Computational Models for Helmet Use Assessment in Motorcycle Accidents

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Abstract - Accidents involving two wheels vehicles represent one of the more important types of accidents in Europe. These accidents are usually not easy to reconstruct specially for the analysis of the injuries and its correlation with accident dynamics and evidences. Different methodologies are applied in this work for the reconstruction of two wheeler accidents, especially accident involving motorcycles. From the typologies of road evidences like skid marks, to the use of Pc-Crash and the use of Madymo models, different reconstruction of real accidents are presented. One of the questions that sometimes arise for legal purposes when some type of head injuries arise is if the occupant was wearing or not a helmet. The correlation of head injuries with the use of the helmet is a very important issue, therefore an important legal aspect. One of the key questions for the reconstructions that is difficult to analyze, is if the vehicle occupant, was or not, wearing the helmet. Based on the previously collected information, a generic model of a helmet was developed on CAD 3D, followed by its conversion into finite elements, all in order to perform impact tests using the Madymo software that would help improve the helmet's safety, but that also can be used as a tool in accident reconstruction.

NOTATION

PTW – Powered Two Wheels
CPSC – U.S. Consumer Product Safety Commission
ASTM – American Society for Testing and Materials
ECE – Economic Commission for Europe
EPS – Expanded Polystyrene
EPP – Expanded Polypropylene

INTRODUCTION

The number of traffic accidents in Portugal is, undoubtedly, one of the highest in Europe. In accordance with the database constructed from the elements provided by DGV[1], 10491 accidents with resulting victims occurred, in the year 2005, 342 of which were fatalities. The study of these accidents is, therefore, urgent and essential to the understanding of the factors from which these numbers originate. Due to a lack of supported studies in this field the implementation of a plan based on studies that aim to identify the critical factors in this type of vehicle becomes commanding.
In figure 1.1 (Care [2]), it's possible to verify that, on a European scenario, the number of fatalities involving PTWs present alarmingly high, especially countries such as France (FR), Spain (ES), the United Kingdom (UK) and Greece (EL), proving that it is not just a problem in Portugal but in most of the European countries. As each country presents different realities concerning road strategies, on of the most viable ways of reducing these numbers in to maximize the helmet's effectiveness. The helmet is precisely the piece of equipment that protects the most vulnerable part of the human body: the head.

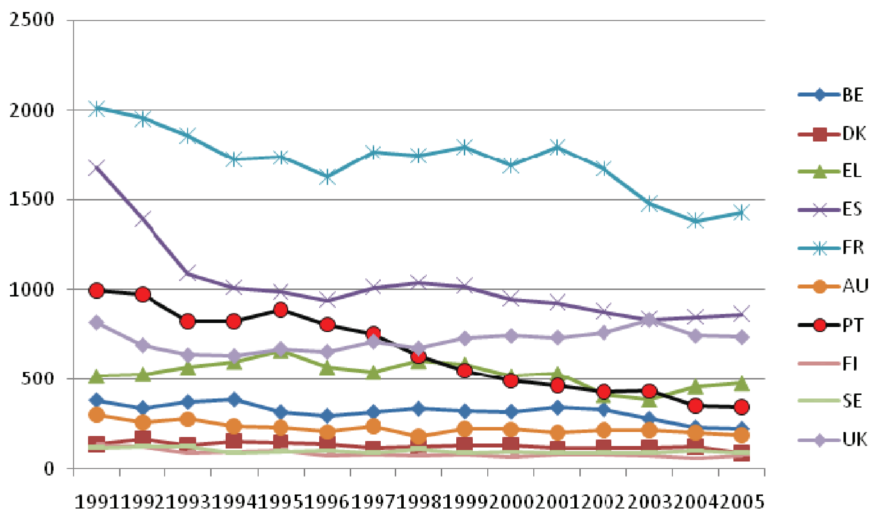


Figure 1 – Distribution of mortal victims with vehicles of two wheels, for country, 1991-2005.

The helmet is essential equipment for drivers and passengers of PTWs and, as such, must obey safety construction regulations like the following: the ECE R22/05 norm [18], most used in the world; Snell M2000/M2005 [16], used mostly in the United States of America; and others as the CPSC and the ASTM F1447, that assure the quality of the equipment. However, the importance of these norms is still tested in relatively archaic methods that expensive for manufacturers, many times leading to the production and subsequent release of materials without the proper certification. Therefore, there is a profound need to develop computational methodologies and models that optimize the safety of two wheel riders, offering, at the same time, a reduction of the production costs for the manufacturers of these equipments.

ACCIDENT ANNUAL REPORT

This chapter consists of an analysis of accidents involving PTWs in Portugal, over the year 2005, from which resulted victims. This analysis was based on the data provided by DGV[1] in an attempt to identify and stand out some of the main causes behind the occurrence of these accidents, such as those related with the vehicles or the human behavior, relating them with the use of the helmet.

Vehicle factors

In Portugal the PTWs are distributed over six different categories: bicycles, engine powered bicycles, mopeds, and 3 types of motorcycles. They represent only 2.7% of all vehicles in the country, while cars represent 72,5%. However, the number of fatalities per 1000 vehicles in circulation is 8 times superior in PTWs to the number represented by cars. These numbers are conclusive and express the vulnerability of PTWs. In order to understand them, it becomes mandatory to realize which are the most dangerous categories. Trough figure 2 it becomes possible to verify that in fact the most hazardous categories are those of the motorcycles with powerful engines and of the bicycles. The motorcycles' high performance and their lack of visibility are easily associated with these degrees of severity. Bicycles, on the other hand, surely have a different explanation for such elevated numbers; despite the fact that they are difficult to make out in traffic, the use of helmet in this category isn't mandatory in Portugal.

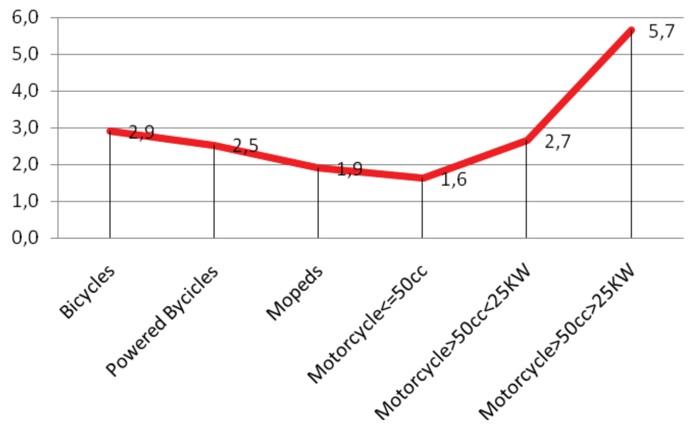


Figure 2 – Vehicle severity indicator in Portugal during 2005.

Human factors

In comparison with the year 2004, figure 3 clearly indicates a decrease in the number of fatalities in 2005, of 10.18%; a reduction in severe injuries of 15.26%; and a decline of 15.64% in light wounds.

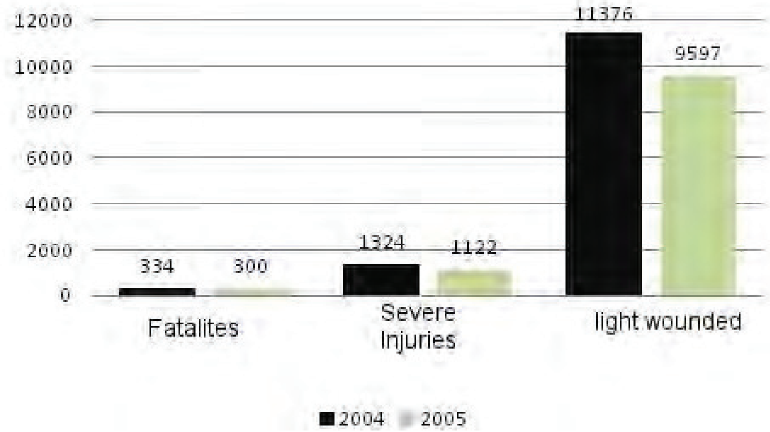


Figure 3 – Victims by type of accidents with passenger heavy vehicles during 2004 and 2005.

Despite the significant reduction of the number of victims, the solution for this problem, in a short-term period, involves the study of some aspects of human behavior such as the use of the helmet.
In Portugal, such as in other countries, the use of helmet isn't mandatory for bicycle riders. In Portugal, over the year 2005, data showed that none of the fatal victims or the severely injured wore a helmet, and only 1% of the light wounded did. These figures indicate, unequivocally, that the use of this equipment should indeed be mandatory, as it would reduce the number of victims.
Data related to mopeds and motorcycles prove that the non-use of the helmet leads to a clear aggravation of injury degrees, also demonstrating how important the use of the helmet really is.

ACCIDENTS RECONSTRUCTION

The present chapter describes the computational simulations - performed in Pc-Crash - of two real accidents, in the scope of legal and litigious processes, from which the necessary information was extracted in order to relate the type of accident with the injuries sustained by the driver.

Accident I: accident between moped and car

This accident originated in a dangerous maneuver on the behalf of the car driver. Nonetheless, the serious injuries sustained by the moped driver - skull trauma - could have been prevented if only he was equipped with a certified helmet and one in good conditions, particularly with a chin strap and protective padding. Another aspect of the helmet that must also be mentioned is the actual helmet type: jet helmets do not offer any sort of protection from facial injuries in contrast to an integral helmet.

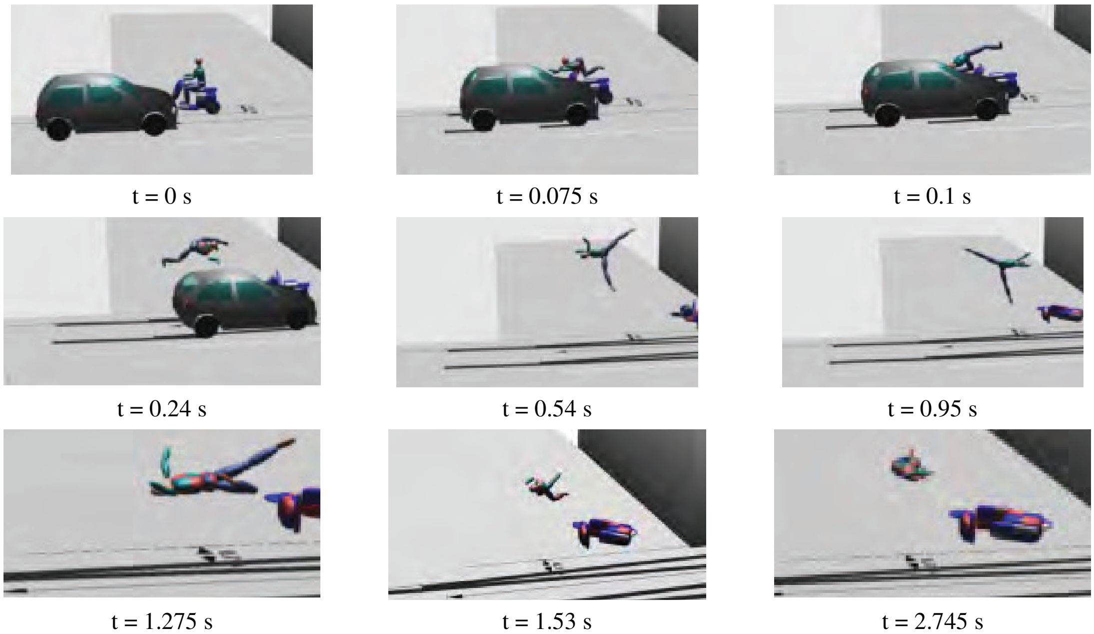


Figure 4 – Frames of the accident computational simulation.

Figure 5 – Photo of the helmet used by the moped driver.

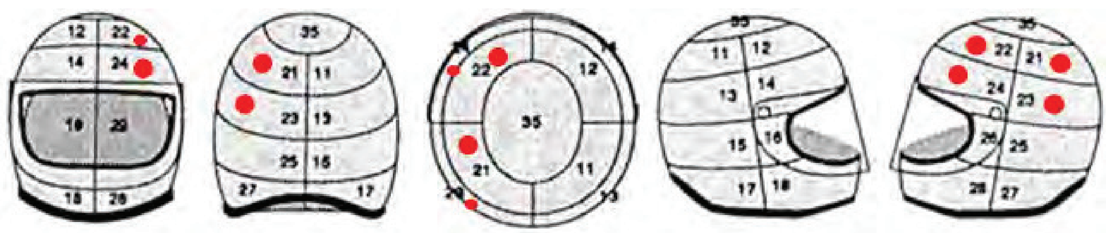


Figure 6 – Damaged zones of the helmet.

This accident had its origin in a dangerous maneuver on the part of the conductor of the car. However, the serious injuries that had resulted in the driver of the moped, skull trauma, could have been prevented if the conductor of the moped was equipped with a certified helmet and in good condition, in particular with chin strap and protective padding. Another one of the aspects of the helmet that also must be mentioned is the helmet type: jet helmets do not offer any type of protection concerning face injuries, in contrast to an integral helmet.

Accident II: accident between truck and motorcycle

This accident is characterized as a collision type 3 (ISO13232), in which the truck intended to leave a crossing with a STOP sign, to take the National Road, when the motorcycle crashed into the lateral of the cargo box (figure 7).

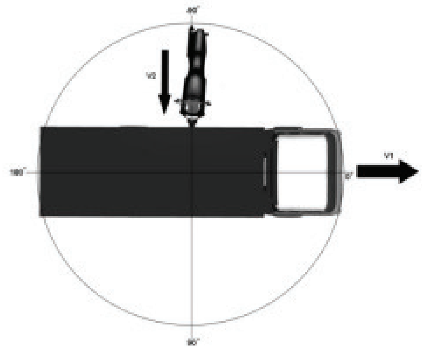


Figure 7 – Photo of the helmet used by the moped driver.

Figure 8 presents the simulation frames of the accident.

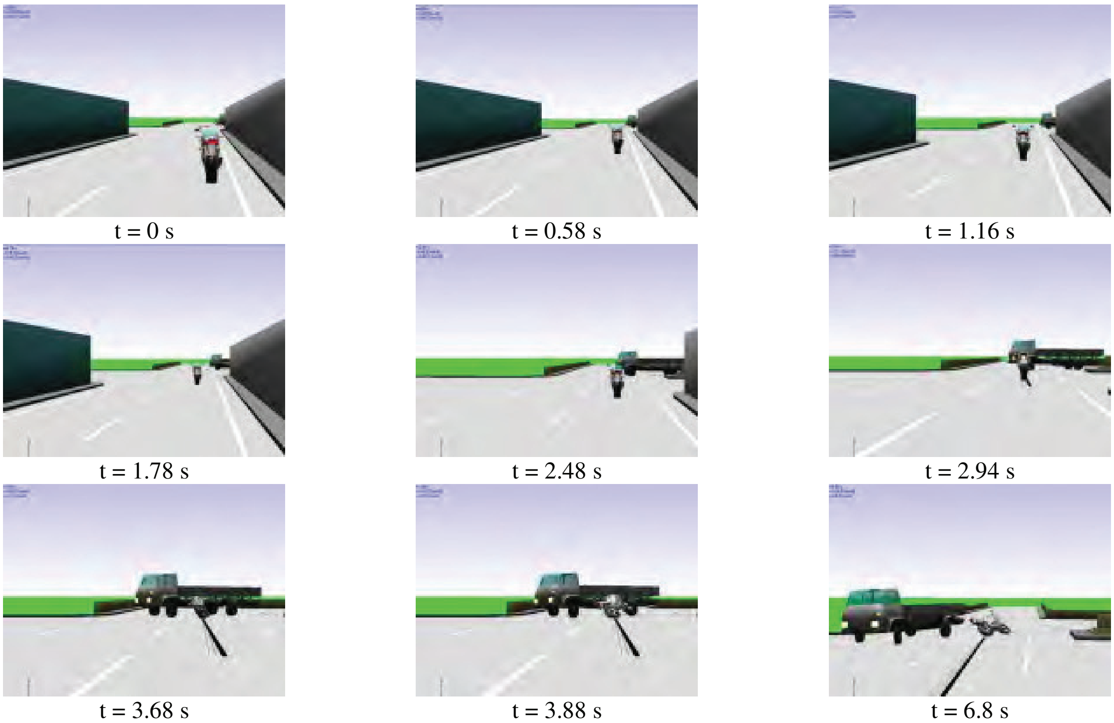


Figure 8 – Frames of the accident computational simulation.

At the time of the accident, the motorcycle driver was again equipped with a jet helmet (figure 9). The damages to the helmet are patent in figure 10 with red dots.

Figure 9 – Helmet involved in the accident.

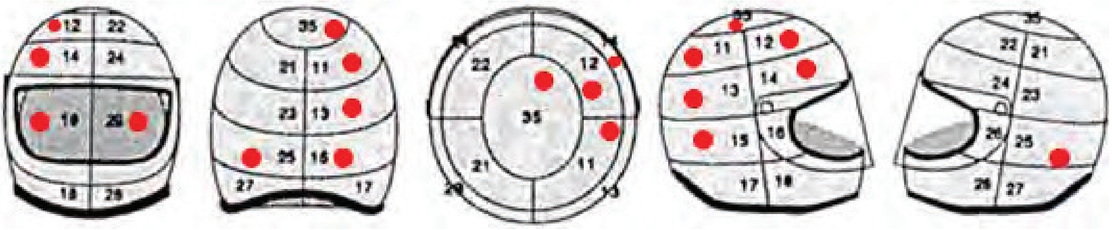


Figure 10 – Damaged zones of the helmet.

Based on the simulation it became possible to prove that the high speed of the motorcycle was the key element in the occurrence of this element.
The helmet worn in this accident is manufactured by Nau, a Portuguese company, and, according to the manufacturer, it is certified equipment in accordance with ECE22/05 standards. The good quality of the helmet was a preponderating factor in the low degree of injuries sustained by the motorcycle driver. Nevertheless, the jet type was not able to prevent some facial cuts and some minor injuries to the face that would most probably have been avoided with the use of an integral helmet.

MOTORCYCLISTS COGNITIVE ABILITIES RELATED TO HELMET

Some information was collected within the reach of the COST357 [8] research project. A survey was carried out in order to obtain data about some of the factors that could influence the motorcyclists' cognitive abilities. In Portugal, the project was essentially conducted by IDMEC IST Technical University of Lisbon. The sampling area was the Lisbon region. During weekdays, between 8 am and 6 pm, the police randomly stopped motorcycle riders, who were then interviewed by members of the COST team. Riders were asked for their cooperation with the control study. Interviews were carried out at motorcycle meeting points and gas stations. Other countries involved in the project carried out several other different methods.
With this survey it became possible to reach conclusions about several interesting issues such as the helmet type most worn - integral; most common colors; age and gender of the riders; their profession; chin strap type; certification label control; light transmission and diffusion test results; and vision field. Another important issue is that the critical points of impact in helmets were the back and both sides. It was also possible to conclude that the majority of the tested helmets (figure 11) have good light transmission and diffusion values in the visor.

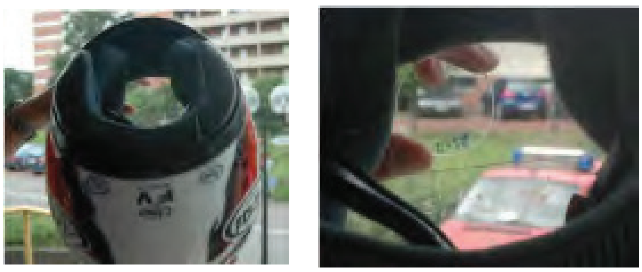


Figure 11 – Test procedure in light diffusion and transmission.

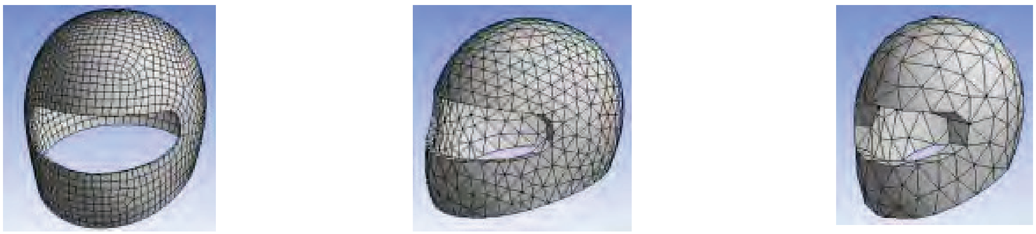
To access all data obtained and conclusions related to all the matters mentioned above, please read the main report [8].

HELMET AND BIOMECHANICS OF HEAD INJURIES

Regarding this subject, a complete introduction to the helmet was laid out, approaching its components and its effectiveness in reducing the acceleration values in the head. A brief study focused the head anatomy and the biomechanics of head injuries. Some considerations were drawn in order to understand how head injuries occur and how they can be reduced or prevented. One of the findings was that head injuries sustained due to high levels of acceleration are extremely sever and dangerous. The only way to reduce these levels is to reduce the inertial forces in the head in case of impact.
A comparative analysis between standards is also presented with the purpose of selecting parameters from impact tests performed in accordance with these standards.

COMPUTATIONAL MODELS AND SIMULATIONS.

A finite elements model of the helmet was developed aiming to reduce head acceleration values. Therefore, the helmet was modeled with the projection of an extra layer of protective padding material. The materials selected for the shell and protective padding were a thermoplastic used before by Decker [20] for the shell, and different types of EPS and EPP with different densities.



a) b) c)

Figure 12 – Finite element model of the different layers of the helmet.

The head form utilized was the FMVSS 201 Hybrid III Headform (figure 13), part of the Madymo library and is composed of SHELL and SOLID1 elements, specified to measure head velocities and accelerations due to impacts.

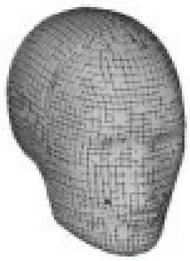


Figure 13 – Finite element model of the different layers of the helmet [22].

In order to validate the finite elements model a drop test was simulated using a speed value of 7.5 m/s. The results were then compared to results from experimental tests carried out by Bosh [2] using the same conditions.
To verify if the model assured the safety values, four simulations were completed according to the conditions imposed by the ECE 22/05 standard [18].
A simulation using a higher density foam material was carried out with the objective of verifying the effect of the density of the protective material in head accelerations.
At last, a simulation was prepared using two different materials, one in each layer of protective padding material, with the purpose of studying the effects they have in the acceleration suffered by the head.

RESULTS AND DISCUSSION

Figure 14 presents an example of a simulation (for detailed simulation results consult main report).

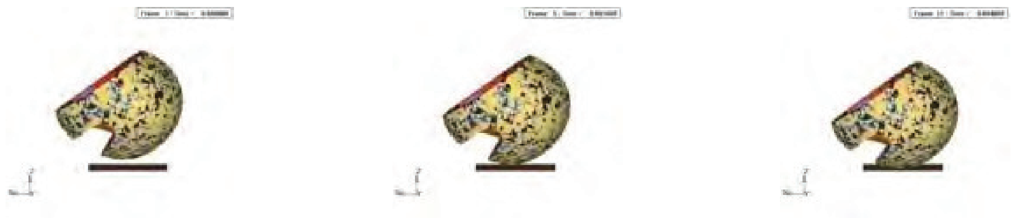


Figure 14 – Frames of the impact test at point B of the Helmet

As a result of the simulation developed in order to validate the model, the acceleration behavior curve is similar to the experimental test performed by Bosh [2]. However, the acceleration peak is lower. Nevertheless, due to the fact that the experimental helmet only had one layer, it is acceptable.

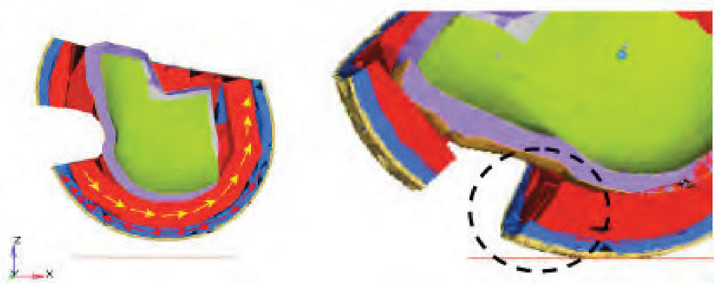


Figure 15 – Independent movement between the two layers of protective padding.

In all ECE R22/05 simulations, the helmet has shown excellent behavior and proves to be safer. The obtained acceleration behavior curve shows that the introduction of a new foam layer considerably reduces the inertia between the head and the helmet.

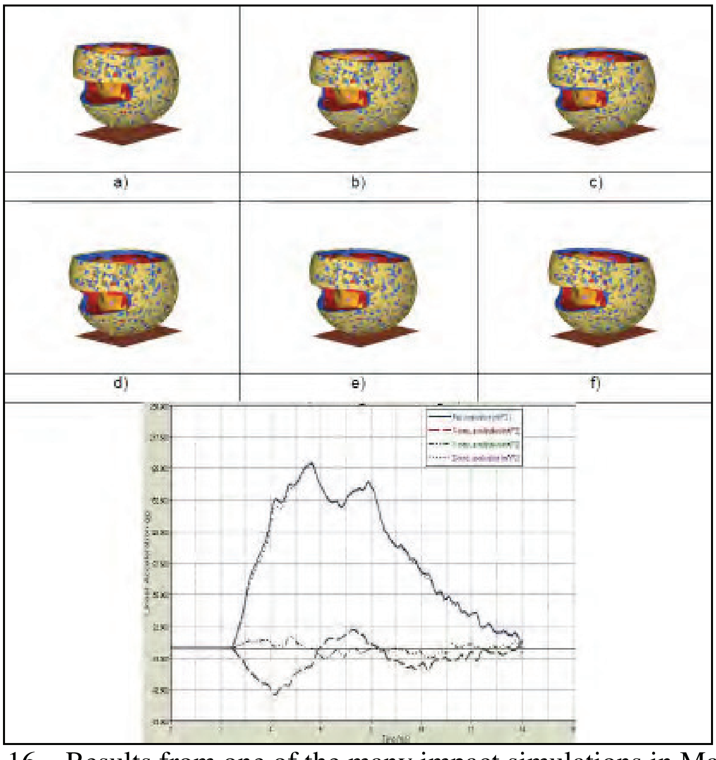


Figure 16 – Results from one of the many impact simulations in Madymo.

Higher density foam materials proved to have a negative effect as they magnified head acceleration.
In simulations with combined layers of different materials explain that the denser material should always be placed between the head and the shell of the helmet or it will not be effective.

CONCLUSIONS

The work developed in this thesis has allowed verifying that, in Portugal and over the year 2005, per 1000 vehicles in circulation, the number of fatal victims in PTWs is eight times superior to the numbers presented by the rest of the vehicles. This large number of fatalities is strongly connected to the use of the helmet, showing that in what concerns bicycles – the use of helmets is not mandatory – none of the fatal or severely injured victims wore helmet. Concerning all the other PTW categories, it was possible to ascertain an increased severity of injuries in the absence of the helmet. Therefore, the mandatory use of the helmet is a key aspect in the reduction of road deaths involving PTWs.
Regarding the work developed in the reach of European project COST357 PROHELM, it was possible to establish that, in Portugal, the majority of interviewed drivers wears integral helmets, which is a good sign considering that this is the type which offers most protection. It is also possible to conclude that those pointed as the most important aspects to consider when purchasing a helmet is the price, followed by the quality and safety. In addition, it was observed that the certification of the equipment is still a problematic issue.
Regarding the damages observed in helmets in Portugal it becomes clear that the most affected areas are the back and both the sides, same as other countries. Though some of the results concerning visibility were slightly different from one country to another, it was possible to observe that, in general, all helmets offer good visibility conditions.
The computational model developed for the helmet was projected with one main goal: improve PTW drivers' safety. It also allows manufacturers to achieve a time-cost benefit while improving their clients' safety.
A new two-layered system was developed, placing the foam in the inner most interior part of the helmet, proving to be quite effective and most promising in reducing acceleration levels and head sustained injuries, by reducing the friction between the head and the equipment.
The ECE R22/05 norm simulations ensured that the proposed helmet was well within the imposed minimum security, making it viable for commercialization.
The density of the foam material is a very important property as it is directly linked to increases or decreases in acceleration values and, therefore, increased or decreased severity of the injuries.
The fact that the developed model presents two foam layers inside is evidence that a combination of different materials is possible. In these simulations, the obtained results merely show that the thinner layer should be the densest if it is expected to be effective in reducing acceleration. However, this subject should be target of new and further studies, namely to investigate a possible combination with some materials which present a non-Newtonian fluid behavior; or some as gel, used in high performance footwear and which present excellent impact absorption properties.

FUTURE DEVELOPMENTS

In the future there is also room to simulate targeting the incorporation of the model helmet developed using the anthropomorphous model Hybrid III. With the main purpose of quantify the degree of effort and injuries concerning the human neck, caused by linear and rotation accelerations.

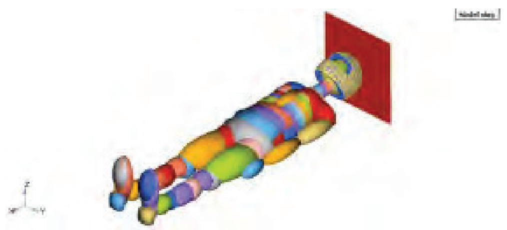


Figure 17 – Future simulations using anthropomorphous model Hybrid III.

Lastly, new crash scenarios should be implemented in order to recreate real accidents incorporating vehicles instead of laboratorial tests.

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