2015) real accidents with pedestrian were analyzed, aided by images recorded by CCTV cameras and car cameras. Wood et al. (2000), Toor and Aeaszewski (2003) and Searl (1993) equations were used to define the wrap trajectories, though correction of the coefficient of friction was needed in some cases in order to obtain better results. This explains the range of values for this coefficient. As the coefficient of friction depends on several factors and different authors use different factors, an average value from all the previous result is going to be used. This way it is going to be considered a value of 0.64 for the coefficient of friction between a motorcyclist and the road surface (μ=0.64) as a standard value. This value can be adjusted looking at Table 3.3 when information about the clothes is given or when analyzing the injuries report it is possible to know the type of movement that the body had after the impact.

Table 3.3 - Values of the coefficient of friction between the pedestrian and the road surface.

Coefficient of friction	Road surface / pedestrian's clothing	Source
0.40-0.75	?	Severy, D. (1966)
0.51-0.61	Dry road surface	Rychter, W. (1973)
0.52-0.59	Dry road surface	Rychter, W. (1973)
0.52-0.67	?	Kuhnel (1974)
0.61-1.02	?	Löhle, U. (1975)
0.4-0.74	?	Sturtz (1976)
1.1	?	Collins, J. C.; Morris, J. L. (1979)
0.37-0.51	?	Lucchini (1980)
0.66	Dry and wet asphalt	Searle, J.; Searle, A. (1983)
0.79	Grass	Searle, J.; Searle, A. (1983)
0.391 - 0.570	?	Searle (1993)
0.61-0.71	Dry road surface	Becke, M.; Golder, U. (1986)
0.46-0.56	Wet road surface	Becke, M.; Golder, U. (1986)
0.6	?	Batista, M. (2008)
0.45-1.2	?	Rotim, F. (1989)
0.80	Tumbling	Hill, G. S. (1994)
0.615 - 0.812	?	Hill, G. S. (1994)
0.641 - 0.868	?	Hill, G. S. (1994)
0.43-0.53	Wet surface	Becke and Golder (1988)
0.5-0.72	?	Becke and Golder (1988)
0.533 - 0.632	?	Bovington (1999)
0.39-0.87	?	Wood, D.; Simms, C. (2000)
0.7-1.2	Dry asphalt, tumbling	Happer, A. et al, (2000)
0.45-0.72	Dry asphalt, sliding	Happer, A. et al, (2000)
0.37-0.75	Dry and wet asphalt	Happer, A. et al, (2000)
0.59-0.85	Asphalt with anti-slip surface coating / pedestrian wearing normal clothing	Hague, D. J. (2001)
0.54-0.65	Asphalt with anti-slip surface coating / pedestrian wearing normal clothing	Hague, D. J. (2001)
0.74	?	Han, I.; Brach, R. M. (2001)
0.73-0.78	Different types of pedestrian's clothing (except nylon)	Han, I.; Brach, R. M. (2001)
0.61	Nylon clothing	Han, I.; Brach, R. M. (2001)
0.31-0.41	Wet asphalt	Fugger, T. F. J. et al. (2002)
0.5 - 0.7	?	Yang (2002)
0.45-0.55	?	Toor, A.; Araszewski, M. (2003)
0.13-0.76	?	Batista, M. (2008)

3.2.3 Coefficient of Friction between a Sliding Motorcycle and the Road Surface

Cialdai et al. (2017) studied the situation when a PTW falls over to the side and then slides. According to Wood et al. (2009) there are three phases associated to a motorcycle falling to the ground: loss of control, impact with the ground and finally, stabilized sliding. To estimate 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.

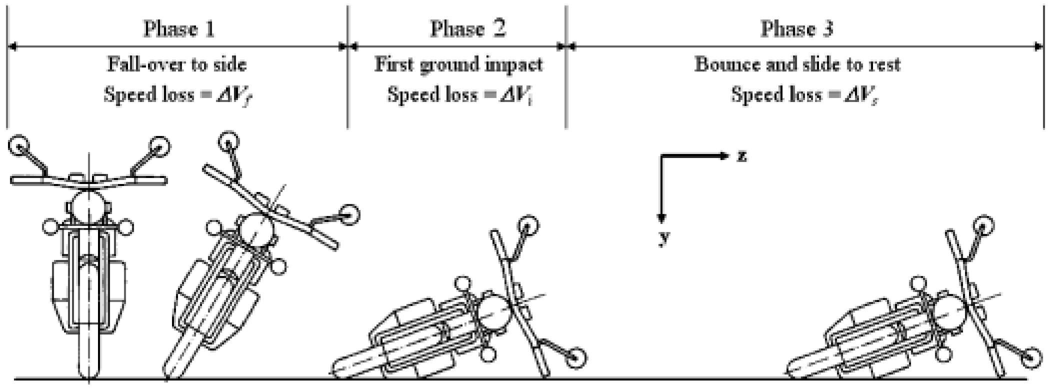


Figure 3.4 - Three main phases of the motorcycle fall-over (Wood et al., 2009).

For this final phase, stabilized sliding, Wood et al. (2009) equation considers the impact of the motorcycle with the ground and defines the coefficient of retardation of the stabilized sliding (μ). Cialdai et al. (2017) also considers for the Wood equation a deceleration rate of the entire phase of impact with the ground and sliding (μ_{app}) and it was concluded with this study that for sliding distances longer than 5 meters and independent of the road surface, the average value between the two deceleration coefficients was less than 0.1. Through tests, Lambourn (1991) determined a difference of 0.05 between the two coefficients for sliding distances greater than 10 meters. This way there is a larger variation in the coefficient of friction of the two previous phases for shorter slides than longer slides.

Cialdai et al. (2017) also studied the influence of the fairing in motorcycles. This effect is independent of the road surface type but the coefficient of friction should be bigger for unfaired motorcycles as there capability of sliding is lower. The deceleration rate experiences a minimal influence for different masses of motorcycles.

The different sources, which can be found in the literature, show a wide range of coefficients of friction. Table 3.4 shows in a chronological order values determined by some authors, in most cases for standard motorcycles. 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.

Table 3.4 - Values of the coefficient of friction between a motorcycle and the road surface.

Coefficient of friction μ	Sliding conditions	Source
0,55 - 0,7	Motorcycles not equipped with crash bars	Collins, J. C. (1979)
0,55 - 0,7		Warner, Charlos Y.; Gregory C.; Jamesm Michael B.; Germane, Geoff J. (1983)
0,35 - 0,50	Motorcycle sliding on dry asphalt	Searle, J.; Searle, A. (1983)
0,30 - 0,10	Motorcycle sliding on wet asphalt	
0,48 - 0,74	Average of 0,66 on experimental tests	Shumborski, W.A., et al. (1984)
0,38 - 0,55	No difference in drag noted for wet roadways	Lynch, George F. (1984)
0,45 - 0,58	Asphalt	Day, Terry D. and Smith, Jay R. (1984)
0,68 - 0,9	Gravel or sodded earth	
0,43 - 0,70		
0,45 - 0,71	Asphalt or cement	
0,78 -1,07	Gravel	
0,2 - 0,6	On pavement (0,2 for motorcycle with crash bars or with fluids from the motorcycle lubricating the surface. Higher values for deeper scratches)	Daily, John. (1988)
0,7 - 1,2	0,7 for harder soil and 0,9 - 1,2 for soft soil or sand	
0,23 - 0,66	The methods ranged from low speed drag tests to drop tests at speed up to 59 miles per hour.	Lambourn, R.F. and Ashton (1989)
0,45 - 0,75	Asphalt or concrete surfaces	Fricke, Lynn B. (1991)
0,65 - 1,05	Gravel surfaces	
0,38 - 0,50		Donohow, M.D. (1991)
0,53 - 0,71		Scott, John C. (1994)
0,55 -0,75		Craig, Victor. (1995)
0,26	Average of 0,26 on a fairing equipped motorcycle	Raftery, Barry. (1995)
0,29 - 0,45		Medwell, Christopher J.; McCarthy, Joseph R.; Shanahan, Michael T. (1997)
0,49 - 0,62		Baxter, Albert, T. (1997)
0,3 - 0,4	With fairing on pavement	Limpert, Rudolf. (1999)
0,35 - 0,5	Without fairing on pavement	
0,9 - 1,1	Grass	

All the previous studies and the studies present in Table 3.4 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, obtained from video data. 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.

When applying a coefficient of friction between a sliding motorcycle and the roadway in an accident reconstruction some considerations should be taken into account according to the manner in which the motorcycle travelled across the roadway and the degree of scraping or gouging that occurred during the slide. Higher coefficients of friction are related to greater degrees of scraping or gouging on the roadway (McNally, 2006).

3.2.4 Discussion

Experiments should be done to determine the effect of an under inflated or flat tire on the friction coefficient in accident reconstruction. As in accident reconstruction, the friction coefficient between the road surface and all the tires of a vehicle is introduced, a proportion for the brake factor of the four wheels, in case of a flat tire or under inflated, should be studied.

Depending on the motorcyclists clothes and the road surface the coefficient of friction between the motorcyclist and the ground can be estimated. However, after the phase of flight, the motorcyclist can be sliding, tumbling or both when moving on the road surface and this creates a range of values for the coefficient of friction. A value of 0.64 is going to be used as it represents an average of the values determined by several authors and so several parameters are taken into account but this values can be adjusted when additional information about the clothe of the motorcycle driver and his injuries are known.

When dealing with motorcycle sliding on the road surface it is not advisable to do the average between all the values found. Depending on the motorcycle type, the surface and the sliding distance the coefficient of friction should be adjusted. The damage of the motorcycle can be used to adjust this parameter too. A range from 0.2 to 1.1 was determined for the coefficient of friction between a motorcycle and the road surface and the value to use in a specific case can be seen in the table presented and then adjusted taking into account the parameters that can have influence in the coefficient of friction.

3.3 Multibody Helmet for Accident Reconstruction

The helmet takes an important role in the injuries of a PTW driver in case of accidents. Paulino (2008) studied the importance of the helmet and in what aspects could be improved the efficiency of the helmet. To do that he developed a 3D model of a helmet and performed crash tests in the software *Madymo*. The critical zones of the helmet are the back part followed by the laterals (Paulino, 2008).

Taking into account the importance of the helmet in its user it should also be used in accident reconstructions. This way, a multibody model of a helmet is going to be created.

3.3.1 Multibody Dynamics

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 3.5. Kinematics describes the absolute motion of mechanical systems, namely position, velocity and acceleration.

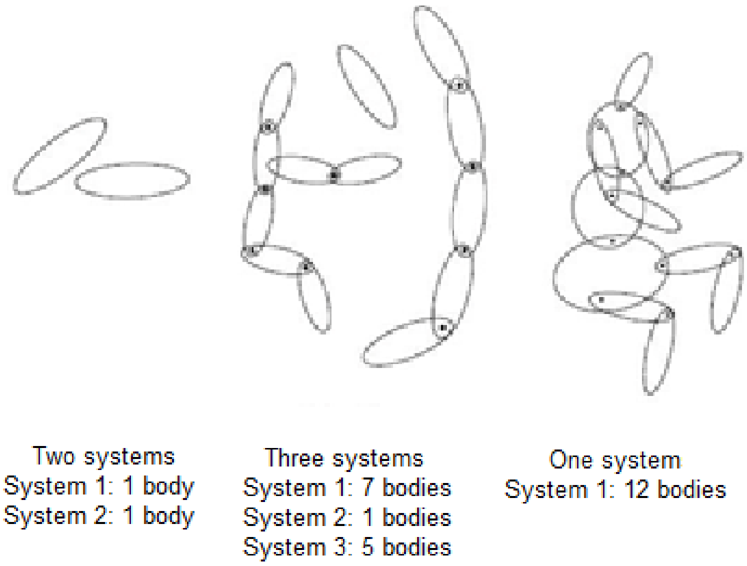


Figure 3.5 - Multibody systems (Nikravesh, 1988).

The degrees of freedom (number of independent motions that are allowed to the body) of a multibody are defined by the joint type. According to the multibody principle, each body or mass point is treated separately. Each body needs to be defined by its mass, center of mass and by its moments and products of inertia. For the equations of motion the body shape is not relevant as it only matters when there is contact between two bodies.

To locate a multibody system in space it is needed to control the body position and that is possible because each body is associated with a local Cartesian (moving or body-fixed) coordinate system with respect to a global (non-moving or inertial) coordinate system, XYZ. This way Euler parameters are expressed by two vectors, r_i (equation (3.1) and p_i (equation (3.2), that give the location and orientation of the system.

$$r_i = [x \quad y \quad z]_i^T \tag{3.1}$$

$$p_i = [e_0 \quad e_1 \quad e_2 \quad e_3]_i^T \tag{3.2}$$

To a rigid body *i*, that makes part of a system, is associated the coordinate vector of equation (3.3):

$$\{q\}_i = [\{r\}_i, \{p\}_i]^T = [x, \; y, \; z, \; e_0, \; e_1, \; e_2, \; e_3]^T \tag{3.3}$$

To locate a point P in a rigid body *i* it is effectuated the sum between the vector of location of point P in the local coordinate system, $\xi_i \eta_i \zeta_i$, and the vector that locates the local coordinate system in the global coordinate system, XYZ. Figure 3.6 represents the position of a point P in a global coordinate system.

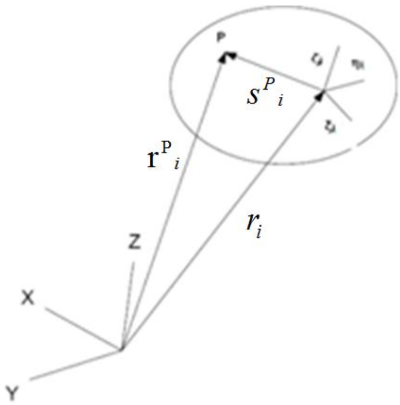


Figure 3.6 - Position of a point P in the inertial frame (Nikravesh, 1988).

This way the position of the point P is represented by the equation (3.4):

$$r^P{}_i = r_i + s^P{}_i \tag{3.4}$$

The previous equation can be written in a matrix form (equation (3.5)):

$$[r^P]_i = \{r\}_i + [A]_i \{s^P\}_i \tag{3.5}$$

The transformation matrix [A] in terms of Euler parameter is represented in equation (3.6). It describes the orientation between the local and the global coordinate systems.

$$[A] = \begin{bmatrix} 2(e_0^2 + e_1^2) - 1 & 2(e_1 e_2 - e_0 e_3) & 2(e_1 e_3 + e_0 e_2) \\ 2(e_1 e_2 - e_0 e_3) & 2(e_0^2 + e_2^2) - 1 & 2(e_2 e_3 + e_0 e_1) \\ 2(e_1 e_3 + e_0 e_2) & 2(e_2 e_3 + e_0 e_1) & 2(e_0^2 + e_3^2) - 1 \end{bmatrix} \tag{3.6}$$

To determine the velocity and the acceleration of the point P, the first and second derivatives of the equation of position of this point P (equation (3.4) can be made up. This way equation (3.7) represents the velocity of the point P where ω_i is the angular velocity of the body *i* and equation (3.8) represents the acceleration of the point P.

$$\dot{r}^P = \dot{r} + \omega_i \times s^P{}_i \tag{3.7}$$

$$\ddot{r}^P = \ddot{r}_i + \dot{\omega}_i \times s^P{}_i + \omega_i \times \left(\omega_i \times s^P{}_i\right) \tag{3.8}$$

A multibody system is said to be constrained if two or more bodies are connected by a joint. A kinematic constraint imposes restrictions on the relative movement between the bodies by means of reaction forces. The equation of motion for constraints multibody systems are represented in the matrix in the Equation (3.9) (Francisco, 2013).

$$\begin{bmatrix} \boldsymbol{M} & \boldsymbol{\Phi_q}^T \\ \boldsymbol{\Phi_q} & \boldsymbol{0} \end{bmatrix} \begin{bmatrix} \ddot{\boldsymbol{q}} \\ -\boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \boldsymbol{g} \\ \boldsymbol{\gamma} \end{bmatrix} \tag{3.9}$$

In the equation (3.9), $\boldsymbol{\Phi_q}$ is the Jacobian matrix of the kinematic constraints, M is the mass matrix, $\ddot{\boldsymbol{q}}$ is the vector of accelerations, $\boldsymbol{\lambda}$ is the vector Lagrange multipliers, g is the generalized force vector and $\boldsymbol{\gamma}$ is the vector of acceleration independent terms.

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 presented before is explained in detail in Nikravesh (1988) and its implementation in the software *PC Crash* in the respective operating and technical manual (Datentechnik, 2016).

3.3.2 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 3.7 shows some examples of helmets that can be projected after a crash when the helmet buckle is not tight or breaks.

Figure 3.7 – 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 3.8 and Figure 3.9 illustrate the multibody helmet model created in the software *PC-Crash*.

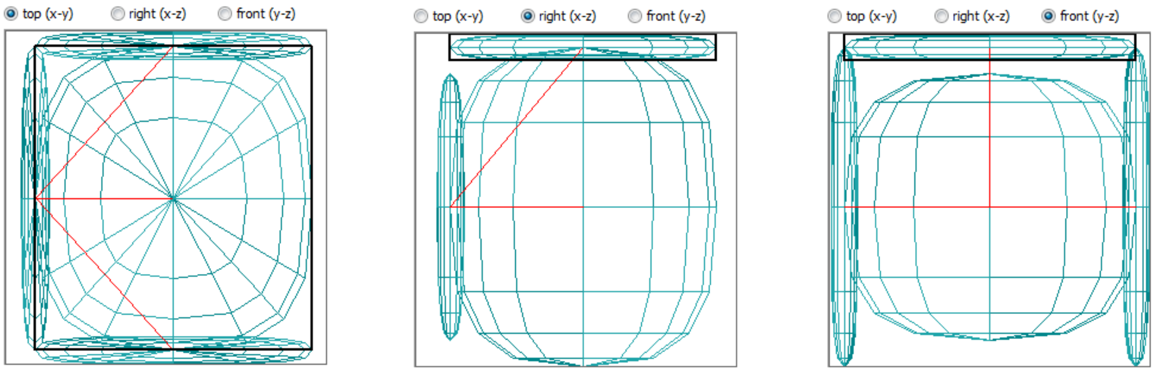


Figure 3.8 – Multibody helmet model (2D view).

Figure 3.9 - Multibody helmet model (3D view).

As a standard helmet of this type its weight is 2 Kg. The helmet dimensions are made to fit the head of the multibody model of the motorcyclist. The model of helmet represents the simplest helmet that can be modeled and this model was considered as it fulfills all the needs for this work as it is going to be used in a real accident that happened in Portugal. Research should be made to build other multibody models of helmets.

3.4 Energy Equivalent Speed, EES

In accident reconstruction 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, E_d, is expressed in terms of kinetic energy of a vehicle with a virtual velocity, EES, in a collision of a vehicle with a mass m with a rigid barrier as expressed in equation (3.10).

$$\boldsymbol{E_d = \frac{1}{2} \times m \times EES^2} \quad \textbf{(3.10)}$$

So, EES is a value of dissipated energy during a collision and its values can be found in data bases of crash tests.

In the software PC-Crash the EES's of the vehicles can be introduced for calculation of the deformation energy in the crash simulation. The total deformation energy is going to be distributed between the vehicles involved in the accident (Datentechnik, 2016).

3.5 Accident Reconstruction of Real PTW Accidents

Two real accidents occurred in Portugal in 2012 and 2013 are going to be analyzed next. The accident reconstruction was realized for both accidents in order to determine what caused the accidents and the responsible driver, among other subjects. For confidentiality issues, the identities of the vehicles as well of their drivers will not be revealed.

3.5.1 Lateral Collision of a Moped and a car with Helmet Projection

The accident that is going to be analyzed occurred in April at 10am in a regular intersection out of locality with the speed limit of 90 Km/h. A moped, Casal K181, collided in the lateral of a car, Mercedes-Benz E-Class, which caused the death of the moped driver. The local of the accident is represented in Figure 3.10 as well as the directions of travelling of each vehicle.

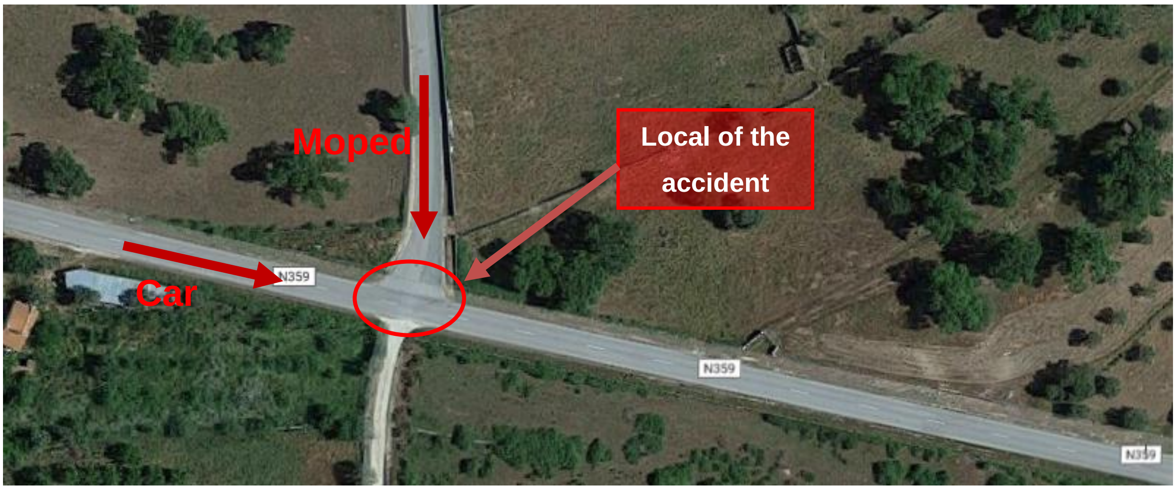


Figure 3.10 - Photography of the local of the accident with the directions of travelling of the vehicles involved.

3.5.1.1 Characteristics of the vehicles

Figure 3.11 represents an example of a moped Casal K181, vehicle nº1, with power under 50 cc, and an example of a Mercedes-Benz E-Class, vehicle nº2, involved in the accident. The main characteristics of each vehicle are described in Table 3.5.

a) **b)**

Figure 3.11 - Examples of the vehicle nº1 (a) and vehicle nº2 (b).

Table 3.5 – Characteristics of vehicle nº1 and vehicle nº2.

	Vehicle nº1	Vehicle nº2
Brand	Casal	Mercedes-Benz
Model	K181	E-Class
Year		2002
Massa (kg)	72	1650
Power (cc)	49	2200
Style	Moped	Car

3.5.1.2 Damage in the vehicles

Figure 3.12 allows to evaluate the damages in the moped after the crash. It can be seen that the damages in vehicle nº1 are concentrated almost exclusively in its right side as well as in its front side.

a) **b)**

Figure 3.12 - Moped photographies: a) general perspective of the damages, b) motor detail.

In Figure 3.13 it can be seen that after the crash the car showed damages in its front left and left sides. The headlight from the left is broken as well as the left mirror and glass of the passenger door.

a) **b)**

Figure 3.13 – Car photographies: a) general perspective of the damages, b) motor detail.

The main damages in both vehicles are compatible as the impact point is between the front of the moped and front left side of the car. After the crash, the moped rotated, damaging the car on its left side.

3.5.1.3 Human Factor

In Table 3.6 is shown the main characteristics of the drivers involved in the accident.

Table 3.6 - Drivers involved in the accident characteristics.

	Moped driver	**Car driver**
Age	77	70
Gender	Male	Male
Years of driving license	57	47
Legal to drive the vehicle	Yes	Yes
BAC (g/l)	0,00	0,00
Influence of drugs	Morphine (47 ng/mL)	No

The driver of the moped was wearing a helmet although it was projected after the crash as can be seen in Figure 3.14.

Figure 3.14 - Final position of the helmet after projection.

3.5.1.4 Environment Factors

The accident occurred in the morning with good weather. At this time of the day blindness due to the sun's position is possible. However, an application in the software PC-Crash allows to determine the exactly sun position in the local of the accident at that time and it was concluded that, for the direction of travelling of each vehicle, there was no chance of blindness due to the sun, Figure 3.15.

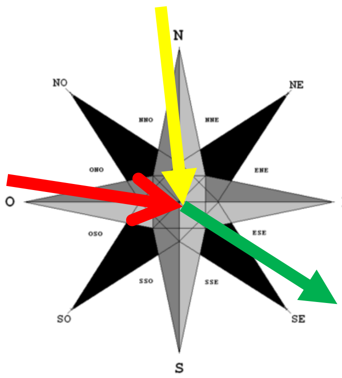


Figure 3.15 – Comparison between the sun's position (green arrow) and the direction of the vehicle nº1 (yellow arrow9 and vehicle nº2 (red arrow).

3.5.1.5 Dynamics of the accident

Through the compatibility of damages in the vehicles and witness testimonies, an initial hypothesis can be made: the moped did not stop in the intersection and crashed against the vehicle. The car was driving in the main road and the moped did not stop in the intersection and crashed with its front on the left front side of the car. The final positions of the vehicles, motorcyclist (blood in the pavement) and helmet are shown in the sketch made by the police in Figure 3.16 of the Appendix 1. According to the tire mark left by the car, it took it 52 meters to stop the vehicle after the crash.

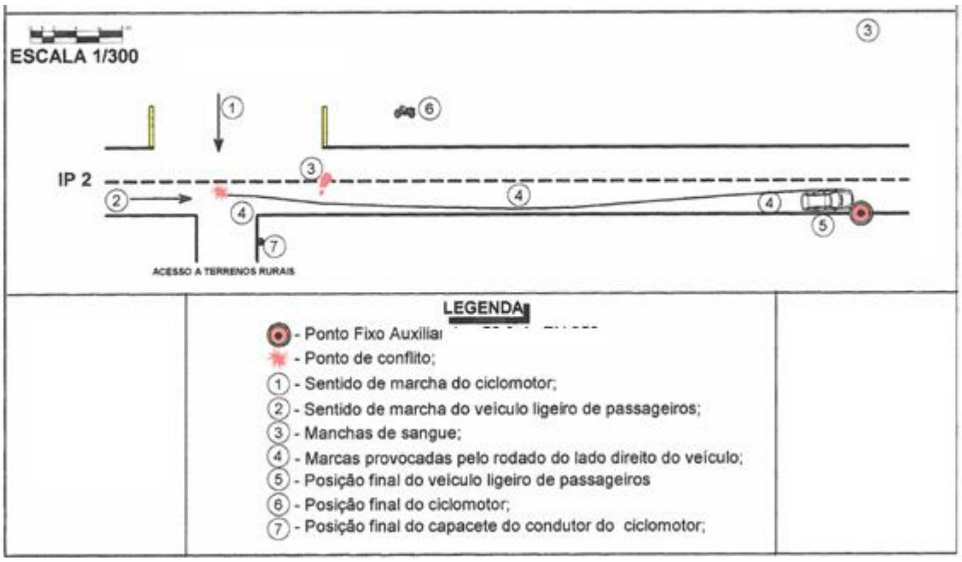


Figure 3.16 - Sketch of the accident made by the police, scale 1:300.

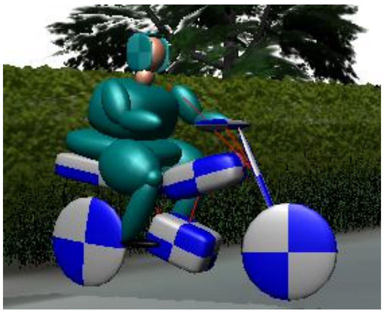
3.5.1.6 Computer Simulation

For the crash simulations it was considered a restitution of 0,1 for both vehicles (almost inelastic collision). For the moped it was considered a friction coefficient of 1,0 between the moped and the pavement justified by the short slide, absence of fairings and taking into account the ditch of the road. The coefficient of friction between the motorcyclist and the pavement used was the value estimated before, 0,64. As the asphalt was not in the best conditions a coefficient of friction of 0,7 was considered between the tires and the pavement. The human characteristics of the drivers of the vehicles introduced in the crash simulations are shown in Table 3.7.

Table 3.7 - Human characteristic of the drivers of the vehicles for the crash simulations.

	Moped driver	Car driver
Age (years)	77	70
Height (m)	1,58	
Weight (Kg)	100	80

In Figure 3.17 is represented the models of the vehicles used in the crash simulations.



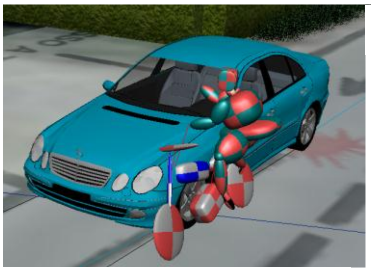
a)

b)

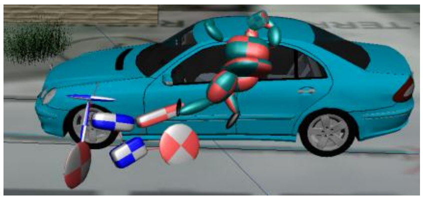
Figure 3.17 - a) multibody model of the moped and driver, b) model of the car used in accident reconstruction.

In Figure 3.18 are represented frames of the crash simulation where the correct final positions for the vehicles, motorcyclist body and helmet were obtained as well as a correct compatibility of the damages in the vehicles.

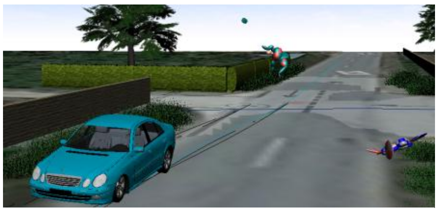
t = 0s – Point of impact



t = 0,054s – Rotation of the moped and motorcyclist

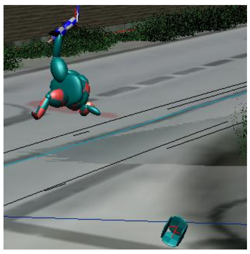


t = 0,103s – Helmet projection



t = 0,740s – Projection of the motorcyclist body and helmet and moped sliding

t = 1,346s – Motorcyclist body hits the floor



t = 1,730s – Helmet hits the floor.

Figure 3.18 – Frames of the crash simulation of the accident.

The final positions obtained with the crash simulation of both the vehicle, passenger car and motorcycle, the motorcyclist body and the helmet are visible in Figure 3.19.

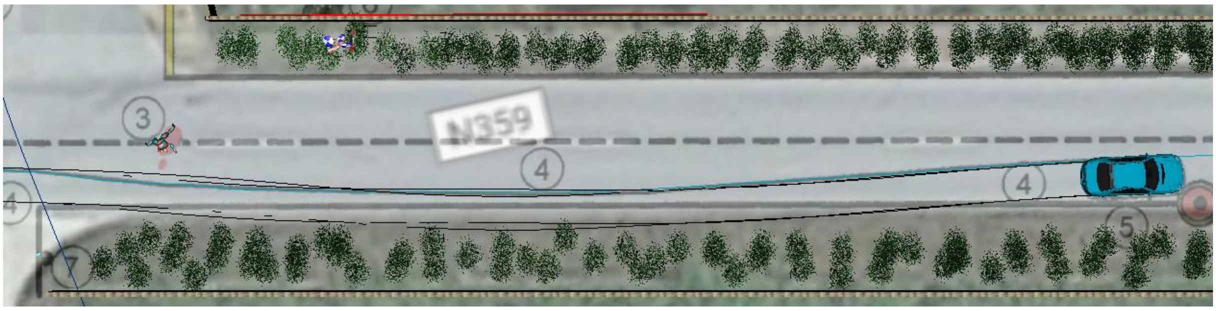


Figure 3.19 - Final positions of the vehicles, motorcyclist body and helmet (3.975s).

3.5.1.7 Discussion and conclusions

Analyzing all the data provided by the authorities and combining it with the crash simulation it can be concluded that the cause of this accident is related with human factors of both drivers.

The final positions of the vehicles, motorcyclist body and helmet are coincident with the ones that occurred in reality. The moped final position is not the same as in the sketch of the police due to its poor representation in comparison with the photos taken by the police after the accident. This way, the final position of the moped in the crash simulation is the same as the one in the photo taken by the police (Figure 3.20).

Figure 3.20 - Final position of the moped in a photo taken by the police after the accident.

The damage caused by the moped and the motorcyclist in the car are compatible with the ones from the photograph of the damaged vehicles after the accident.

In the crash simulation the moped has a velocity of 42 Km/h and the car a velocity of 99,5 Km/h. To stop after the crash, the car had its wheels fully locked and the right ones left the asphalt for a while and were in dirt with grass. If this second type of pavement was considered the velocity of the car would be reduced by 2 Km/h. This way, for both vehicles, it is going to be considered a margin of approximately 5 Km/h. As the speed limit was of 90 Km/h in that road, the car was travelling over the speed limit.

The moped had a relative position of 55^o relatively to the car in the crash simulation, considering the position of the car was 0^o 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 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 car driver, even if he was driving within the speed limit, as the erratic behavior of the moped driver was not possible to be foreseen, reducing significantly the reaction time of the car driver. This way the cause of the accident was the fact that the mopped did not stop in the intersection.

With the coefficients of friction that were determined with the literature review it was possible to achieve these results. As these results correspond to the solution of the problem the values used for the friction coefficient seem appropriated for the cause. As final position of the projected helmet was coincident with the registered position by the police and the other final positions were correct too, the multibody model of the helmet seems appropriated for the cause too.

3.5.2 Front Collision of a Moped and a car with a bus involved

The accident that is going to be analyzed occurred in April at 07.50am in a T intersection within a locality where the speed limit is 50 Km/h. A moped, Famel Zundapp z3, collided in the front of a car, BMW 316 E30, which caused the death of the moped driver. The car collided again with its rear against the front of a truck, a bus, Mercedes-Benz O345. The local of the accident is represented in Figure 3.21 as well as the directions of travelling of each vehicle.

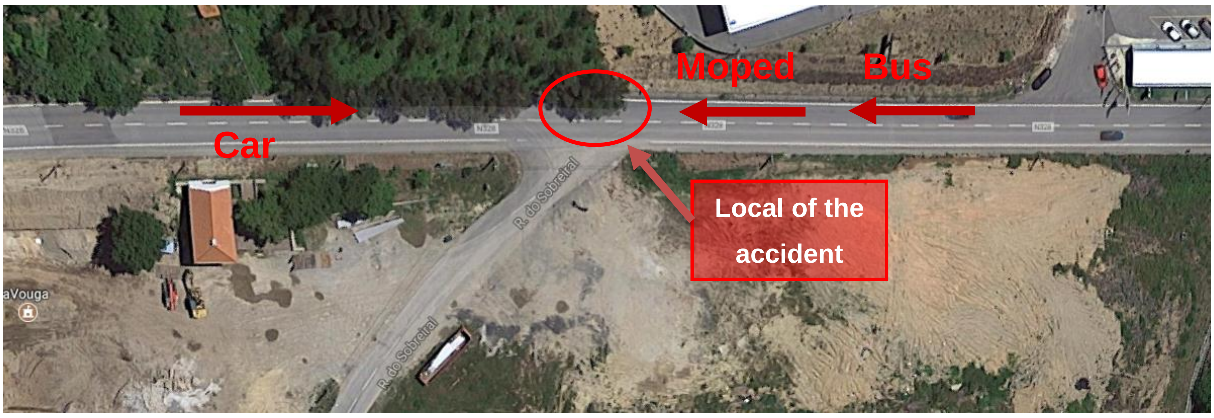


Figure 3.21 - Photography of the local of the accident with the directions of travelling of the vehicles involved.

3.5.2.1 Characteristics of the vehicles

Figure 3.22 represents examples of a moped Famel Zundapp z3, vehicle nº1, with power under 50 cc, a BMW 316 E30, vehicle nº2, and a Mercedes-Benz O345 involved in the accident. The main characteristics of each vehicle are described in Table 3.8.

a)

b)

c)

Figure 3.22 - Examples of the vehicle nº1 (a), vehicle nº2 (b) and vehicle nº3 (c).

Table 3.8 – Characteristics of vehicle nº1 vehicle nº2 and vehicle nº3.

	Vehicle nº1	Vehicle nº2	Vehicle nº3
Brand	Famel Zundapp	BMW	Mercedes-Benz
Model	Z3	316 E30	O 345
Year		1986	2008
Weight (kg)	80	1030	10780
Power (cc)	49	1573	11967
Style	Moped	Car	Truck (bus)

3.5.2.2 Damage in the vehicles

Figure 3.23 allows to evaluate the damages in the moped after the crash. It can be seen that the damages in vehicle nº1 are concentrated almost exclusively in its front.

a) **b)**

Figure 3.23 - Moped photographies: a) general perspective of the damages, b) rear.

In Figure 3.24 can be seen that after the first crash the car suffered damages in the right side of its front. A second impact occurred and that way the vehicle nº2 has damages in the left side of its rear.

a) **b)**

Figure 3.24 – Car photographies: a) front, b) rear.

Figure 3.25 shows the truck, vehicle nº3, and its damages concentrated in its left side of its front.

a) b)

Figure 3.25 – Truck, bus, photographies: a) front and left side, b) detail of the front damages.

The main damages in both vehicles are compatible as the first impact point is between the front of the moped and front left right of the car. After the crash the car lost control and rotated. With this rotation the vehicle nº3 collided with its left rear side in the front left side of the truck.

3.5.2.3 Human Factor

In Table 3.9 is shown the main characteristics of the drivers involved in the accident.

Table 3.9 - Drivers involved in the accident characteristics.

	Moped driver	**Car driver**	**Truck driver**
Age	54	31	45
Gender	Male	Male	Male
Years of driving license	19	11	23
Legal to drive the vehicle	Yes	Yes	Yes
BAC (g/l)	0,00	0,00	0,00
Influence of drugs	No	No	No

3.5.2.4 Natural Factor

The accident occurred in the morning of a work day with good weather. From the police report can be inferred that the visibility conditions were good in the day of the accident.

3.5.2.5 Dynamics of the accident

Through the compatibility of damages in the vehicles and witness testimonies two hypothesis can be discussed: either the moped did not stop in the intersection and crashed in the car or the car was speeding. The final positions of the vehicles and motorcyclist are shown in the sketch made by the police in Figure 3.26. According to the tire marks left by the car, it breaks before the first impact and its rotation is visible after the first impact.

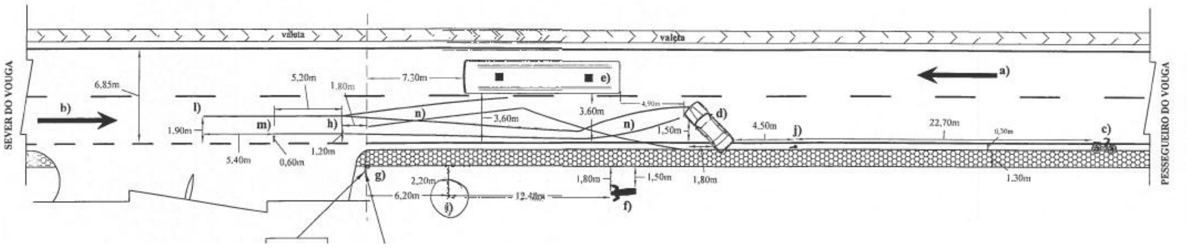


Figure 3.26 - Sketch of the accident made by the police, scale 1:250.

3.5.2.6 Computer Simulation

For the crash simulations, a restitution of 0,1 was considered for both vehicles (inelastic collision). The road where the accident took place has a slope of 3,6% that corresponds to an angle of 2,06 degrees. A straight road was considered for the simulation and so the friction coefficients were adjusted due to the slope. The friction coefficients used are obtained with the subtraction of the original friction coefficient, if there was no slope, and the original coefficient multiplied by the sin of the angle of the slope. For the moped it was considered an original friction coefficient of 0,55 between the moped and the pavement, justified by the absence of crash bars and the long slide on the pavement, that results in a final friction coefficient due to the slope of 0,53. Table 3.10 represents all the coefficients of friction as in the same analysis before. All the coefficients of friction were lowered as both car, motorcycle and motorcyclist body had a descendent movement after the impact.

Table 3.10 – Friction coefficients used in the crash simulations

	Original friction coefficient	**Friction coefficient due to the slope**
Motorcycle and ground	0,55	0,53
Motorcyclist body and ground	0,64	0,62
Tires and ground	0,7	0,67

The human characteristics of the drivers of the vehicles introduced in the crash simulations are shown in Table 3.11.

Table 3.11 - Human characteristic of the drivers of the vehicles for the crash simulations.

	Moped driver	**Car driver**	**Truck driver**
Age (years)	54	31	45
Height (m)	1,66		
Weight (Kg)	66	80	80

In Figure 3.27 are represented the models of the vehicles used in the crash simulations.

a)

b)

c)

Figure 3.27 - a) multibody model of the moped and driver, b) model of the car, c) model of the truck used in accident reconstruction.

In Figure 3.28 and Figure 3.29 are represented frames of the crash simulation where approximated final positions for the vehicles, motorcyclist body and helmet were obtained as well as a good compatibility of the damages in the vehicles.

t = 0s – Point of impact of the first collision

t = 0,058s – Motorcyclist hitting the hood of the car

t = 0,652s – Car losing control

t = 0,950s – Point of impact of the second collision

t = 1,445s – Motorcyclist body hits the floor

t = 4,970s – Final positions

Figure 3.28 – Frames of the crash simulation of the accident.

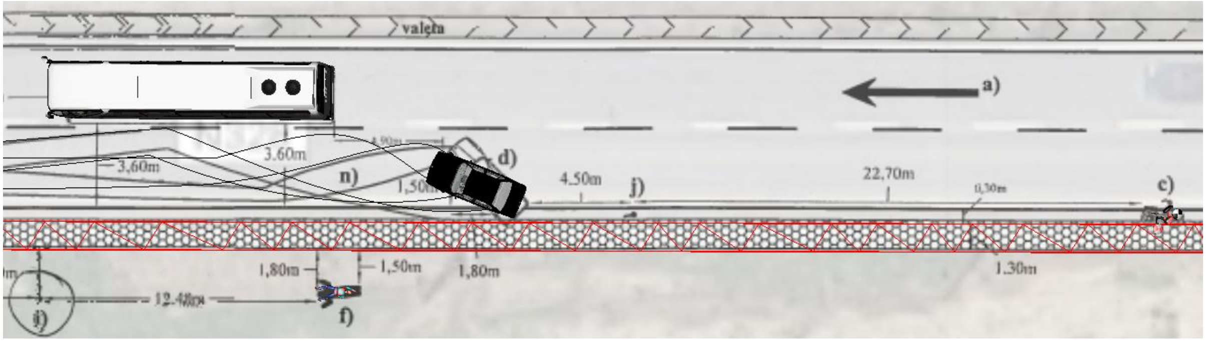


Figure 3.29 - Final positions of the vehicles, motorcyclist body and helmet (t=4,970s).

To determine the velocity of the car in the moment that it started to break it was considered a 10 meter break as can be seen in the police sketch of Figure 3.26. In Figure 3.30 the breaking phase before the impact is represent.

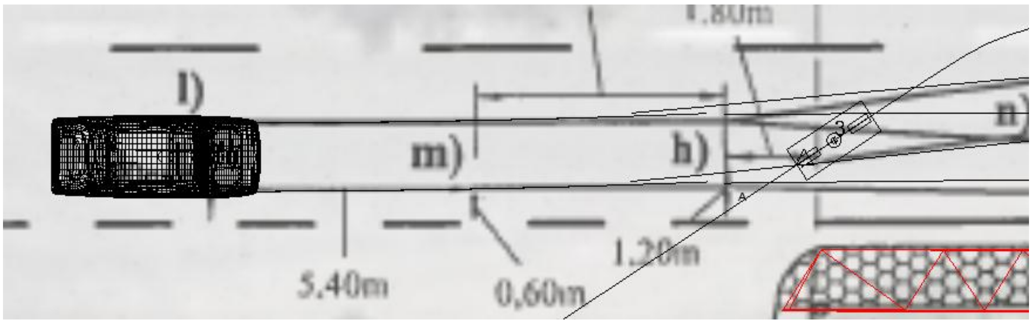


Figure 3.30 - Beginning of the breaking phase before impact of the car.

Considering this phase is possible to determine the velocity of the car before breaking that is higher than the impact velocity.

3.5.2.7 Discussion and conclusions

Human factors were associated to the cause of this accident namely speeding of the car. In the moment of the impact the car had a velocity of 85 km/h. 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 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.

In Figure 3.31 it is visible how far the car was of the intersection when the moped reached it, 2,871 seconds before. In that moment the car was approximately 84 meters away.

Figure 3.31 - Moment when the motorcycle reached the intersection (t=-2,871s).

The final positions obtained for the vehicles and motorcyclist are close to reality. The skid tire marks in the pavement left by the car that demonstrate its rotation were achieved. The damage caused by the moped and the motorcyclist in the car are compatible with the ones from the photography's of the damage vehicle after the accident as well as the damage between the rear of the car and the front of the bus.

If the car was driving within the speed limit the accident would not happen.

All the coefficients of friction used allowed achieving these results. These results are the desirable ones and this way the coefficients of friction were appropriated for the crash simulations.

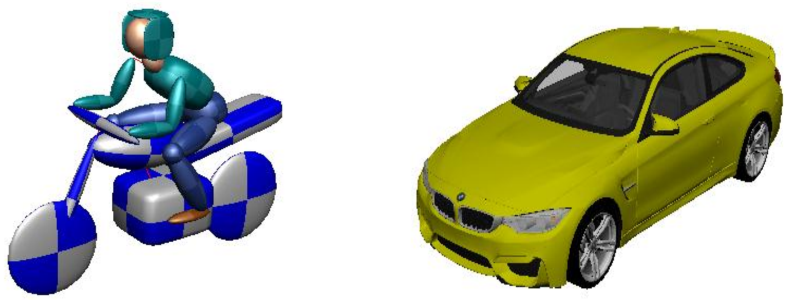
3.6 Influence of the Helmet in Accident Reconstruction

In the case of reconstruction of PTW accidents a multibody model needs to be used when considering the motorcycle, the moped or their occupants, drivers and passengers. In the software *PC Crash* the value of EES cannot be introduced in a multibody and therefore this parameter cannot be considered in a PTW accident reconstruction. This can be a problem when taking conclusions out of a crash simulation.

Firstly, it is going to be demonstrated the importance of the EES's in a crash simulation to then understand why it can be necessary to introduce a multibody helmet in a crash simulation. In Appendix B is presented a real accident that happened in Portugal between two passenger cars. If the EES's where not used in this crash simulations, at least three different solutions could be achieved and all of them would be correct. This way the EES take an important role in crash simulation

3.6.1 Lateral collision between a motorcycle and a car with helmet projection

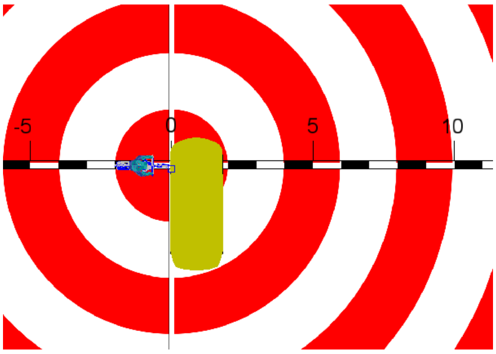
The multibody helmet model presented before is going to be used in the crash simulations. When the helmet buckle is not tight or breaks its projection will happen after a crash. The crash simulations that are going to be presented next will demonstrate the different distances of projections for different impact velocities. Figure 3.32 represents the motorcycle, Suzuki gs500e, and the car, BMW M4 form 2015, which were used in the crash simulations. A motorcyclist with 1,84m and 80 Kg was considered as well as a car driver with 80 Kg.



a) b)

Figure 3.32 - a) multibody model of the motorcycle and driver, b) model of the car used in crash simulations.

Figure 3.33 represents the point of impact that was considered for the crash simulations. The car is stationary and the motorcycle will crash against its front lateral side with different velocities in order to study and discuss the distances of projection of the motorcyclist body and helmet.



a)

b)

Figure 3.33 - Point of impact considered in the crash simulation: a) 2D view, b) 3D view.

In Table 3.12 can be seen the results of the crash simulations. It is easy to verify that, for lower motorcycle impact velocities, the distance of projection of the helmet is lower too.

Table 3.12 – 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)
100	15	60	32
90	13	46	25
80	11	37	20
70	9	28	15
60	8	21	11
50	7	15	8
40	5	10	6
30	4	5	4
20	2	2,5	0

Despite the motorcycle's position after the crash suffered little variations, in all the velocities of impact, the final position of the motorcyclist body was always different and so the final position of the helmet is not strictly necessary for the crash simulation. If the motorcycle and motorcyclist body final positions were coincident in more than one crash simulation then the helmet's final position could be an important parameter for the final conclusions of an accident.

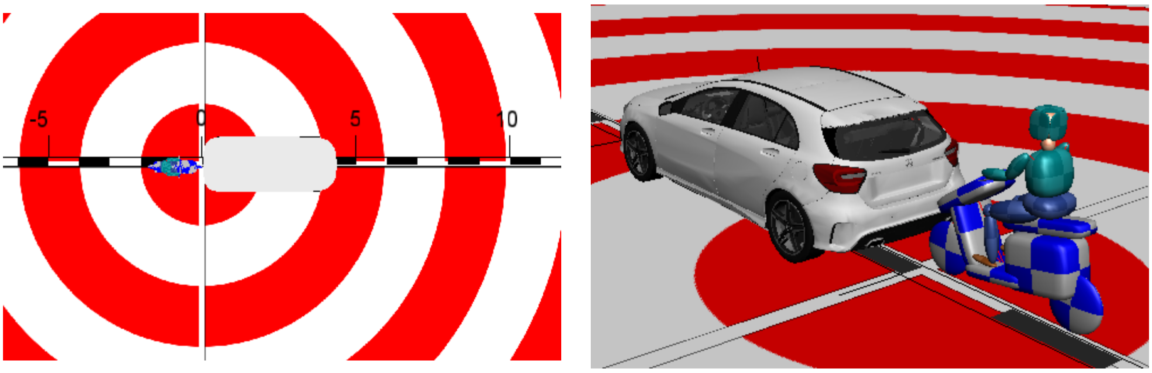
3.6.2 Rear collision between a motorcycle and a car with helmet projection

With the previous crash simulations the importance of the helmet in accident reconstruction was not proved. This way a rear collision between a scooter and a car was simulated in order to demonstrate that. Figure 3.34 represents the motorcycle, Keeway ARN125, and the 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 car driver with 80 Kg.

a) b)

Figure 3.34 - a) car , modelb) multibody model of the scooter and driver used in crash simulations.

Figure 3.35 represents the point of impact that was considered in the crash simulations. The car is stationary and the motorcycle will crash against its rear side with different velocities.



a) b)

Figure 3.35 - Point of impact considered in the crash simulation: a) 2D view, b) 3D view.

In Table 3.13 can be seen the results of the crash simulations.

Table 3.13 – Results of the crash simulations for differents motorcycle crash velocities.

Motorcycle velocity (km/m)	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 car
60	10	20	0
50	9	14	0
40	7	8	0
30	4	5	0
20	0	0	0

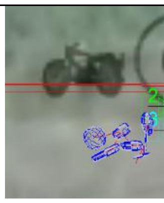
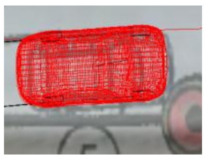
The scooter's final position in all the crash simulations suffered very little changes as it remained in the back of the car. This way, the scooter's final position would not help in determination of the dynamics of an accident of this type. The motorcyclist body, on the other hand, was the same for 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 is the decisive factor to take into account in the crash simulations. To conclude the helmet final position in a PTW accident, when its projection occurs, can be a decisive factor in the crash simulations to determine the accident dynamics. That is, for different pre impact parameters, pre impact velocities and positions, the final position of the vehicles and bodies can be the same and so the final position of the helmet will allow to choose the crash simulation that is closer to reality.

3.6.3 Helmet projection in a real PTW accident

In chapter 3.5.1 was analyzed a real accident between a moped and a car that happened in Portugal. In this accident the helmet was projected as it was not fasten as the driver of the moped did not do it before driving. The helmet projection was considered in the crash simulation to determine the accident dynamics closer to reality. In this topic, it is going to be shown the simulation closer to reality, crash simulation nº1, and a simulation that could be valid although the helmet final position was not appropriated, simulation nº2.

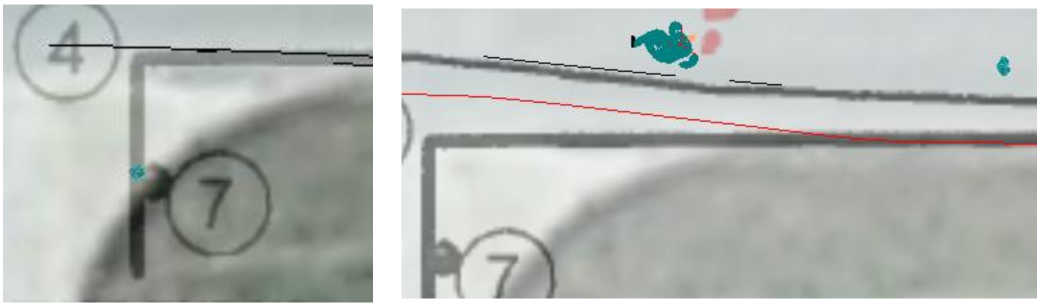
In Table 3.14 some pre impact parameters for both crash simulations as well as the final positions of the vehicles and the motorcyclist body are presented. Through the figures of the final positions it is visible that, for both crash simulations, the final positions are close to the registered positions. This way it van be thought that can be two different final conclusions for the responsible of the accident as the pre impact velocities change.

Table 3.14- Pre impact parameters and final positions in the crash simulations.

Crash simulation nº	Pre impact parameters			Car break deceleration after impact (m/s^2)	Final positions		
	Moped velocity (Km/h)	Car velocity (Km/h)	Moped angle (º)		Final moped position	Final body position	Final car position
1	41	99,5	55	6,87 (full in pedal position)			
2	28	73	60	3,30 (half in pedal position)			

However the accident happen in one way and the pre impact parameters must be found. To do so, the simulations were made with the projection of the helmet in order to have additional information to see if can be decided which crash simulation is closer to reality.

Figure 3.36 illustrates the final position of the helmet for both crash simulations. It is easier to see that the position of the helmet in crash simulation nº1 correspond to reality and the position of the helmet in the crash simulation nº2 is far from it.



a) **b)**

Figure 3.36 - Final position of the helmet: a) crash simulation nº1, b) crash simulation nº2.

The projection of the helmet can be an important element for the determination of the dynamics of this accident and the pre impact parameters. However the previous simulation was not only validated taking into account the helmet projection as more other parameters are needed to be taken into account. The example is just intended to illustrate that when helmet projection occur, the final position of the helmet takes an important position in accident reconstruction.

3.6.4 Discussion and conclusions

In the software *PC-Crash*, the EES cannot be introduced in a multibody model. Taking into account that, in order to consider occupants in a PTW in crash simulations, a multibody model must be used, the total deformation energy of the vehicles cannot be considered.

The final position of the helmet, when its projection occurs after an accident, revealed to be an important factor to take the conclusions about the pre impact parameters and the accident dynamics.

New multibody models for helmets should be created and developed for this matter in other to achieve better results. For different types of helmets there should be different multibody models.

The helmet should not be the decisive factor in accident reconstruction as all the parameters should be taken into account.

4 Conclusions and Future Work

In this chapter all the main results achieved with this work are going to be presented. To finalize are presented some ideas for future work in order to continue this investigation.

The main purpose of this work was to analyze the causes of PTW occupant's injury severity through a statistical analysis. To begin with it was performed a literature review about the topic of PTW accidents. Afterwards a descriptive analysis, between the years of 2010 and 2015, was performed from information from ANSR. To finish with an ordered logistic regression was applied to a discretized data set in order to determine the risk factors associated to PTW accidents.

As accident reconstruction takes an important role in engineering two import factors for this manner were discussed: friction coefficients involved in crash simulations and the influence of the helmet in that simulations.

4.1 Conclusions

Throughout the ordered logistic regression, Table 4.1 presents all the risk factors in the increase of the severity of the injuries of PTW accidents that were achieved.

Table 4.1 – Summary of thr isk factors determined with the ordered logistic regression.

Variables	Risk Factor
PTW category	Motorcycle
Accident type	Single Vehicle Collision
Month	September to February
Day of the month	1 to 10
Work day or rest day	Work day
Hour	20h to 5h59
Grip	Clean and dry road
Regions	Braga and Viana do Castelo
Wheather	Good Weather
Location	Outside urban area
Segment type	Bended
Road type	National roads, Highways and Freeways
PTW driver's age	22 to 29 and over 76 years old
PTW driver's gender	Male
PTW driver's action	Overtaking
PTW driver's safety accessories	Without helmet
PTW driver's alcohol	0,5 - 0,8 g/L
Other vehicle category	Truck
Other vehicle driver's injuries	Harmed

To summarize, the analysis of this data set confirmed the existence of several types of factors that influence the severity of the injuries in the occupants of PTW in case of accident. They are factors related to the PTW driver, the other vehicle and the characteristics of the accident.

Some measures should be taken in order to reduce the risk in the injuries of PTW accidents. Prevention plans should be promoted in order to improve the motorcyclist safety. Not only the other vehicles driver's should be aware of the high risk of injuries in PTW occupants when involved in an accident with then but more important, the PTW drivers should take notice of theirs risks. As single vehicle accidents take the highest risk in terms of accident type, motorcyclist cannot blame other vehicles and this way is motorcyclists who should be aware of the consequences.

Despite the speed of the PTW is not in the data set it is believed that in a big part of the accidents there are present speeding as overtaking is a risk factor as well as highways and freeways. To reduce the impact of the speed in the severity of the injuries more control of the speed should be done by the authorities. If more control was done by the authorities the number of risk maneuvers would be reduced too. That increase in the control should be done more intensely in the most critical periods as the workdays, from 20h to 5h59 and in days with good weather.

The places where there are more and more severe PTW accidents could be signalized in order to alert the PTW drivers of the risks in those roads, namely outside urban areas where the risks are higher.

The legal alcohol blood content should be adjusted as a BAC superior to 0.2 g/L has a huge risk of more severe injuries. In Portugal it is legal to drive a PTW with license over 3 years with a BAC less than 0.5 g/L.

When getting a driving license, the PTW drivers should be aware in first hand of all the risks associated with incorrect driving attitudes. If the information comes from the begging some problems may be avoided.

Of all the actions, the use of a helmet should always be present as it may be the decide factor between living or dying. The PTW drivers should too be alerted to use protective wearing as they can reduce the injuries in case of accident.

All the measures taken regarding PTW should be directed to motorcycles or mopeds as these two types of vehicles have some differences.

With a literature review the coefficients of friction involved in a PTW accident reconstruction were analyzed. In the case of a motorcycle accident reconstruction a multibody model for the motorcycle can be used. In this case the coefficient of friction between the ground and the tires of the vehicles is not the only one involved. For a multibody model of a motorcycle with an occupant two more coefficients of friction should be introduced that are the coefficient of friction between the round and the motorcyclist and the coefficient of friction between the ground and the motorcycle.

Experiments should be done to determine the effect of an under inflated or flat tire on the friction coefficient in accident reconstruction. When the tire blows after a collision the coefficient of friction will change but there is not enough studies on this subject yet.

Depending on the motorcyclists clothes and the road surface the coefficient of friction between the motorcyclist and the ground can be estimated. From 23 authors, with works between 1966 and 2008, and 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 was performed and a value of 0.64

was used for this coefficient. This value can be adjusted if information about the clothes and the injuries of the motorcycle driver is known.

The coefficient of friction between a sliding motorcycle and the ground depends on several conditions. The type of surface, the type of motorcycle and as well as the sliding distance have influence on this parameter. From 21 authors, with studies between 1979 and 2012, it was estimated a range from 0.2 to 1.1 for the coefficient of friction between a motorcycle and the road surface. To estimate this coefficient for a specific case, a table should be consulted and then the value should be adjusted taking in consideration the sliding distance and the damages on the motorcycle. For longer slides, higher than 10 meters, the initial impact phase has a short duration compared with the slide and so the overall average deceleration is less affected and this way for shorter sliding distances, higher coefficients of friction should be used. Higher coefficients of friction are related to greater degrees of scraping or gouging on the roadway

A multibody model of a helmet was created to study the influence of its projection in crash simulations. The projection of the helmet can occur when its buckle is not properly tight or it has some kind of deficiency. The helmet was added in the accident reconstruction because to use a multibody model of a motorcycle with an occupant the parameter energy equivalent speed (ESS) cannot be introduced in the simulation. The helmet turned out to be an important factor to help in determining the accident dynamics.

4.2 Future Work

A more extensive data set with more information for a larger period of time can be an interesting topic in a future research. Data as for example the speed of the PTW, the injuries and the number of kilometers travelled by a vehicle would give even more precise results. The data set should not only have the police records but also should have all the information on the accident dynamics. In depth investigation should be performed.

Other statistical methods could be applied to the data set. Data mining techniques can be used for this manner.

Regarding the friction coefficients involved in accident reconstruction, more studies should be done in order to determine more precise values for the coefficient of friction between the ground and the motorcyclist, and between the ground and the motorcycle. Studies on flat tires or under inflated should also be done to determine the influence of a tire with this characteristics in accident reconstruction.

More multibody models of different type helmets should be created in order to increase the quality of accident reconstructions. The multibody model should also be developed in order to be possible to use the energy equivalent speed and this way to consider the damages of the motorcycles. The optimization process is too slow for multibody model and some research should be done to improve this problem.

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Appendix A – Original data, discretized data and results from SPSS

Table A.1 - Description and explanation of each class of each variable of the original data.

Variables	Description	Classes
PTW category	PTW category	Motorcycle; Moped
Accident type	Type of Nature	Collision; Single vehicle accident; Run over pedestrians
Year	Year	2010 to 2015
Month	Month	January to December
Day of the month	Day of the month	1 to 31
Work day or rest day	Work day or rest day (weekend or holiday)	Work day; Rest day (weekend or holiday)
Hour	Hour	12 am to 12 pm
Total of drivers	Number of drivers involved in the accident	1 to 17
Technical characteristics	Technical characteristic of the road	Road without separator; Highway; Other type of road
Grip	Grip conditions	Standing water on the road; Ice, fronst or snow on the road; Gravel or sand on the road; Mud on the road; Oil on the road; Damp on the road; Wet road; Clean and dry road
Administrative region	Country district	Aveiro; Beja, Braga; Bragança; Castelo Branco; Coimbra; Évora; Faro; Guarda; Leiria; Lisboa; Portalegre; Porto; Santarém; Setúbal; Viana do Castelo; Vila Real; Viseu
Road surface conditions	Road surface conditions	Good; Reasonable; Bad
Wheather	Wheather conditions	Good weather; Rain; Hail; Snow; Fog; Smoke cloud; Strong wind
Direction	Road direction	Two ways road; Reversible direction road; One way road
Intersection	Road intersection	Intersection; Crossroad; Railway crossing; Connecting road (entry); Connecting road (exit); Roundabout; Entry lane; Exit lane; Outside intersection
Location	Location	Inside urban area; Ouside urban area
Light	Light	Dawn or twilight; Daylight; Night with light; Night without light; Dazzling sunlight
Road surface marking	Road surface marking	With road surface marks; Without road surface marks

Obstacles	Obstacles in the road	Properly signalized; Nonexistent; Unproperly signalized; Non signalized
Road and traffic signs	Road and traffic signs	Give away to traffic on major road; Pedestrian crossing; No overtaking; Stop; Other signs
Traffic light	Traffic light	Working; Not working; Flashing
Road surface	Road surface	Cement; Asphalt; Traditional portuguese mosaic paving; Gravel
Segment type 1	Road segment type 1	Straight; Bended
Segment type 2	Road segment type 2	Slope; Hump; Road on landing
Segment type 3	Road segment type 3	Road side without road surface; Road side with road surface; Without road side
Segment type 4	Road segment type 4	Parking lot; Road; Exclusive road; Road side; Side walk
Traffic lane	Traffic lane	Right; Left; Central
Police type	Police type	Polícia de Segurança Pública; Guarda Nacional Republicana
Service type	Service type	Public service; Private service
Road type	Road type	Highway; Street; Forest road; Municipal road; National road; Regional road; Complementary itinerary; Principal itinerary; Other types of roads
PTW injuries	PTW driver's injuries	Minor injury; Severe injury; Fatality
PTW age	PTW driver's age	8 to 100
PTW gender	PTW driver's gender	Male; Female
PTW years of license	PTW years of driver's license	0 to 75
PTW license	PTW driver's license	With driver license expired/suspended; With driver license; With no proper driving license; In driving lessons/test; No driving license required; Without driving license

PTW driver's action	PTW driver's action	Cross the road; Driving in the opposite direction; Abrupt deviation of direction; Regular driving; Start of driving; Reversing the direction; In reverse; Change direction to the right; Change direction to the left; Change to the right lane og the road; Change to the left lane of the road; Parked or stopped; Exist the parking; Driving in transit with parallel rows; Unexpected breaking; Overtaking by right lane; Overtaking by left lane
PTW safety accessories	PTW driver's safety accessories	Helmet; Seat belt; Vehicle without safety accessories; No use of helmet or seat belt
PTW alcohol	PTW driver's alcohol level	0 to 5
PTW age	PTW age	0 to 82
PTW complementary driver's action	PTW complementary driver's action	Open the door; Without needed lights; Riding far away from the side road or side walk; Disrespect of traffic lights; Disrespect of traffic signs; Disrespect of safety distance; Disrespect of road marks; Chaining; Vehicle mechanical failure; Irregular maneuver; Maneuver without signaling; Obstacle in the road; Cargo or object fall; Blow of a tire; Speeding
PTW inspection	PTW inspection	With valid inspection; Without valid inspection; No inspection required
PTW tires	PTW tires	Tires without defects; Tires with defects
PTW insurance	PTW insurance	With insurance; No insurance required; Without insurance
Other vehicle category	Other vehicle category	Car; Truck; Moped; Indstrial vehicle; Motorcycle; Quadricycle; Tricycle; Agricultural vehicle; Animal traction vehicle; Rail vehicle; Bicycle; Bicycle with motor
Other vehicle injuries	Other vehicle driver's injuries	Unharmed; Minor injury; Severe injury; Fatality
Other vehicle age	Other vehicle driver's age	8 to 100
Other vehicle gender	Other vehicle driver's gender	Male; Female

Other vehicle years of license	Other vehicle years of driver's license	0 to 75
Other vehicle license	Other vehicle driver's license	With driver license expired/suspended; With driver license; With no proper driving license; In driving lessons/test; No driving license required; Without driving license
Other vehicle driver's action	Other vehicle driver's action	Cross the road; Driving in the opposite direction; Abrupt deviation of direction; Regular driving; Start of driving; Reversing the direction; In reverse; Change direction to the right; Change direction to the left; Change to the right lane og the road; Change to the left lane of the road; Parked or stopped; Exist the parking; Driving in transit with parallel rows; Unexpected breaking; Overtaking by right lane; Overtaking by left lane
Other vehicle safety accessories	Other vehicle driver's safety accessories	Helmet; Seat belt; Vehicle without safety accessories; No use of helmet or seat belt
Other vehicle alcohol	Other vehicle driver's alcohol level	0 to 5
Other vehicle age	Other vehicle age	0 to 70
Other vehicle complementary driver's action	Other vehicle complementary driver's action	Open the door; Without needed lights; Riding far away from the side road or side walk; Disrespect of traffic lights; Disrespect of traffic signs; Disrespect of safety distance; Disrespect of road marks; Chaining; Vehicle mechanical failure; Irregular maneuver; Maneuver without signaling; Obstacle in the road; Cargo or object fall; Blow of a tire; Speeding
Other vehicle inspection	Other vehicle inspection	With valid inspection; Without valid inspection; No inspection required
Other vehicle tires	Other vehicle tires	Tires without defects; Tires with defects
Other vehicle insurance	Other vehicle insurance	With insurance; No insurance required; Without insurance

Table A.2 - Description of each class of each variable of the discretized data.

Variables	Class category	Classes	Number of observations	Marginal percentage
PTW category	1	Moped	15837	43,1%
	2	Motorcycle	20941	56,9%
Accident type	1	Run over pedestrians	594	1,6%
	2	Collision	22862	62,2%
	3	Single vehicle accident	13322	36,2%
Month	1	December, January and February	6990	19,0%
	2	September, October and November	9295	25,3%
	3	March, April and May	8895	24,2%
	4	June, July and August	11598	31,5%
Day of the month	1	1 to 10	12047	32,8%
	2	21 to 31	12407	33,7%
	3	11 to 20	12324	33,5%
Work day or rest day	1	Rest day	26228	71,3%
	2	Work day	10550	28,7%
Hour	1	00 - 05h59	1527	4,2%
	2	20 - 23h59	5153	14,0%
	3	10 - 15h59	13128	35,7%
	4	16 - 19h59	11761	32,0%
	5	06 - 09h59	5209	14,2%
Grip	1	Other road conditions	8541	23,2%
	2	Clean and dry road	28237	76,8%
Administrative regions	1	Évora, Beja, Faro and Portalegre	7246	19,7%
	2	Castelo Branco, Leiria, Setúbal and Santarém	6905	18,8%
	3	Bragança, Coimbra, Guarda, Viseu and Vila Real	4018	10,9%
	4	Braga and Viana Castelo	226	,6%
	5	Aveiro	3791	10,3%
	6	Porto	5901	16,0%
	7	Lisboa	8691	23,6%
Wheather	1	Other weather coditions	4275	11,6%
	2	Good weather	32503	88,4%
Location	1	Inside urban area	30900	84,0%
	2	Outside urban area	5878	16,0%
Segment type 1	1	Bended	10663	29,0%
	2	Straight	26115	71,0%
Road type	1	Other typed of roads	3298	9,0%
	2	Highways, Complementary itinerary and Principal itinerary	1553	4,2%
	3	National road	6980	19,0%
	4	Street	24947	67,8%
PTW driver's injuries	1	Fatality	832	2,3%
	2	Severe injury	2630	7,2%

	3	Minor injury	33316	90,6%
PTW driver's Age group	1	>= 76	1374	3,7%
	2	<= 15	158	,4%
	3	60 -75	4223	11,5%
	4	50 - 59	4935	13,4%
	5	40 - 49	7123	19,4%
	6	16 - 18	2558	7,0%
	7	30 - 39	8788	23,9%
	8	22 - 29	5753	15,6%
	9	18 - 21	1866	5,1%
PTW driver's gender	1	Female	4109	11,2%
	2	Male	32669	88,8%
PTW driver's action	1	Other actions	2483	6,8%
	2	Overtaking	1875	5,1%
	3	Change of direction	1950	5,3%
	4	Regular driving	30470	82,8%
PTW driver's safety accessories	1	Without safety accessories	433	1,2%
	2	With safety accessories	36345	98,8%
PTW driver's alcohol	1	Not tested	2999	8,2%
	2	>= 1.2 g/L	1938	5,3%
	3	0.8 - 1.2 g/L	461	1,3%
	4	0.5 - 0.8 g/L	317	,9%
	5	0.2 - 0.5 g/L	594	1,6%
	6	<= 0.2 g/L	30469	82,8%
Other vehicle category	1	Without other vehicle involved	14002	38,1%
	2	Other type of vehicles	141	,4%
	3	Bicycle and bicycle with motor	115	,3%
	4	Moped	180	,5%
	5	Motorcycle	160	,4%
	6	Truck	620	1,7%
	7	Car	21560	58,6%
Other vehicle driver's injuries	1	Without other vehicle involved	13869	37,7%
	2	Fatality	21	,1%
	3	Severe injury	63	,2%
	4	Minor injury	856	2,3%
	5	Unharmed	21969	59,7%

Table A.3 - Parameter estimated from SPSS for PTW accidents.

Parameter Estimates

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[Lesoes_1 = 1,0]	-5,151	,310	276,888	1	,000	-5,758	-4,544
	[Lesoes_1 = 2,0]	-3,324	,307	116,942	1	,000	-3,927	-2,722
Location	[Categ_Veic=1,0]	,380	,047	65,338	1	,000	,288	,472
	[Categ_Veic=2,0]	0[a]	.	.	0	.	.	.
	[Tipo_Natureza=1,0]	,152	,185	,675	1	,411	-,211	,515
	[Tipo_Natureza=2,0]	,087	,108	,647	1	,421	-,125	,300
	[Tipo_Natureza=3,0]	0[a]	.	.	0	.	.	.
	[Mês=1,0]	-,081	,059	1,864	1	,172	-,196	,035
	[Mês=2,0]	-,080	,052	2,302	1	,129	-,182	,023
	[Mês=3,0]	-,026	,053	,243	1	,622	-,129	,077
	[Mês=4,0]	0[a]	.	.	0	.	.	.
	[Dia_Mes=1,0]	-,062	,048	1,644	1	,200	-,156	,033
	[Dia_Mes=2,0]	,003	,048	,003	1	,958	-,092	,097
	[Dia_Mes=3,0]	0[a]	.	.	0	.	.	.
	[Dia_Trabalho=1,0]	,217	,042	26,650	1	,000	,135	,300
	[Dia_Trabalho=2,0]	0[a]	.	.	0	.	.	.
	[Hora=1,0]	-,441	,097	20,573	1	,000	-,631	-,250
	[Hora=2,0]	-,189	,078	5,853	1	,016	-,342	-,036
	[Hora=3,0]	-,005	,069	,006	1	,937	-,141	,130
	[Hora=4,0]	-,080	,069	1,344	1	,246	-,216	,055
	[Hora=5,0]	0[a]	.	.	0	.	.	.
	[Cond_Aderencia=1,0]	,219	,063	12,181	1	,000	,096	,343
	[Cond_Aderencia=2,0]	0[a]	.	.	0	.	.	.
	[Distrito=1,0]	-,472	,065	52,017	1	,000	-,600	-,343
	[Distrito=2,0]	-,657	,064	107,044	1	,000	-,782	-,533
	[Distrito=3,0]	-,271	,077	12,407	1	,000	-,421	-,120
	[Distrito=4,0]	-1,318	,182	52,684	1	,000	-1,674	-,962
	[Distrito=5,0]	-,075	,087	,745	1	,388	-,246	,095
	[Distrito=6,0]	,029	,075	,150	1	,699	-,118	,176
	[Distrito=7,0]	0[a]	.	.	0	.	.	.
	[Fact_Atmosf=1,0]	,111	,087	1,652	1	,199	-,058	,281
	[Fact_Atmosf=2,0]	0[a]	.	.	0	.	.	.

	[Localizacoes=1,0]	,285	,061	21,757	1	,000	,165	,405
	[Localizacoes=2,0]	0[a]	.	.	0	.	.	.
	[Tracado1=1,0]	-,094	,043	4,638	1	,031	-,179	-,008
	[Tracado1=2,0]	0[a]	.	.	0	.	.	.
	[Tipo_Vias=1,0]	-,357	,073	23,897	1	,000	-,500	-,214
	[Tipo_Vias=2,0]	-,450	,103	19,028	1	,000	-,653	-,248
	[Tipo_Vias=3,0]	-,519	,054	91,083	1	,000	-,625	-,412
	[Tipo_Vias=4,0]	0[a]	.	.	0	.	.	.
	[Idade_1=1,0]	-,227	,137	2,726	1	,099	-,496	,042
	[Idade_1=2,0]	,219	,336	,427	1	,514	-,438	,877
	[Idade_1=3,0]	,120	,114	1,125	1	,289	-,102	,343
	[Idade_1=4,0]	-,068	,108	,392	1	,531	-,279	,144
	[Idade_1=5,0]	,116	,104	1,241	1	,265	-,088	,320
	[Idade_1=6,0]	,112	,126	,784	1	,376	-,136	,359
	[Idade_1=7,0]	-,002	,102	,000	1	,986	-,201	,197
	[Idade_1=8,0]	-,090	,105	,728	1	,393	-,296	,116
	[Idade_1=9,0]	0[a]	.	.	0	.	.	.
	[Genero_1=1,0]	,714	,097	54,424	1	,000	,524	,903
	[Genero_1=2,0]	0[a]	.	.	0	.	.	.
	[Accoes_1=1,0]	-,111	,075	2,208	1	,137	-,257	,035
	[Accoes_1=2,0]	-,157	,087	3,235	1	,072	-,328	,014
	[Accoes_1=3,0]	,029	,095	,093	1	,760	-,158	,216
	[Accoes_1=4,0]	0[a]	.	.	0	.	.	.
	[Acessorios_1=1,0]	-1,495	,111	180,857	1	,000	-1,713	-1,277
	[Acessorios_1=2,0]	0[a]	.	.	0	.	.	.
	[Alcool_1=1,0]	-2,791	,048	3386,447	1	,000	-2,885	-2,697
	[Alcool_1=2,0]	-1,360	,075	332,169	1	,000	-1,506	-1,213
	[Alcool_1=3,0]	-1,528	,122	156,066	1	,000	-1,768	-1,288
	[Alcool_1=4,0]	-1,574	,143	120,410	1	,000	-1,855	-1,293
	[Alcool_1=5,0]	-,798	,136	34,384	1	,000	-1,065	-,532
	[Alcool_1=6,0]	0[a]	.	.	0	.	.	.
	[Tipo_Veic_2=1,0]	-,448	,240	3,492	1	,062	-,918	,022
	[Tipo_Veic_2=2,0]	-,150	,282	,282	1	,596	-,703	,403
	[Tipo_Veic_2=3,0]	2,561	,565	20,568	1	,000	1,454	3,668
	[Tipo_Veic_2=4,0]	1,847	,326	32,150	1	,000	1,209	2,486
	[Tipo_Veic_2=5,0]	1,689	,303	31,137	1	,000	1,096	2,283
	[Tipo_Veic_2=6,0]	-1,071	,110	95,489	1	,000	-1,286	-,856

[Tipo_Veic_2=7,0]	0[a]	.	.	0	.	.	.
[Lesoes_2=1,0]	,369	,348	1,124	1	,289	-,313	1,052
[Lesoes_2=2,0]	-2,387	,535	19,919	1	,000	-3,435	-1,339
[Lesoes_2=3,0]	-2,731	,321	72,322	1	,000	-3,360	-2,101
[Lesoes_2=4,0]	-1,461	,104	198,991	1	,000	-1,664	-1,258
[Lesoes_2=5,0]	0[a]	.	.	0	.	.	.
[Lesoes_2=3,0]	-2,731	,321	72,322	1	,000	-3,360	-2,101
[Lesoes_2=4,0]	-1,461	,104	198,991	1	,000	-1,664	-1,258

Table A.4 - Statistical significance and OR (CI of 95%) of the discretized data just for motorcycle accidents.

Variables	Classes	OR	Confidence interval of 95%	P-value
Accident type	Run over pedestrians	0,984	1,501 - 0,645	,941
	Collision	0,917	1,175 - 0,716	,495
	Single vehicle accdient			
Month	December, January and February	1,161	1,354 - 0,996	,056
	September, October and November	1,129	1,292 - 0,987	,077
	March, April and May	1,090	1,245 - 0,954	,206
	June, July and August			
Day of the month	1 to 10	1,076	1,217 - 0,951	,243
	21 to 31	0,992	1,122 - 0,877	,894
	11 to 20			
Work day or rest day	Rest day	0,820	0,913 - 0,737	,000
	Work day			
Hour	00 - 05h59	1,845	2,369 - 1,437	,000
	20 - 23h59	1,534	1,886 - 1,249	,000
	10 - 15h59	1,239	1,494 - 1,027	,025
	16 - 19h59	1,322	1,593 - 1,097	,003
	06 - 09h59			
Grip	Other road conditions	0,808	0,945 - 0,691	,008
	Clean and dry road			
Regions	Évora, Beja, Faro and Portalegre	1,616	1,889 - 1,383	,000
	Castelo Branco, Leiria, Setúbal and Santarém	1,902	2,206 - 1,639	,000
	Bragança, Coimbra, Guarda, Viseu and Vila Real	1,350	1,638 - 1,114	,002
	Braga and Viana Castelo	3,067	4,907 - 1,916	,000
	Aveiro	1,175	1,487 - 0,929	,178
	Porto	0,888	1,062 - 0,742	,193

	Lisboa			
Wheather	Other weather coditions	0,716	0,913 - 0,562	,007
	Good weather			
Location	Inside urban area	0,795	0,931 - 0,678	,004
	Outside urban area			
Segment type 1	Bended	1,057	1,184 - 0,943	,339
	Straight			
Road type	Other typed of roads	1,476	1,798 - 1,212	,000
	Highways and Freeways	1,706	2,157 - 1,349	,000
	National road	1,686	1,940 - 1,466	,000
	Street			
PTW driver's age	>= 76	1,353	2,484 - 0,738	,328
	<= 15	0,622	2,333 - 0,166	,482
	60 -75	0,633	0,888 - 0,451	,008
	50 - 59	1,125	1,481 - 0,855	,399
	40 - 49	0,896	1,156 - 0,695	,399
	16 - 18	0,884	1,209 - 0,646	,439
	30 - 39	1,053	1,342 - 0,826	,679
	22 - 29	1,117	1,434 - 0,870	,386
	18 - 21			
PTW driver's gender	Female	0,447	0,615 - 0,325	,000
	Male			
PTW driver's action	Other actions	1,127	1,378 - 0,923	,241
	Overtaking	1,279	1,552 - 1,053	,013
	Change of direction	0,607	0,853 - 0,432	,004
	Regular driving			
PTW driver's safety accessories	Without helmet	5,712	7,755 - 4,208	,000
	With helmet			
PTW driver's alcohol	Not tested	21,365	24,142 - 18,908	0,000
	>= 1.2 g/L	4,626	5,750 - 3,721	,000
	0.8 - 1.2 g/L	5,327	7,283 - 3,896	,000
	0.5 - 0.8 g/L	5,714	8,292 - 3,938	,000
	0.2 - 0.5 g/L	2,275	3,267 - 1,584	,000
	<= 0.2 g/L			
Other vehicle category	Without other vehicle involved	1,129	2,368 - 0,538	,749
	Other type of vehicles	0,801	1,878 - 0,341	,609
	Bicycle and bicycle with motor	0,111	0,348 - 0,035	,000
	Moped	0,157	0,477 - 0,052	,001
	Motorcycle	0,246	0,454 - 0,133	,000
	Truck	3,470	4,679 - 2,574	,000
	Car			
Other vehicle	Without other vehicle involved	0,658	1,424 - 0,304	,288
	Fatality	7,179	23,128 -	,001

driver's injuries			2,229	
	Severe injury	11,883	24,688 - 5,719	,000
	Minor injury	4,204	5,358 - 3,299	,000
	Unharmed			

Appendix B - Real accident between two cars: head-on collision

A real accident between two cars is going to be presented next to understand the importance of the EES's in a crash simulation. This accident happened between a Renault Megane III Gt Line from 2012 (vehicle nº1) and a Honda Civic from 1988 (vehicle nº2). A head-on collision occurred because the vehicle nº2 invaded the lane of the vehicle nº1.

Comparing Figure B.1 and Figure B.2, damaged vehicles after the accident, with - EES values: a) 64 Km/h for a Renault Megane, b) 70-75 Km/h for a Ford Escort., crash test of two vehicles in Euroncap data base (a) and in Dr. Malegh 2002 (b), a value of approximately 64 Km/h and 70-75 Km/h can be assigned to the EES's of vehicle nº1 and vehicle nº2, respectively.

a)

b)

Figure B.1 - Vehicle nº1 after the accident: a) front side, b) rear side.

a)

b)

Figure B.2 - Vehicle nº2 after the accident.

a)

b)

Figure B.3 - EES values: a) 64 Km/h for a Renault Megane, b) 70-75 Km/h for a Ford Escort.

In Table B.1 are presented the results of three crash simulations for the accident in hands. The point of impact was practically the same (Figure B.4). As can be seen in **Table B.**1 for all the three simulations the trajectory error is really low which means that the final positions of the vehicles after the accident are close to reality. What is more, there was also compatibility in the damages of the two cars in all the simulations. This way, the only parameter that can be used to find the closest to reality crash simulation is the EES's of each vehicle. The crash simulation nº1 is the only one where the EES's are close to reality and so the velocities of the vehicles in the moment of impact are 90 Km/h for the vehicle nº1 and 40 Km/h for the vehicle nº2.

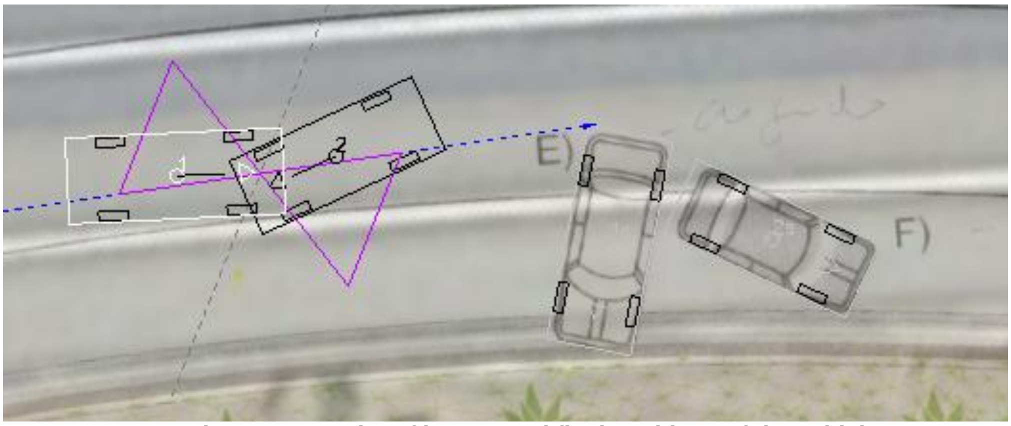

Figure B.4 - Point of impact and final positions of the vehicles.

Table B.1 - Crash simulation of a front collision between two cars.

	Vehicle nº	Impact velocities (Km/h)	EES (Km/h)	Trajectory error
Crash simulation nº1	1	90	58,45	2,20%
	2	40	67,48	
Crash simulation nº2	1	83	56,99	2,80%
	2	30	50,44	
Crash simulation nº2	1	80	58,42	2,20%
	2	24	31,86	

To conclude, if the EES's where not used in this crash simulation, at least three different solutions would be achieved and all of them would be correct. This way the EES take an important role in crash simulation.