A methodology to evaluate injury risk and accident conditions from injuries in vehicle-to-pedestrian accidents

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Abstract - Pedestrians represent about 20% of the overall fatalities in Europe's road traffic accidents. In this paper a methodology is proposed to understand why the numbers are so high, especially in the south of Europe and particularly in Portugal, . First a detailed statistical analysis using Ordinal Logistic Regression model (OLR) was applied to the gathered data from all Portuguese accidents with victims in the period 2010-2012. In a second stage accident reconstruction computational techniques using pedestrian biomechanical models are used to evaluate the accident conditions that lead to the injuries, such as the speed and the impact location. For biomechanical injury criterions, the AIS (Abbreviated Injury Scale), the HIC (Head Injury Criterion) and other injury criterions based on the resulting accelerations in the pedestrian's body are used.

The statistical model reported that there were several predictors that significantly influenced the pedestrian injury severity in the event of a road accident, such as Pedestrian's age, Pedestrian's gender, Vehicle Design/Category or Driver's gender. The use of injury scales and biomechanical criterions in in-depth investigation of road accidents, such as AIS, can significantly improve the quality of the reconstruction process.

NOTATION

HIC	Head Injury Criterion
ANSR	Portuguese National Road Safety Authority
AIS	Abbreviated Injury Scale
a	Acceleration
EES	Energy Equivalent Speed
m	Mass
t	Time
v	Velocity
OR	Odds Ratio

INTRODUCTION

The 2013 global status report on road safety conducted by the World Health Organization [1] states that injuries resulting from road traffic accidents are a public health problem and an impediment to development, being expected, if immediate measures are not implemented, that road accidents will become the 5th leading cause of death in the world by 2030. The Southern European countries have specific accident patterns and Portugal is one of them. Despite the recent reduction in road accident numbers reported in Portugal, it has not been reflected so distinctly among pedestrians, which still present concerning numbers of road accidents and in terms of accidents severity. Pedestrian fatalities are a social health issue in Portugal. For every 100 accidents of the same type, cars generate 1.5 fatalities whereas pedestrian run-overs generate 3.4.

Figure 1 shows the evolution in the number of pedestrian fatalities in the European Union with 15 Member States (excluding Luxembourg because of its small numbers) up to the available 2012 data according to the latest CARE database statistics [2]. From this perspective it is clear that even having a continuous improvement since 2000, Portugal still constitutes one of the worst cases in terms of pedestrian accidents in the most recent years, lagging behind the European average and around the same level as or below larger countries.

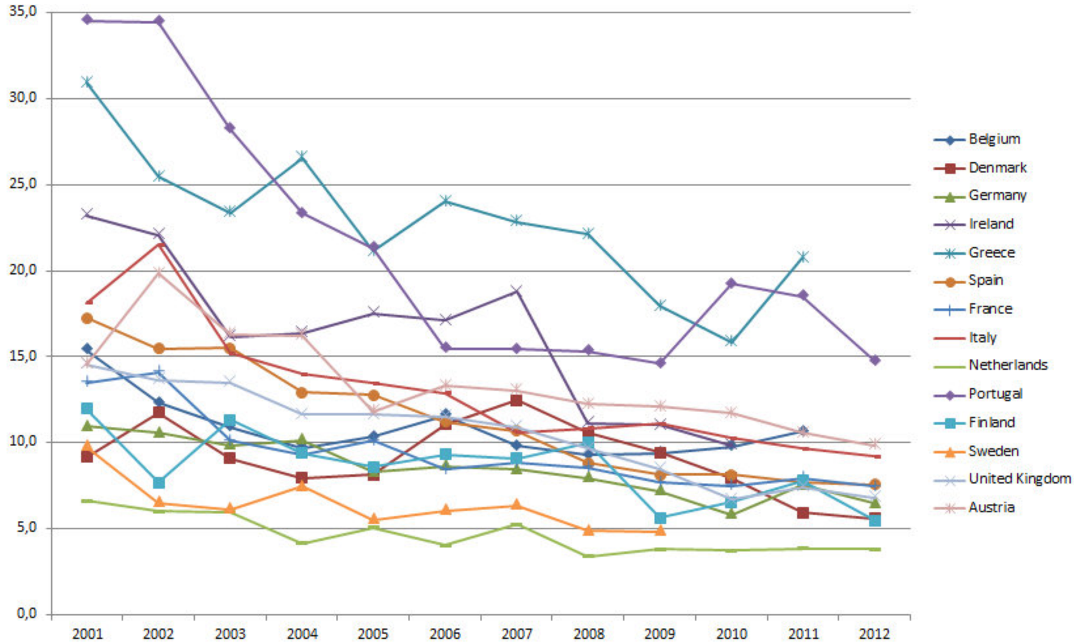

Figure 1. Pedestrian fatalities per million inhabitants in the EU15.

In 2012 alone, in Portugal's mainland, 38823 casualties in road accidents occurred, resulting 718 deaths, from which 22% were pedestrians [3]. It follows that pedestrian accident severity in Portugal is a real problem that demands the development and implementation of specific road safety measures. Through the statistical analysis of road accidents one can determine patterns and identify the determinant factors in the occurrence and severity of accidents, and in this particular case, of pedestrian accidents. The in-depth study of these specific accidents, resorting to scientific methods and namely, the use of computational models, allows the increase of knowledge in this particular field in order to evaluate tendencies, isolate problems and areas where taking actions is a priority and supports the development of effective countermeasures to improve pedestrian safety.

METHODS

This work uses the 2010, 2011 and 2012 accident databases of Portuguese National Road Safety Authority (ANSR) [4]. Each of them encompasses detailed information on every accident with victims occurred in the 2010-2012 three year period, such as casualties, injury severity, crash location, main cause of collision, alcohol tests, among others. Concerning pedestrians, the database stores information on 16305 run-overs.

During the database preparation, a critical assessment of the validity and consistency of each entry was performed. In some run-overs, the pedestrian was hit by more than one vehicle. In such cases, only the primary vehicle's information was considered. On the other hand, the Portuguese National Road Safety Authority stores their accident data in different tables, i.e., there is a table for the accidents themselves, a table for drivers, a table for passengers and a table for pedestrians. This method poses some problems, as the only common column is the accident ID. In such a way, using the raw database it is impossible, for instance, in the driver's table to determine the injuries caused to the pedestrians or in the pedestrian's table to determine which type of vehicle hit the pedestrian. To overcome this, a Matlab routine was developed to connect all the information in a new table to be used for the statistical analysis. In this process, the pedestrian run-overs that did not possess driver's information were eliminated, as well as the remainder of the entries with missing values on relevant variables, namely, 3400 entries. The final sample was comprised of 12905 pedestrian victims, 11502 of which sustained slight injuries, 964 severe injuries and 434 fatalities. Levels of injury severity resulting from a crash are included in the ANSR database [4] thereby enabling the construction of a categorical variable that captures different ranks of severity following a similar strategy as Albalate and Fernández-Villadangos [5]. Thus, the dependent variable contains 3 increasing degrees of severity according to police reports following the crash: slight, severe, and fatal. The ordinal regression was then applied using a number of potential determinants as explanatory variables of injury severity to estimate the determinants of differences in the degree of accident severity. The theoretical background concerning regression models and in particular, ordinal regression models, is described more in detail in the literature [6, 7].

STATISTICAL ANALYSIS

The results are presented in terms of the odds ratio (OR) associated to each predictor category. If OR = 1, it indicates that there is no effects in the categories in analysis. If OR > 1 or OR < 1, it indicates an increase or a decrease in the likelihood [7]. For all these conclusions and analyses we also need to consider the statistical significance (p-value) of the results. A 95% confidence interval (CI) was used because a p-value of 5% is the convention for rejecting the null hypothesis in a significance test. This means that there is 95% likelihood for the fact that true OR value falls between the lower and upper portion of the 95% confidence interval.

The demographic results confirm what is commonly assumed. Table 1 shows that for pedestrians there is a decrease in injury severity the younger they are, when compared to the reference category. For the younger pedestrians considered, aged up to 14, the 95% confidence interval reports an OR between 0.750 and 0.516. Regarding vehicle drivers, the reference category is an age between 30 and 39 and only one category was found to be statistically significant, namely, category 4 (more than or equal to 70). The results indicate that there is a decrease in injury severity when the vehicle driver is an elderly person, with an OR of 0.725. Note that the entire 95% confidence interval reports a reduction in injury severity, with results between 0.557 and 0.943.

Table 1 - Estimates on the determinants of road accident severity for the Pedestrian's Age variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Pedestrian's Age	1. Less than or equal to 14	0.623	0.000	0.750	0.516	2113	16.4%
	2. 15 - 39	0.607	0.000	0.713	0.516	3092	24.0%
	3. 40 - 64	0.675	0.000	0.780	0.584	3801	29.5%
	4. More than or equal to 65 (reference)	--	--	--	--	3994	30.2%

Table 2 - Estimates on the determinants of road accident severity for the Driver's Age variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Driver's Age	1. 40 - 49	1.040	0.655	1.232	0.877	2649	20.5%
	2. 50 - 59	0.871	0.159	1.055	0.719	2028	15.7%
	3. 60 - 69	0.916	0.422	1.135	0.739	1433	11.1%
	4. More than or equal to 70	0.725	0.016	0.943	0.557	1066	8.3%
	5. Less than or equal to 19	0.954	0.806	1.392	0.653	363	2.8%
	6. 20 - 29	1.161	0.086	1.376	0.979	2415	18.7%
	7. 30 - 39 (reference)	--	--	--	--	2946	22.8%

Driver’s gender, displayed on Table 2, also plays an important role in injury severity. If the vehicle driver is of the female gender, an OR of 0.829 reports a decrease in injury severity, which extends to the whole 95% confidence interval, with values lying between 0.721 and 0.952.

Table 3 - Estimates on the determinants of road accident severity for the Driver's Gender variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Driver's Gender	1. Feminine	0.829	0.008	0.952	0.721	3408	26.4%
	2. Masculine (reference)	--	--	--	--	9492	73.6%

Portugal’s capital city is Lisbon. It is commonly assumed by the Portuguese that Lisbon has a great deal of Portugal’s road accident victims. Where pedestrians are concerned, Lisbon has in fact the highest number of fatalities, the highest number of severe injured and the highest number of slightly injured. Lisbon also has the highest number of habitants. The geographic analysis presented in Table 4 concludes that, even though Lisbon leads the way in terms of global numbers, the pedestrian injury severity increases in every other District. Note that two of them, Coimbra and Oporto, are not statistically significant, on account of their higher than 0.05 p-value.

Table 4 - Estimates on the determinants of road accident severity for the District variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
District	1. Aveiro	1.317	0.042	1.714	1.010	777	6.0%
	2. Beja	2.197	0.007	3.896	1.239	88	0.7%
	3. Braga	1.958	0.000	2.433	1.575	1057	8.2%
	4. Bragança	3.281	0.000	5.280	2.038	109	0.8%
	5. Castelo Branco	2.210	0.000	3.408	1.433	176	1.4%
	6. Coimbra	0.854	0.427	1.261	0.579	432	3.3%
	7. Évora	2.286	0.001	3.728	1.402	134	1.0%
	8. Faro	2.077	0.000	2.697	1.602	607	4.7%
	9. Guarda	2.168	0.002	3.532	1.331	121	0.9%
	10. Leiria	1.422	0.016	1.893	1.069	590	4.6%
	11. Viseu	1.571	0.006	2.173	1.137	411	3.2%
	12. Portalegre	2.452	0.001	4.216	1.426	96	0.7%
	13. Oporto	1.142	0.159	1.374	0.949	2647	20.5%
	14. Santarém	2.307	0.000	3.152	1.689	360	2.8%
	15. Setúbal	1.470	0.001	1.848	1.169	1081	8.4%
	16. Viana do Castelo	1.786	0.002	2.588	1.234	264	2.0%
	17. Vila Real	1.557	0.038	2.363	1.025	229	1.8%
	18. Lisbon (reference)	--	--	--	--	3721	28.8%

Regarding road grip conditions, the considered reference category was a clean and dry surface (see Table 5). The analysis determined that if the road surface is coated with ice, frost, snow, gravel or sand there is a massive increase in injury severity. In the ice frost or snow category, the 95% confidence intervals predicts an OR that can be as high as 18.247. Unfortunately, the wet surface category was not found to be statistically significant.

Table 5 - Estimates on the determinants of road accident severity for the Grip Conditions variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Grip Conditions	1. Wet	0.966	0.575	1.092	0.853	4897	38.0%
	2. With ice, frost or snow	4.371	0.043	18.247	1.048	7	0.1%
	3. With gravel or sand	3.364	0.004	7.706	1.470	26	0.2%
	4. Clean and dry (reference)	--	--	--	--	7970	61.8%

The analysis of lighting conditions presented on Table 6 determined that there is an increase in injury severity the worse they are, with both night categories presenting OR's greater than 1. Comparing categories 2 and 3, it can be concluded that the absence of illumination during nigh time is a critical factor for pedestrian injury severity.

Table 6 - Estimates on the determinants of road accident severity for the Luminosity variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Luminosity	1. Dawn or dusk	1.269	0.152	1.756	0.917	401	3.1%
	2. Night, with illumination	1.242	0.022	1.496	1.031	2810	21.8%
	3. Night, without illumination	2.024	0.000	2.633	1.556	491	3.8%
	4. Day (reference)	--	--	--	--	9198	71.3%

Vehicle type was also considered as a possible determinant of injury severity. Being a light vehicle the reference category, the results presented on Table 7 state that there is a decrease of injury severity when getting hit by a two-wheeled vehicle and an increase of injury severity when the pedestrian is hit by a heavy goods vehicle.

Table 7 - Estimates on the determinants of road accident severity for the Vehicle Category variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Vehicle Category	1. Heavy goods vehicle	2.366	0.000	2.980	1.878	516	4.0%
	2. Motorcycle/Moped	0.457	0.000	0.665	0.314	492	3.8%
	3. Other (agricultural or industrial vehicle, vehicle on rails)	2.002	0.013	3.456	1.161	81	0.6%
	4. Bicycle (with or without an engine)	0.440	0.044	0.978	0.198	110	0.9%
	5. Car (reference)	--	--	--	--	11701	90.7%

The analysis of the driver's injury severity variable, presented on Table 8, concluded that the worse the driver's injuries are, so too are the pedestrian's. In a case where the driver dies or suffers graves injuries, the 95% confidence interval states that the OR can be as high as 14.895.

Table 8 - Estimates on the determinants of road accident severity for the Driver's Injury Severity variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Driver's Injury Severity	1. Deceased/Severely Injured	6.482	0.000	14.895	2.821	29	0.2%
	2. Slightly Injured	2.323	0.000	3.203	1.687	359	2.8%
	3. Unharmed (reference)	--	--	--	--	12512	97.0%

The actions undertaken by the pedestrian prior to the accident play a key role in injury severity (see Table 9).

Table 9 - Estimates on the determinants of road accident severity for the Pedestrian's Actions variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Pedestrian 's Actions	1. In the middle of the road	1.919	0.000	2.298	1.603	1589	12.3%
	2. Walking along the right lane	1.251	0.196	1.756	0.891	389	3.0%
	3. Walking along the left lane	1.313	0.198	1.986	0.868	230	1.8%
	4. Walking along the curb or sidewalk	1.340	0.012	1.687	1.065	974	7.6%
	5. In a pedestrian refuge on the road	0.869	0.711	1.822	0.414	108	0.8%
	6. In a road subject to construction work	1.456	0.272	2.843	0.745	84	0.7%
	7. Crossing a signalized passage with semaphore signalling disrespect	1.473	0.046	2.153	1.007	300	2.3%
	8. Crossing outside the pedestrian crossing, less than 50 meters from a pedestrian crossing	1.505	0.000	1.818	1.245	1656	12.8%
	9. Crossing outside the pedestrian crossing, more than 50 meters from a pedestrian crossing or where there is none	1.404	0.001	1.728	1.140	1272	9.9%
	10. Exiting or entering a vehicle	1.067	0.784	1.697	0.671	225	1.7%
	11. Appearing unexpectedly on the road from behind an obstacle	1.652	0.000	2.067	1.320	1114	8.6%
	12. Crossing at a signalized crossing (reference)	--	--	--	--	4959	38.4%

The reference considered is to cross the street at a signalized pedestrian crossing. The highest increase is reported by category 1, when the pedestrian is in the middle of the road, with an OR between 1.603 and 2.298. If the pedestrian is crossing the road at a crosswalk but disregarding the light signals (category 7) or crossing the road outside the proper crossing (category 8), the OR's are 1.437 and 1.505, respectively, indicating an increase on injury severity with these illegal actions.

When the pedestrian appears unexpectedly from behind a vehicle (category 11), there is also an increase on injury severity, with an OR ranging from 1.320 to 2.067. However and from in-depth accident investigation, has been found than this is a typical driver excuse if the driver is speeding. In accident investigation and for the determination of the legal responsibilities it's necessary to evaluate the dynamics of the accident and to check the driver's statement.

INJURY BIOMECHANICS

Statistical analysis provides an evaluation of the measures applied for improving road traffic accidents. However, this type of analysis corresponds just to a first phase of an investigation process and lacks fundamental information to increase the level of detail and understanding peculiarities associated with pedestrian road accidents, given the limitations imposed by the events to which the police do not have access on the accident site, such as the pre-impact vehicle velocities, the cause of the accident and the responsibility of their occurrence. So, the need arises for an in-depth investigation in order to analyze and have access to important and fundamental aspects of an accident, absent in a mere statistical analysis.

Engineering plays a key role, acting in two ways to solve pedestrian road accidents problems: after the accident, combining research with computer simulations in order to clarify how it occurred, isolating the key factors for its occurrence and determining responsibilities; in terms of prevention, recreating impact situations to analyze and evaluate the influence of certain parameters on the occurrence of pedestrian road accidents resulting in injuries, the effectiveness of the solutions/measures on the safety of pedestrians currently available or projecting new solutions in a simple, efficient and economically feasible way. The outputs of these reconstructions do not only target the scientific community. They also have a social interest where they may lead to the definition of measures and procedures in order to reduce the high rates associated with pedestrian road accidents as well as for dissemination by the entire population of the risk involved in certain type of situations identified as dangerous in these accidents, to try to mitigate the problem.

Impact biomechanics studies the forces acting on the human body, namely, impact forces, the effects produced by these forces and ways to reduce or eliminate the structural and functional damages on the body deriving from an impact situation [10]. The software PC-Crash can be used to evaluate the pedestrian's biomechanical behavior in an impact and analyze the injury severity based on acceleration levels obtained in the collision simulation. In its base are the multibody dynamics formulations, which are explained in detail in the literature [11] and on the software applied technical manual [12]. In practical terms, the injury level evaluation is done by using injury criteria applied to acceleration data withdrawn from the multibody models representing the human body in the impact simulation.

Injury criteria are a set of physical parameters correlated with the severity of the injury inflicted in the body area in analysis that indicate the potential for inducing injuries from the impact. These criteria are essential in the development of safety devices and for evaluating their efficiency. Concerning a fundamental vital area of the human body, the head, criteria to assess injury severity in an impact such as HIC (Head Injury Criterion) are available.

Head Injury Criterion

HIC is a criterion based on the head linear acceleration evaluated, for example, from biomechanical models, in a given interval, that is computed with the following expression:

$$HIC = \left\{(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\}_{Max} \quad (1)$$

In this expression the acceleration pulse *a(t)* at the head's center of mass is measured in multiples of the acceleration of gravity [g] in the time interval (t_2-t_1) that maximizes the HIC value. The maximum HIC value admitted, beyond which the resultant injuries are expected to be severe and permanent, requires t_2 and t_1 not to lay more than 15ms apart for a direct impact or an interval (t_2-t_1) of 36ms for an indirect one, with a HIC tolerance limit of 700 (HIC_{15}) and 1000 (HIC_{36}) for each case and considering the 50th percentile male [10,13].

Abbreviated Injury Scale

The Abbreviated Injury Scale (AIS) is a criterion based on an anatomic scale divided in six different levels that define the kind of injury and respective severity level for each part of the human body and the higher the AIS value, the higher the respective injury severity, culminating in death. There is a direct correlation between HIC and AIS (Figure 2) that enables the conversion of the head acceleration levels determined in computational simulations into injury severity.

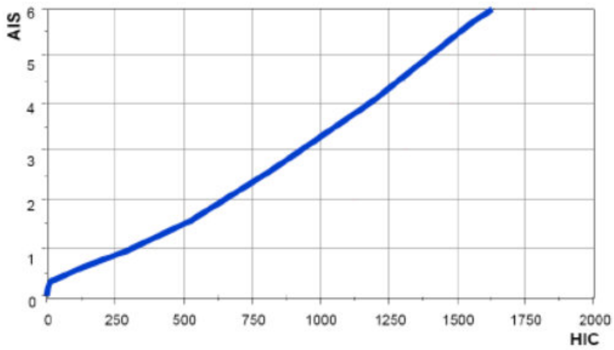

Figure 2. Correlation between HIC and the AIS scale [14].

This relation is used to evaluate the head injuries.

RECONSTRUCTION OF VEHICLE-TO-PEDESTRIAN ACCIDENTS

The methodology applied on the in-depth study of pedestrian accidents is an adaptation of the MAIDS methodology [8], following the same objectives, but in its application it's similar to the study undertaken by Clarke *et al.* [9]. The computational reconstitution of accidents is treated as an optimization process, where velocities and pre-impact positions are variable parameters. The procedures include the analysis of post-accident records handled by the police authorities, such as the accident sketch, pictures of the site and vehicles, as well as autopsy reports. The next step involves building the accidents computational layout based on this data and performing the computational simulations. Then one can estimate the pre-impact conditions, such as speed, position and course of the vehicles.

In a pedestrian run-over reconstruction, the only information collected by the police forces is usually the rest positions of the vehicle and the pedestrian's body. In most cases, one is seeking to determine both the impact speed and location. Thus, a problem arises: irregardless of the considered impact point, it's possible to determine an impact speed that throws the pedestrian to his recorded rest position. The differences between this wide set of possible solutions lie in the severity of the injuries sustained by the pedestrian, i.e., whether or not they are consistent with the contact forces. For each simulation, the pedestrian's injuries can be evaluated through the use of biomechanical injury criterions, which are then compared with the value stated in the autopsy report.

This work uses the Head Injury Criterion (HIC), which is based on the evaluation of the resultant head acceleration. For values greater than 700, serious and permanent injuries are to be expected. There is also a correlation between the HIC value and the Abbreviated Injury Scale (AIS) that enables the transformation of the HIC value in an AIS value, more easily compared with the autopsy report.

The case study represents a run-over involving a 59 years-old pedestrian and a BMW 318 during nigh time conditions. For the pedestrian's model, the anthropometric dimensions considered were a mass of 78,4 kg and height of 1,75 m, which correspond to the 50th percentile adult male [13] and the computational simulations were carried out considering a restitution coefficient of 0,1, a friction coefficient for the ground of 0,7 and a friction coefficient between the pedestrian and the pavement of 0,4. In the accident sketch provided by the police forces, multiple points of view can be seen. The witness report that the run-over occurred in a point situated 19 meters after the crosswalk, offering no estimation for the impact speed. The driver reports that he hit the pedestrian in a point 11.5 meters after the one reported by the witnesses, at a speed of 40 km/h. 14 meters after the point reported by the driver, we get to the pedestrian's rest position.

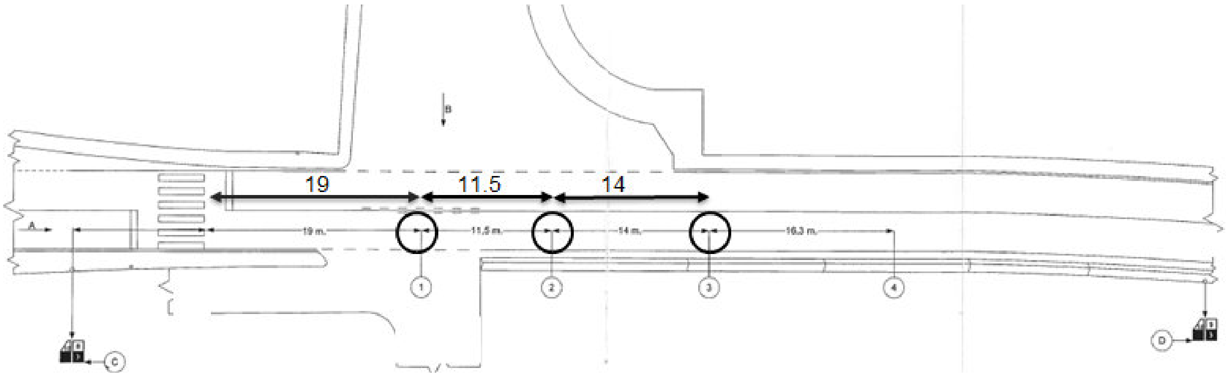

Figure 3. Accident sketch.

In a pedestrian run-over both the impact speed and impact location need to be determined. The problem is, no matter what impact location is chosen it's possible to determine an impact speed that throws the pedestrian to his rest position. The difference between all the possible scenarios will be given by the biomechanical injury criterions results. In this case, the pedestrian suffered skull and cervical injuries, fractured multiple ribs, both tibias and both humerus.

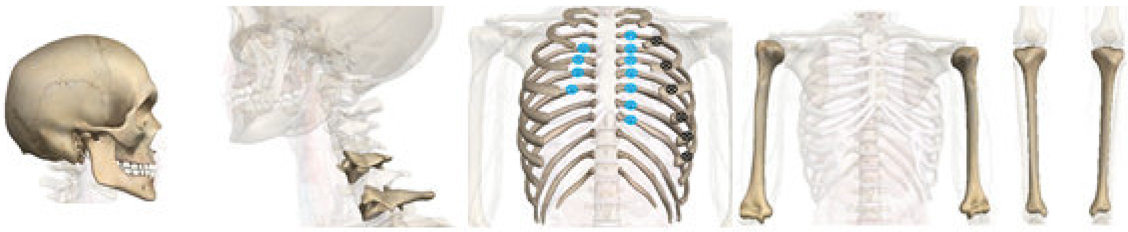

Figure 4. Bone injuries sustained by the pedestrian.

Bearing this in mind, three scenarios were investigated. In the first scenario, using the speed an impact point provided by the vehicle's driver, it was determined that neither the pedestrian's projection nor the biomechanical injury criterions were compatible with the ones described in the autopsy report. In the second scenario, still using the impact point reported by the driver but with an impact speed compatible with a projection to the pedestrian's rest position, the biomechanical injury criterions still were not compatible. In the third scenario, using the impact point reported by the witnesses with an impact speed compatible with a projection to the pedestrian's rest position, an AIS of 6, very different from the previous two scenarios was obtained. To determine the minimum speed compatible with both the injuries and the projection, starting on the impact point reported by the driver, several impact points behind it were considered, spaced 2 meters from one another. The injury results are presented on Table 11.

Table 10 - Injury output for the additional simulations.

Distance [m]	Velocity [km/h]	HIC	AIS
2	51	695.35	2
4	55.5	933.47	3
6	60	1360.26	4
8	63.5	1435.94	5
10	66	1697.32	5

It was determined that the minimum impact speed compatible with both the injuries and projection was of 60 km/h, 10 km/h, over the speed limit, in a point situated 6 meters behind the one reported by the driver. Furthermore, for this simulation there is compatibility between the vehicle's structural deformation and the injuries sustained by the pedestrian, namely, a primary impact between the lower limbs and the front of the vehicle and a secondary impact between the pedestrian's neck and the windshield, in which the cervical fracture may have occurred.

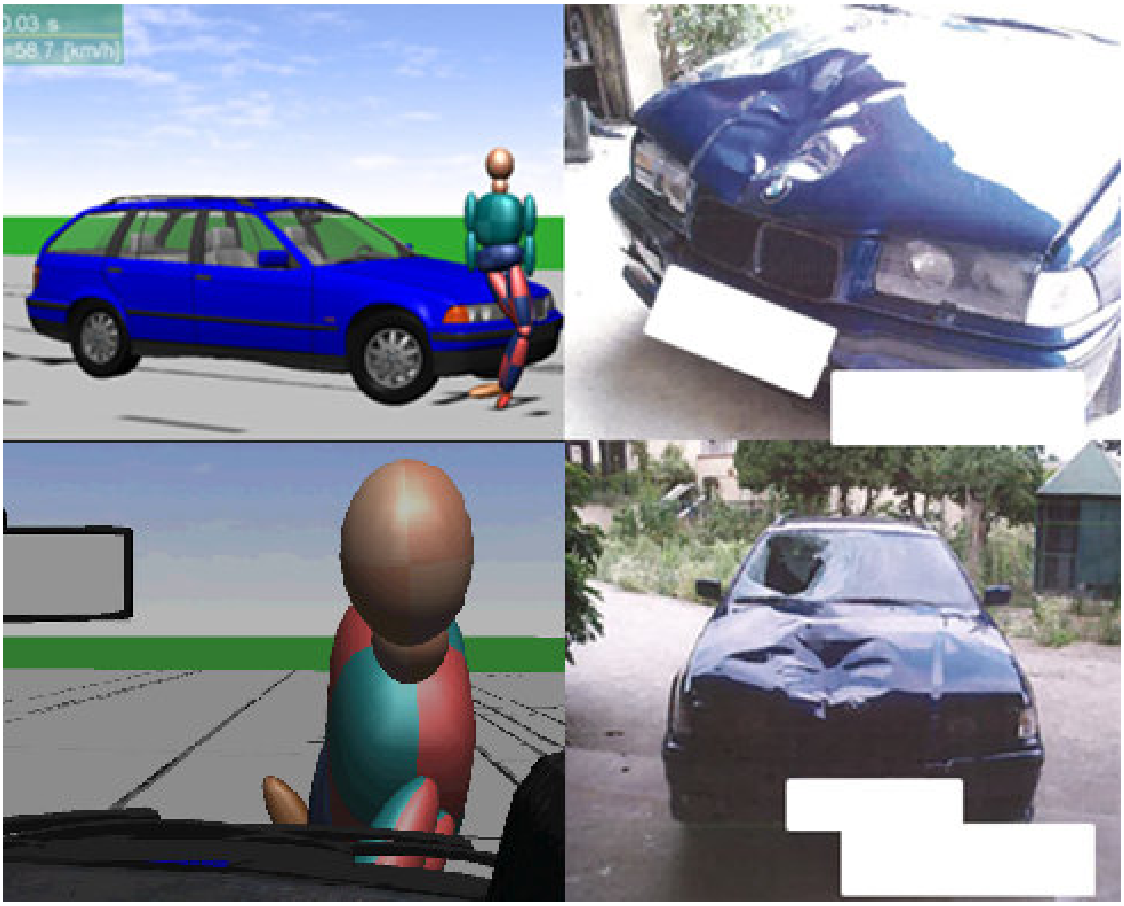

Figure 5. Compatibility between injuries and structural deformation.

The calculated impact speed is also well correlated with EES (Energy Equivalent Speed) databases, namely, the structural deformations are, seemingly, between the 60 km/h and the 70 km/h level, as it can be seen on Figure 6.

Figure 6. Reference EES values for pedestrian run-overs.

This methodology is widely used to determine the accident conditions.

CONCLUSIONS

This work established a connection between impact biomechanics, accident reconstruction and autopsy data for application to a real pedestrian run-over occurred in Portugal. Besides demonstrating the use and importance of injury biomechanics, it was intended to demonstrate the importance of computational reconstruction of road traffic accidents with the use of accident reconstruction software. The determined injury severity key factors may be used by police forces to more quickly assess the situation, establishing a theoretical framework between accident conditions and injury severity. The detailed comprehension of severe accidents involving pedestrians, injury mechanisms and their distribution in the pedestrian, translated into measurable data reveal themselves to be a valuable instrument to have a based perspective on the problem and identify the primary measures to apply, as well as in monitoring their efficiency. Preventive actions should combine education, law enforcement and engineering. Educational policies should influence and guide driving training and mainly the driver's and pedestrian's attitude more intensively by increasing their information about risk exposure and the responsibility of their actions. Police control interventions should be focused in reducing high risk behaviours, mainly, high speed driving and intensified in times and locations identified as critical. Engineering can act in the development of systems that increase pedestrian safety in case of an accident, like frontal airbags. Accident investigation and computational reconstitution are also important to clarify the responsibility of their occurrence, causes and to support safety measures.

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REFERENCES

1. World Health Organization, Global Status Report on Road Safety: Time for Action, Geneva, World Health Organization, 2013.
2. CARE, "CARE database - reports and graphics", Accessed 13th May 2014, <http://ec.europa.eu/transport/road_safety/specialist/statistics/care_reports_graphics/>.
3. ANSR, Sinistralidade Rodoviária 2012, Observatório de Segurança Rodoviária, 2013.
4. Pedestrian database, Portugal, ANSR, 2012.
5. D Albalate, L Fernández-Villadangos, Motorcycle Injury Severity in Barcelona: The Role of Vehicle Type and Congestion, Traffic Injury Prevention, 11 (6), 623-631, 2010.
6. W D Hosmer, S Lemeshow, Applied Logistic Regression, New York, Wiley, 2000.
7. M Norusis, SPSS 13 Advanced statistical procedures companion New Jersey, Prentice Hall Inc, 2004.
8. ACEM, MAIDS In-depth investigations of accidents involving powered two wheelers Final Report 2.0, Brussels, 2009.
9. D D Clarke, P Ward, C Bartle, W Truman, In Depth Study of Motorcycle Accidents Road Safety Research Report Nº 54, ISSN 1468 – 9138, 2004.
10. M Silva, “Biomechanics of Motion”, Lisbon, Instituto Superior Técnico – Technical University of Lisbon, 2004.
11. P E Nikravesh, Computer-Aided Analysis of Mechanical Systems, Englewood Cliffs, New Jersey, Prentice-Hall, 1988.
12. S Datentechnik, PC-Crash A Simulation program for Vehicle Accidents - Technical Manual 6.2, Linz, Austria, 2001.
13. K-U Schmitt, P Niederer, M Muser, F Walz, Trauma Biomechanics- Accidental injury in traffic and sports, Verlag Berlin Heidelber, Springer, 2010.