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The influence of urban network characteristics in pedestrian injury severity. A case study from Lisbon.

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Abstract

In Portugal, from 2010 to 2016, 97% of the injured pedestrians occurred on streets and roads in urban areas. This study aims to investigate the risk factors associated with various levels of injury severity that pedestrians experience in the city of Lisbon, Portugal. To accomplish this analysis, a geocoded database on road accidents and victims occurred in Lisbon between 2008 and 2011 was used.
The analysis was conducted using a multinomial logit model, to estimate pedestrian' injury outcomes variables, disaggregated by level of severity. The driver's gender, the pedestrian's age, the type of pedestrian crossing, the land use characteristics, and the time of day were identified as influential in pedestrian injury severity. It was also found that, business areas increased the probability of pedestrian death and that serious pedestrian injuries were less likely to occur in the presence of female drivers compared to male drivers.

Keywords: Pedestrian safety; Injury severity; Built environment; Multinomial logit model; GIS.

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1. Introduction

Crash occurrence in urban environments represents a critical safety issue for every city in the world, as the opportunities for crashes involving pedestrians or cyclists and motorized vehicles increase with urbanization growth. According to the CARE database (the Community database on road accidents resulting in death or injury), in 2015, the percentage of pedestrian deaths rounded 69% in urban areas and 31% in rural areas (ERSO, 2017). In Portugal, pedestrian deaths accounted for 24% of all road deaths in 2015, which is slightly higher than the European average (21%). However, when pedestrian fatal injuries are analysed according to their place of occurrence, it is found that 76% occur in urban areas, which reflects the magnitude and the special characteristics of the Portuguese problem (ANSR, 2015).

Walking in a safe environment is indispensable to promote pedestrian traffic. However, following recent urbanization and motorization developments, the built environment has become less friendly for pedestrians, making walking activities unsafer than previously, even in developed countries. Pedestrian safety can be improved by knowing the underlying factors involved in crash occurrence and resulting injuries. The consideration of variables related to the built environment in the explanation of crashes and injury outcomes is frequent and helpful. Several studies have examined the relationship between built environment factors and pedestrian crash severity.

Lee and Abdel-Aty (2005) studied vehicle–pedestrian crashes at intersections in Florida for a period of four years. They estimated the likelihood of pedestrian injury severity when pedestrians are involved in crashes using an ordered probit model. The results showed that pedestrians between 15 and 24 years of age are less likely to suffer severe injuries in crashes, while older pedestrians are more likely to sustain severe injuries, as a result of weaker physical conditions.

Sze and Wong (2007) worked on the evaluation of injury risk of pedestrian casualties in traffic crashes and in the identification of the factors that contribute to mortality and severe injuries in Hong Kong. Through the use of a binary logistic regression, they identified a decreasing trend in pedestrian injury risk, controlling for the influences of demographic, road environment, and other risk factors. The factors identified as decreasing risk of pedestrian mortality and severe injury were being male and aged below 15, being on an overcrowded or obstructed footpath, and being involved in a daytime crash on a road section with severe or moderate congestion. A casualty age above 65 years, head injury, a crash at a crossing or within 15 m of a crosswalk, and a crash on a road section with a speed limit above 50 km/h, a signalized intersection, or two or more lanes led to a higher risk of mortality and severe injury.

Kim et al. (2010) addressed unobserved heterogeneity using a mixed logit model to analyse pedestrian-injury severity in pedestrian-vehicle crashes. The data set comprised police-reported collisions from 1997 to 2000 from North Carolina. Several factors were found to affect the probability of pedestrian fatal injuries in motor-vehicle crashes, including: darkness without streetlights (400% increase in fatality probability), truck involvement (370% increase), freeway (330% increase), speeding (360% increase), and collisions involving a drunk driver (250% increase).

Miranda-Moreno et al. (2011) analysed the influence of the built environment (land use types, road network connectivity, transit supply, and demographic characteristics) at signalized intersections on pedestrian activity and pedestrian–vehicle collision occurrence, using a two-equation modelling framework. It was found that the built environment in the proximity of an intersection has a small direct effect on pedestrian-vehicle collision frequency, a 30% reduction in the traffic volume induces a reduction of 35% in the total number of injured pedestrians and 50% reduction in the average risk of pedestrian collision.

Pulugurtha and Sambhara (2011) studied the non-linear relationship between pedestrian crashes at intersections and variables such as demographic characteristics (population and number of household units), socioeconomic characteristics (mean income and total employment), land use characteristics, road network characteristics (the number of lanes, speed limit, and presence of median, and pedestrian and vehicular volume) and accessibility to public transit systems. This study was performed using a generalized linear pedestrian crash estimation model, and concluded that an increase in the population, the number of transit stops, the number of approaches at an intersection and the pedestrian volume will exponential increase the number of pedestrian crashes. Land use predictor variables such as single family residential area, urban residential commercial area, commercial center area and neighborhood service district have a negative effect on the pedestrian crashes.

Tarko and Azam (2011) used a bivariate ordered probit model with sample selection (to check for the presence of the selectivity bias) in the pedestrian injury analysis. The authors found that male and older pedestrians were particularly exposed to severe injuries; that rural roads and high-speed urban roads appear to be more dangerous for pedestrians, particularly when crossing such roads. Crossing a road in between intersections was found to be particularly hazardous behaviour. The size and weight of the vehicle involved in a pedestrian crash were also found to affect the pedestrian injury level.

Rothman et al. (2012) investigated the relationship between pedestrian motor vehicle collision injury severity and crossing location in Toronto, Canada. The analysis was made through binary and multinomial logistic regression models to estimate Odds-Ratios of injury severity with 95% confidence intervals. The authors concluded that crossing at uncontrolled mid-block locations resulted in greater injury severity compared with crossing at signalised intersections.

Mohamed et al. (2013) combined data mining and statistical regression methods to identify the main factors associated with the levels of pedestrian injury severity outcomes from New York City, US, and the City of Montreal, Canada. Different approaches were used in these two datasets: for the New York dataset, a latent class with ordered probit method provided the best results, and for the Montreal dataset, K-means with a multinomial logit model proved to be the most appropriate. Among other findings, it was found that pedestrian age, location type, driver age, vehicle type, driver alcohol involvement, lighting conditions, and several built environment characteristics influence the likelihood of fatal crashes.

The study performed by Islam and Jones (2014) explored the factors contributing to the injury severity resulting from pedestrian at-fault crashes in rural and urban locations in Alabama incorporating the effects of randomness across the observations. The authors found that that pedestrian crash severity is influenced by dark lighting conditions and the number of lanes (i.e., two-lane roadways).

Haleem et al. (2015) analysed pedestrian crash injury severity in signalized and unsignalised intersections in Florida. The authors used a mixed logit modelling approach. Their results revealed that standard crosswalks experience a 1.36% reduction in severity at unsignalised intersections and that at-fault pedestrians are more vulnerable to severe injuries at unsignalised intersections.

Sasidharan et al. (2015) developed pedestrian crash injury severity models for Switzerland, using the latent class clustered regression approach. The results revealed that this approach is suitable for reducing heterogeneity and revealed important hidden relationships in traffic safety analyses. The authors concluded that not all variables were found to be significant using the whole dataset and individual clusters. This was the case of heavy vehicles, that when involved in crashes with pedestrian would most likely lead to severe outcome, but for some clusters (mainly from residential areas, with low operating speeds), this effect may not be statistically significant. The study also revealed the need of educational actions and policy changes to prevent pedestrians from making midblock road crossings at locations without zebra crossings. In addition, extensive enforcement measures need to be undertaken in Switzerland to make sure that drivers, especially drivers of heavy vehicles, are giving right of way to the pedestrians at intersections and midblock locations with zebra crossings.

Peng and Zhou (2016) explored the relationship between automobile-involved pedestrian crash frequency versus risk and various built environment factors such as road network and land use, using Bayesian hierarchical intrinsic conditional auto regressive models.

Sun et al. (2019) applied the Latent Class Cluster (LCC) model and the Multinomial Logit (MNL) to identify the main factors in pedestrian crash severity in Louisiana. This combined analysis showed that certain variables that have not been identified as significant in the full data set analysis with the LCC models are identified as significant for a specific cluster with the MNL model, such as pedestrian crossing and entering roads, crash hours between midnight to 6 pm, dark-unlighted conditions, dark-lighted conditions, and non-intersection locations.

Zhai et al. (2019) measured the association between pedestrian crash severity, weather, and possible risk factors, using a mixed logit model. The results indicated that high temperature and the presence of rain were associated with a higher likelihood of fatal and severe injury crashes. Weather conditions (hot weather and presence of rain) were also found to be associated with pedestrian crash severity and pedestrian and driver behaviour (such as jaywalking, speeding, and driving under the influence).

The work done in the scope of the analysis of pedestrian injuries in Portuguese roads is somewhat limited and mainly focused on the computational reconstruction of accidents. Francisco et al. (2015) have used accident reconstruction computational techniques with pedestrian biomechanical models to evaluate the accident conditions that lead to the injuries, such as the speed and the impact location. The statistical model reported that several predictors significantly influenced the pedestrian injury severity in the event of a road accident, such as pedestrian age and gender, vehicle design/category and vehicle driver gender. Teixeira P. (2012) performed an analysis of a set of 100 pedestrian accidents that occurred between 2009 and 2011 in Portugal, to identify factors influencing certain types of injuries and their severity by age group, with a dynamic analysis of the accident and the resulting injuries. Some risk factors were identified in pedestrian accidents, such as the age and gender of the driver, pedestrian road accidents location, lighting conditions and age and gender of pedestrians.

Pedestrian safety analysis in Portugal was also performed by Vieira Gomes (2013), but focusing on pedestrian accident frequencies, instead of injuries. Several models to estimate the frequency of accidents on urban networks were developed using the GLM approach with the Poisson-gamma distribution. Specifically on pedestrian accidents, the following desegregations were considered: according to the road element – at intersections (three legs, four legs, and roundabouts) and in segments; and according to the inclusion of explanatory variables related to the road environment – simplified (only with the exposure variables) and global (with all potential explanatory variables). Several environment characteristics were found to influence pedestrian accident occurrence:

- 3 and 4 legged intersections, with the following factors increasing accident frequency: lane balance, 3 or more entering lanes on major direction, average lane width on minor direction, presence right turn lanes on minor direction; with a decrease of accident frequency: number of legs with traffic in only one direction;

- Roundabouts, with the following factors associated with higher accident frequency: number of legs of the intersection;

- Mid-block segments, with higher accident frequencies in the case of 4 or more lanes in both directions.

Poisson and Negative Binomial regression models can be considered the most common statistical methods for accident frequency prediction (Lord et al., 2005). However, the factors that influence accident frequency may differ from those that affect crash severity, as stated by (Savolainen et al., 2011).

This study aims to investigate the contributing factors that affect the severity of pedestrian crashes in the city of Lisbon, Portugal. To accomplish this analysis, a geocoded database on road accidents and victims occurred in Lisbon between 2008 and 2011 was used, with a total of 9063 injury accidents, of which, 2031 involved pedestrians. The factors identified included seasonal attributes, infrastructure attributes, accident information, and pedestrian and vehicle driver information.

This analysis made it possible to identify factors in common with those found in similar studies, while also keeping alternative factors within the scope of the study. Accordingly, our modelling approach is mainly explanatory (based on past observations) rather than predictive (predicting new values for the future). Additionally, we used a multinomial logit model, which is a statistical technique found in Sun et al. 2019, but different from the mixed logit models (Kim et al., 2010), and the LCL model (also in Sun et al. 2019) also found in the literature for pedestrian crashes. Based on our empirical findings we also present particular aspects to be taken into consideration for supporting decisions on urban design policy making directed for the improvement of pedestrian safety in Lisbon.

2. Data description

The data collected for this study is geographically limited to the Lisbon municipality. Four types of data were used, namely crash data, land use information, population census data, and pedestrian exposure data, comprising a total of 96 variables.
Error! Reference source not found. shows the distribution of the accidents by injury category for the variable of interest considered. The most severe outcomes (fatal and severe injury) account for 8.3% of all pedestrian accidents, while a large majority of crashes were minor injury crashes (91.7%).

Table 1. Descriptive statistics of pedestrian crash severity

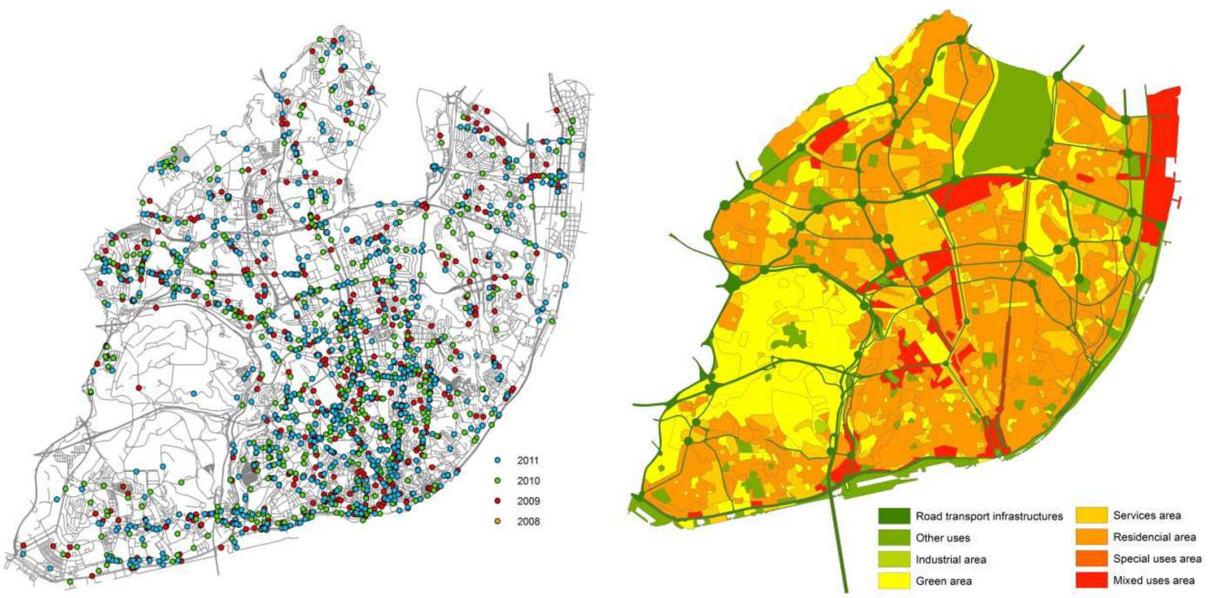
Outcome variable	Fatal	Severe injury	Minor injury	Total
Number of occurrences	14	152	1836	2002
Percentage	0.7%	7.6%	91.7%	100.0%

The crash sample only includes crashes that involved at least one vehicle and one pedestrian. The dataset contains information on some attributes related to the pedestrian crashes from five variable categories: seasonal attributes, infrastructure attributes, information on accident characteristics, pedestrians, and drivers.

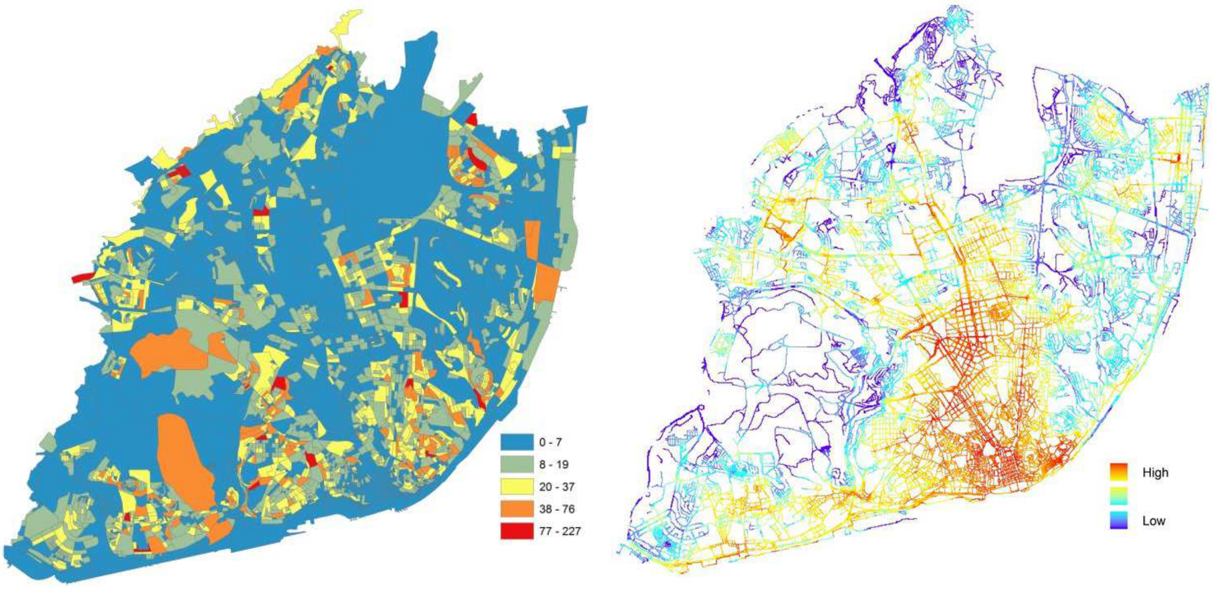
Land use information was provided by the Lisbon's City Council and included eight different classes of use, at the block level, namely industrial areas, green areas, housing areas, historical areas, services areas, special uses areas, mixed-use areas, rails, roads, and buildings.

Census information was obtained from the National Statistical Institute and included characteristics of dwelling units, number of families, and number of inhabitants per gender, age group, and main activity.

Finally, pedestrian exposure proxy data were calculated using a numeric scale conversion of the pedestrian potential map (MAPPe) developed within the Pedestrian Accessibility Plan of Lisbon. This MAPPe presents the sections of the road network where concentration of pedestrian flows are most probable and was used as an alternative variable to pedestrian traffic volumes, which are not available in the analyzed area. This map was developed based on three types of variables: the population density (which represents the dynamics of pedestrian flows in home-work travels), the road network as a support infrastructure for pedestrian mobility (also considering the cycling network, since it is also used by pedestrians), and the main pedestrian traffic generator/attractor poles in the city of Lisbon (Morais, 2013). Examples of the geographic distribution of key analyzed variables are presented in Figure 1.



(a) (b)



(c) (d)

Fig. 1 (a) accidents with pedestrians occurred in Lisbon between 2008 and 2011; (b) land use information; (c) number of housing units per Census section; (d) Pedestrian potential map (MAPPe), for Lisbon (Morais, 2013)

3. Methods and Results

When a crash severity analysis is foreseen, several models can be used (Savolainen et al., 2011). The most frequent can be grouped into unordered and ordered framework models.

The ordered response frameworks are more suited for examining discrete variables that have an ordinal nature while the unordered response frameworks are applicable for discrete variables. Ordered logit, generalized ordered logit and ordered probit, are some examples of ordered models (Eluru, 2013). Amongst the unordered framework models, one can find several types, such as multinomial logit (MNL), nested logit, probit, and mixed logit models, among others.

The choice is usually depended on the data particularities, as stated by some authors. Eluru (2013) and Yasmin and Eluru (2013) compared the performance ordered and unordered models and concluded that the Generalized Ordered Logit (GOL) model is the equivalent to the unordered Multinomial Logit (MNL) model for examining ordinal discrete variables. They found that some disadvantages of traditional ordered models could be surpassed with the GOL model.

One of such disadvantages is related to data underreporting especially concerning property damage only (PDO) crashes, for which traditional ordered probability models are particularly susceptible (Savolainen et al., 2011; Manner and Wunsch-Ziegler, 2013). Eluru (2013) demonstrated that it is possible to address this limitation with GOL model framework and that this performance is likely to be very similar to the MNL.

Another disadvantage of traditional ordered framework models in comparison with unordered models is that the former can restrict the influence of explanatory variables on severity outcomes (see Khorashadi et al., 2005, or Yasmin and Eluru, 2013), causing those factors to either increase the probability of greater severity or to increase the probability of lesser severity. Eluru (2013) also found that the MNL model outperforms other model frameworks in aggregate samples that are left skewed, i.e., where less severe injuries are more represented than more severe injuries or fatalities (which is the case of the analyzed data).

Given the nature of discrete outcomes in the present data, both ordered, and unordered framework models are adequate. As so, we opted to disregard the ordered nature of the outcome data and favored the more common unordered discrete outcome model approach, choosing the MNL model, with a structure of three levels: fatal injury, severe injury and minor injury.

The framework used to model the degree of injury severity of a crash-involved individual begins with the definition of a linear function, *T*, that determines the specific injury severity level *j* for observation *i* as (Washington et al., 2011):

$$T_{ij} = \beta_j X_{ij} + \varepsilon_{ij} \tag{1}$$

where β_j is a vector of coefficients to be estimated for outcome *j*, X_{ij} is a vector of exogenous (or explanatory) variables, and ε_{ij} is the random component assumed to follow a Gumbel type 1 distribution.

Thus, the probability (P_{ij}) of a driver (or most severely injured occupant) *i* sustaining a specific injury severity level *j* is expressed as follows (Washington et al., 2011):

$$P_{ij} = \frac{EXP\left[\beta_j X_{ij}\right]}{\sum_j EXP\left[\beta_j X_{ij}\right]} \tag{2}$$

This type of model is a traditional discrete outcome model that may consider several outcomes and does not explicitly consider the ordering that may be present in these outcomes. The MNL model in equation (2) requires the assumption that the unobserved terms (ε_{ij}) are independent of the injury severity level– the Independence of Irrelevant Alternatives (IIA) property. If some injury severity levels share unobserved terms (being as so correlated), coefficients and severity probabilities will be erroneously estimated (Shankar et al., 1996).

Altogether, 19 parameters were calibrated, through which we attempted to identify the potential effects of different factors related to the categories listed above. The estimated coefficients are shown in Table 2. To correctly evaluate the vector of the estimated parameters' coefficients (β_j), the specific parameter average direct elasticities (for continuous variables) and pseudo-elasticities (in the case of categorical variables) were also calculated (see Table 3). These allow capturing the effect that a change in a variable determining the likelihood of injury severity level *j* has on the injury outcome probabilities of injury severity level *j*. When analysing the effects of continuous variables, the percentage variation of the severity levels resulting from the pedestrian accident is compared with a 10% variation of the stimulus variable (in this case, the factors to be analysed). In the case of categorical variables, since the factor variation (that is, dummy variables) is necessarily from 0 (the base condition) to 1, the percentage variation of the results in the severity levels of the injury refers to a variation of 100% in the regressors.

Table 2.Estimated coefficients of the model

Severity level	**Variable Coefficient**	**Coefficient estimate**	**t-test**	**p-value**
Fatal injury	Constant	-3.560	-3.45	<0.001
	Driver injured	5.190	3.53	<0.001
	Abrupt manoeuvre	3.050	2.64	0.01
	Business	2.190	3.37	<0.001
	Pedestrian potential	-0.044	-1.75	0.08
Severe injury	Constant	-2.760	-2.77	0.01
	Crosswalk	0.437	1.52	0.13
	Age	0.018	4.56	<0.001
	Normal	0.822	3.55	<0.001
	Female Driver	-0.621	-2.32	0.02
	Sudden braking	2.300	2.3	0.02
Minor injury	House	0.002	2.11	0.03
	Street	1.510	1.57	0.12
	Dawn	-1.230	-3.26	<0.001
	Two-way	-0.705	-2.87	<0.001
	Multimodal	-0.591	-3.07	<0.001
	Direction left	1.420	1.91	0.06
	Night	-0.919	-3.69	<0.001
	Female pedestrian	0.738	4.17	<0.001
Number of observations		2002		
Log Likelihood at zero		-2199.422		
Log Likelihood at convergence		-542.052		
Degrees of Freedom (dof)		20		
Adjusted-ρ^2		0.745		
Bayesian Information Criteria (BIC)		932.065		

Table 3. Elasticities and Pseudo-elasticities of the significant variables, by injury level

Variable	Fatal injury	Severe injury	Minor injury
Driver injured	160.61		
Abrupt manoeuvre	19.66		
Business	7.85		
Pedestrian potential	-0.35		
Crosswalk		0.51	
Age		0.01	
Normal		1.19	
Female Driver		-0.45	
Sudden braking		9.59	
House			0.00
Street			0.91
Dawn			0.01
Two-way			-0.14
Multimodal			-0.28
Direction left			0.29
Night			-0.25
Female pedestrian			0.22

From Table 3 it is possible to highlight some results. Regarding the probability of minor injuries, the model shows that a 10% increase in the number of housing units corresponds to a modest increase (0.2%) in the probability of minor injuries in pedestrians. Also, it was found that when accidents occur in two-way streets, it is 14% less likely that pedestrians suffer minor injuries when compared to other streets. Similar findings were observed by Kim et al. (2010), although the variable used by the authors considered a physical division of ways. The probability of minor injury is decreased by 14% during dawn, compared to the other periods of the day, mainly due to increased vehicle speeds and poor visibility. This result is consistent with the studies by Haleem et al. (2015) and Sun et al. (2019). Local roads are associated with an increase of 91% in the probability of minor injuries when compared with roads from other categories. Left turn manoeuvres have a similar effect: increasing the probability of minor injuries in about 29% when compared to the baseline situation of driver not changing direction to the left.

It was also found that: minor injuries in pedestrians are 25% less likely in accidents occurring at night, when compared to other periods of the day. This is consistent with the findings of Kim et al. (2010) and Sun et al. (2019). Minor injuries in pedestrians are 28% less likely in the vicinities of multimodal interfaces when compared to areas outside multimodal nodes. Also, a female pedestrian is 22% more likely to have minor injuries than a male pedestrian. This finding is in accordance with the study by Tarko and Azam (2011) but differs from the finding of Lee and Abdel-Aty (2005), which concluded that female pedestrians had higher injury severity than male pedestrians and Sun et al. (2019), which included female pedestrians in the list of variables that significantly increase the probability of fatal and severe crashes are.

The model also shows that in pedestrian crossings the probability of severe injuries is 51% higher than elsewhere on the streets. This makes sense as pedestrians would expect the vehicles to stop before a zebra crossing and hence, would not attempt to avoid a collision. This result is partially consistent with the studies by Sasidharan et al. (2015) but differs from the finding of Mohamed et al. (2013) and Haleem et al. (2015). Sasidharan et al. (2015) finding is relative to pedestrian crashes with heavy vehicles due to the driver not giving right of way to the pedestrian. Mohamed et al. (2013) concluded that crossing without a signal or crosswalk increased the risk of fatal crashes while analysing pedestrian-vehicle crashes in New York and Montreal. One possible reason for this discrepancy could be the difference in drivers and pedestrians behaviours.

The model shows that increasing the age of pedestrians by 10% corresponds to an increase in the risk of pedestrian severe injuries by 0.1%. This is consistent with the study by Sun et al. (2019). Female drivers have a 45% lower probability of inducing severe injuries in pedestrians than male drivers. This is consistent with the findings of Mohamed et al. (2013) and Islam and Jones (2014).

Finally, for the most severe case, the variable that most influences the probability of fatality is the severe injury of the driver, with a risk of death for pedestrians 160 times higher than for accidents without this type of injuries. This finding was to be expected, as only high impact speeds should lead to severe driver injuries in urban roads and, consequently, to a very significant increase in the pedestrian's risk of death. One can also observe that an abrupt steering manoeuvre by the driver increases the chance of fatal injury to the pedestrian by 1966%, in comparison to pedestrian crashes without these manoeuvres. This is consistent with the findings of Zhai et al. (2019).

It was also found that business areas have a probability of pedestrian fatality 785% higher than in other areas of the city of Lisbon. This finding differs from the result of Islam and Jones (2014), which identified an increased probability for shopping and business areas. One possible reason for this discrepancy could be the inclusion of shopping areas in the previously mentioned study, where people in general drive slowly and more carefully. This finding also suggests the need for more detailed information on business areas characteristics and the understanding of its impact on pedestrian and driver behaviours. Also at this level of severity, the pedestrian potential variable as measured in MAPPe (i.e., the proxy for pedestrian exposure) stands out, since a 10% increase in the pedestrian potential (which is a continuous variable) corresponds to a 35% decrease in the probability of fatal injury. Drivers are expected to behave differently in areas with a higher number of pedestrians, compared to other areas, for example through a reduction in speed, which improves pedestrian safety; also, the urban design in these areas promotes safer driving and pedestrian-vehicle interactions.

To further explore the outputs of the modelling process, it is possible to analyse the spatial location of the crashes where they are most likely to correspond to higher injury severity. This analysis is particularly useful when the final goal is to use the modelling outputs as a basis for urban design policy making, or supporting decisions concerning infrastructure correction measures. Fig.2 presents an example of the location of pedestrian crashes, highlighting those within the vicinity of businesses areas, which, according to the model output, present a probability of fatal injury 7.9 times higher than the remaining areas.

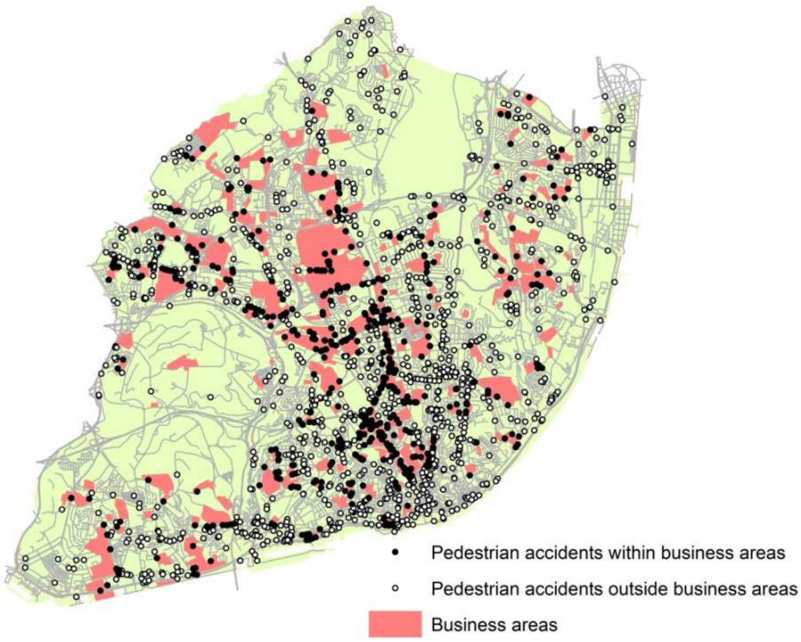


Fig. 2. Pedestrian accidents with higher probability of fatal injury within business areas

5. Conclusion

This study demonstrates the importance of crash severity models for the knowledge of factors influencing the occurrence of accidents and victims, which can be used as a basis for policy formulation and for the implementation of corrective measures to mitigate the severity of the injuries associated with pedestrian accidents.

In order to carry out this analysis, a database containing information on road accidents occurred between 2008 and 2011 in Lisbon, land use information, census data, and pedestrian exposure data was used.
The multinomial logit model used considered as a response variable the severity of pedestrian injuries. The direct elasticities and pseudoelasticities were also calculated to complete the analysis.

The empirical results of the developed model allow us to identify the areas with the highest or lowest probability of accidents, such as the business areas, which are associated with an important increase of the probability of death in pedestrians.

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