ROAD SAFETY OF ELDER PEDESTRIANS IN THE URBAN CONTEXT: AN APPROACH BASED ON INFRASTRUCTURE AND SOCIOECONOMIC VARIABLES

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ABSTRACT

The world generalized phenomenon of population ageing, caused by an increase in life expectancy, has led to a more elderly being actively part of mobility and road traffic. In developed countries, like Spain, fatalities and severe injuries among elderly pedestrians in the urban context are a matter of concern since, in the last decades, the fatal accident risk for elderly pedestrians is rising. Although there is an extensive literature on the decline of driving and pedestrian skills in the elderly, few research has been devoted to the impact of the street type and socioeconomic factors per urban district on this type of collisions.

The road safety analysis of pedestrians´ collisions is complex due to the diversity of the features, the dispersion of the data and the lack of infrastructure information associated to the accident location at official databases. The main target of this paper is the identification of the basic socioeconomic and infrastructure factors that contribute to elder pedestrian accident at urban level, taking the administrative units (districts) as territorial accident location. Madrid is the capital of one of the most rapidly ageing nations in the world, and was selected as case study because it also has a high proportion of elderly residents (19%). The Spanish General Directorate of Traffic (DGT) provided the database (2006-2018) on accident statistics and the crashes involving an elderly in Madrid were filtered to elaborate and ad-hoc data base. The study methodology was based on a negative binomial model to test the accident occurrence at district level. Results revealed the clear influence of the district population variables (density and total inhabitants) together with the activity centres associated to the elderly mobility, followed by the road length and the ageing rate per district.

1. INTRODUCTION

According to UE statistics (Eurostat, 2015), the 24% of the population in Europe will be aged over 65 years in 2030 and in 2050 this figure will reach the 28%. This fact will be translated, in terms of mobility, into more elderly being actively part of road traffic.

Road safety figures have started to provide evidence of the consequences: at the moment one road traffic fatality out of five is aged 65 or over (European Commission, 2015); but by 2050 (if the risk rates of older people and younger age groups decline at the same pace) it is expected that one road traffic fatality out of three will be an older person (European Commission, 2015).

Elder Pedestrians and cyclists, which concentrate in urban areas, are the weakest users. Statistics reflects that elderly make up 39% of all pedestrian fatalities and 40% of all pedal cyclist fatalities compared to 18 and 19% of all car driver and passenger fatalities (European Commission, 2015). If we check statistics provided by OECD countries, the real fact is that persons 65 years and over 65 years represent 13 to 20% of the population, but they make up more than 50% of pedestrian fatalities (ITF, 2012). Consequently, there is a scientific need to understand the factors that affects the elder pedestrian accidents and prevent them implementing countermeasures on our streets.

Although there is an extensive literature on the decline of driving and pedestrian skills in the elderly, few research has been devoted to the impact of the street type and socioeconomic factors per urban district on this type of collisions. Using a negative binomial model applied to Madrid case study, the main target of this paper is the identification of the basic socioeconomic and infrastructure factors that contribute to elder pedestrian accident at urban district level. The paper is divided into the following sections: Section 1 contains a brief introduction; Section 2, the state of the art on elderly pedestrians; Section 3 gives a detailed description of the case study, model structure and main results; Finally, Section 4 shows the conclusions and future research lines.

2. ROAD SAFETY OF ELDER USERS

An extensive literature (Dunbar et al, 2004; Oxley et al. 2004; Palamara and Broughton, 2013) has been devoted to study the specific physical and mental limitations of the elderly as road users. These physical and mental limitations use to be exacerbated by age-related illnesses and certain chronic medication. Having more than on illness (comorbidity) is also more usual among the elderly population and is also linked to a higher accident´s risk. Due to their physical and mental state, also this age group registers greater fatality rates (Henary et al, 2006). Until now, the higher road collision risk of the elderly has been linked to the reduction in physical and mental faculties with advancing age, which can lead to an inappropriate and unexpected behaviour in elderly pedestrians and drivers compares to the rest of road users (except children).

Elderly drivers have been paid more scientific interest than elderly pedestrians (Charlton et al, 2017; Charlton et al; 2006), although figures reflect that fatal accidents involving elderly drivers are still very few compared to elderly pedestrian fatalities (Langford et al., 2006).

We know that physical and mental limitations of elderly pedestrian are usually related to a lower walking speeds, reduced ability to make head and neck movements, less muscle agility, a poorer vision, poorer hearing, and longer reaction time. The idea of adapting street infrastructure for an ageing society is starting to grow among policymakers and local authorities and institutions like the World Health Organization is promoting the approach of creating “age-friendly” cities (WHO, 2007).

According to this idea of adapting street infrastructure to an ageing society, there is a need to study how the location features of the accident is affecting to the crash occurrence. The location of the accident can be linked to infrastructure features (street crossings, parking lots, signalling, sidewalks width, etc.) and also to socioeconomic factors of the urban district (population density, land use features, ageing rates, etc).

But in most literature studies dealing with elderly users, the analysis of infrastructure and socioeconomic variables is reduced to subjective perceptions declared by the elderly by surveys (Bernhoft and Carstensen, G. 2008, Oxley et al, 2004) and rarely backed by pedestrian collision data and the analysis of the accident location in the city.

In relation to road infrastructure as variable (sidewalks, parking lots and carriageway) some recent studies (Galanis et al, 2017; Corazza et al, 2018; Demasi et al, 2019) have analysed pedestrian road safety in relation to urban road type and traffic flows, but only a few of them have special consideration for elderly pedestrians (Corazza et al, 2018).

The works developed by Galanis et al (2017) are more focused on pedestrian behaviour (legal or illegal walking behaviour) in relation to infrastructure type and traffic flows. Pedestrian walking on the sidewalk for the entire length of the tested street segment was considered a legal behaviour and otherwise was illegally considered.

In a Greek city of 130.000 inhabitants, the legal or illegal walking behaviour in six different types of streets was recorded by video cameras and photos. Results showed that the highest rate of legal behaviour was presented in main arterials (91.8%) and the lowest one in local streets (53.7%). Low motorized traffic flow levels in combination with maintenance and mobility problems in pedestrian infrastructure push pedestrians to walk outside the sidewalk, underestimating road safety issues.

Corazza et al (2018) focused on the pavement state of the sidewalks and its influence on elderly pedestrian accidents. Distressed or too narrow sidewalks may induce pedestrians to walk outside the sidewalks and on the carriageways, providing very unsafe situations, especially for the elderly. Authors classified the pavement state of the sidewalks in a district of Rome (Italy) and studied the relationship with a higher recurrence of accidents involving pedestrians with special attention to elderly pedestrian accidents.

Finally, Demasi et al (2019) focused on all vulnerable users (pedestrians, cyclists and motorcyclists) and designed a methodology to estimate the level of road safety of each section of a street and the hazard index of the overall branch.

Apart from considering traffic flows and speed limitations, authors identified 9 categories of elements of the street infrastructure to evaluate: pavement, geometry (narrow sidewalk, narrow lane width), lighting, intersections, cross-section (missing pedestrian crossing, pedestrian crossing without ramps), private access (lack of visibility, lack of ramps), road signs (traffic lights, roadside signs), urban furniture (safety barriers, urban furniture causes lack of visibility at intersections, urban furniture occupies shoulder or lane) and stopping (illegal parking).

Although the approach of Demasi et al. (2019) is the most interesting and would be linked and applied to elderly pedestrian accidents, it needs a database fed with a very detailed road inventory. Official accident databases use to give poor infrastructure data associated to the location of the accident and sometimes local authorities cannot supply a good inventory of their streets. The quality of the accident database always conditions the research methodology of road safety studies. This database is designed by the national authorities in each country and is compiled from a collection of road traffic accident information. In comparison to other national data bases, the Spanish one is sufficiently consolidated (Casado-Sanz et al, 2019). The pedestrian accident data used in this paper was extracted from the Spanish Accident Statistics database, and includes the accidents on Madrid city streets involving single vehicle and a pedestrian, during a period of 11 years (2006-2018). Three of the weakest points of the Spanish accident database are:

- The absence of traffic exposure data (traffic flow) associated to the accident location.
- The absence of the street road layout (lane width, sidewalk width) and traffic signalling information associated to the accident location.
- The absence GPS coordinates associated to the accident location (as in the US), using instead the kilometric point on the road in interurban roads or the closest street number in urban scenarios, leading to further data processing problems.

The two first points push researchers to collect these variables from other official databases or develop a systematic procedure of ad-hoc measurement. These ad-hoc works are very laborious, but is the only way to obtain a holistic approach for road safety assessments. The third issue is especially important in urban scenarios because working with GPS coordinates eases the process of assignment of other variables (traffic flows, road layout, sidewalk geometry, etc.) to the accident location point. In this preliminary study, a great effort has been devoted to the GPD coordinates procurement process, while basic infrastructure and socioeconomic variables have been obtained directly from official databases.

3. MADRID DATA BASE AND METHODOLOGY

3.1. Madrid case study

Spain is one of the countries in the world (together with Sweden, Finland, Germany, Italy, Greece and Japan) with the largest number of elderly people. In 2019, Spanish people over the age of 65 were approximately 19.3%, and almost 6% were over the age of 80 (INE, 2019); and this amount could reach 40% in 2060 (United Nations, 2019).

Madrid city has been selected as case study in this research because it is the capital of one of the countries in the world that presents the most positive evolution of the ageing of the population. Furthermore, the city has a high overall elderly proportion of 19%. It is a large city with almost 3.5 million of inhabitants and it is divided into 21 districts. This administrative division will be used in the statistical analysis of this research, as information is available and officially provided at this detail level.

The available data for this study consists of a subset of the Spanish Accident Statistics Database during the period 2006-2018, where collisions involving 1 vehicle and 1 elderly pedestrian took place in Madrid city, as it is explained in the next section. The main issue with the database was to geolocate the events, because their location is recorded using the name of the street and not with GPS coordinates.

3.2. Database

In this section it is explained how the database for the statistical operations was constructed. It consists of two separated operation: dependent (number of crashes per district) and independent variables gathering. This last group is comprised of different nature features about each district. It was intended to use only direct data (i.e., already available) as independent variables in this research.

The first step of the data collecting process was to obtain a clean elderly road safety database containing the location and basic characteristics (e.g., date, time, and type) of the accident to perform further processes of filtration. A simplified National Spanish database of accidents for the period 2006-2018 was the starting point.

Accidents with the profile of “vehicle-pedestrian collisions” where kept, summing up a total of 20,236 accidents. Later, a subset of accidents with a configuration of “1 person and 1 vehicle involved” of 18,118 (89 % of total collisions) records were found suitable to be studied for homogeneity purposes. Finally, the database was filtered to obtain events where the involved pedestrian was 65 years or older. This process provided information about 4,663 elderly pedestrian collisions. A preliminary analysis of this database manifests the fragility of the elderly, as this group represents only 25.7% of total collisions but 50.9% and 34.2% of total fatalities and serious injuries, respectively.

One of the most important operations to perform in the proposed study was to geolocate the accidents based on the name of the street and the number or the name of two streets for street crossings. This procedure became more challenging because of the lack or misspelling of this information in some records. The geolocation of the data required the creation of a database containing every possible location of Madrid city. This was accomplished using GIS operations and different databases, mainly the Madrid Council Open Data Portal and Spain National Geographic Institute (IGN). This information was joined to the accidents database using string-searching algorithms and it was possible to geolocate 97 % of the accidents. Later, the district code was added to each observation and this dataset was grouped by district to obtain the dependent variable to study in this analysis: the number of crashes per district. Figure 1 shows the location of the accidents per city district and victim severity.

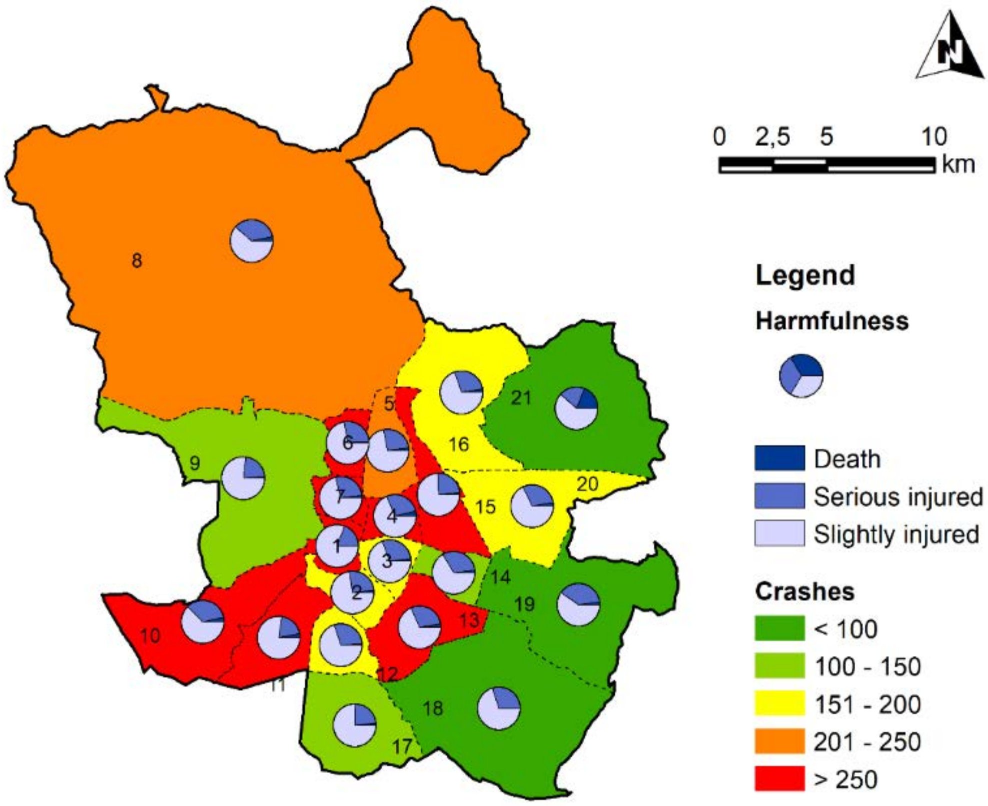

Figure 1: Number of collisions between vehicles and elderly pedestrians and harmfulness in Madrid Districts.

To measure the impact of socio-economic and infrastructure features on elderly road safety in this macroscopic analysis, different variables (see Table 1 and Figure 2) regarding Madrid districts were gathered and processed from various data sources.

Socio-economic variables are inhabitants, population density, ageing rate, average annual income per household and Activity Centres (Point of Interest, POIs). Inhabitants is an indicator of the exposure, in the absence of pedestrian flow data. Population density reflects how crowded a certain district is. Ageing rate captures the population structure.

Average annual income per household states the socioeconomic status of a district. Inhabitants information was available via the Spanish Statistics National Institute (INE) for the period 2006-2014. These data were grouped per year and census section and five-year age group, and via Madrid Council Open Data Portal for the period 2014-2018. These data were grouped per year, district, and age of inhabitants.

It was possible to postprocess both files to construct a single homogenous dataset containing the number of inhabitants living in each district and year, separating them in five-year age groups. Population density was calculated regarding the surface of each district and the information about inhabitants.

Furthermore, ageing rate was obtained as the ratio between inhabitants over the age of 65 and total inhabitants of each district. In the following analysis only last year data will be used for simplicity reasons, because ageing rate has increased slightly in Madrid city. Finally, average annual income per household was obtained for each district directly from the Madrid Council Statistical Portal for the year 2015.

Activity centres were included in this study through the location of Points of Interest (POIs) existing in each district. The number of POIs indicates the possible locations where pedestrians can access to. Hence, it can be associated with a higher pedestrian flow.

This information was obtained directly from the Madrid Council Data Base, when it was possible, and from the Madrid Council Open Data Portal in the form of point-shapefiles that were located on a map and intersected with Madrid districts' geometry. The number of locals per type -restaurants, stores, senior centres, and hospital centres- was calculated in each district. In this study, it was used the total number of these points as a unique variable named POIs.

Infrastructure data group different features about the existing road network. At this point of the research, only direct data will be used. This way, infrastructure variables that require a complex process to be obtained, such as sidewalk widths, are planned to be used in further research. Total length of roads was obtained for each district from the Madrid Council Database.

In consequence, road density considering the surface of each district was computed. Street crossing location was found ad-hoc using the geometry of the street axis and GIS techniques. In addition, signalised street crossing locations is available at Madrid Council Open Data Portal. Hence, it was calculated the proportion of signalised intersections of each district.

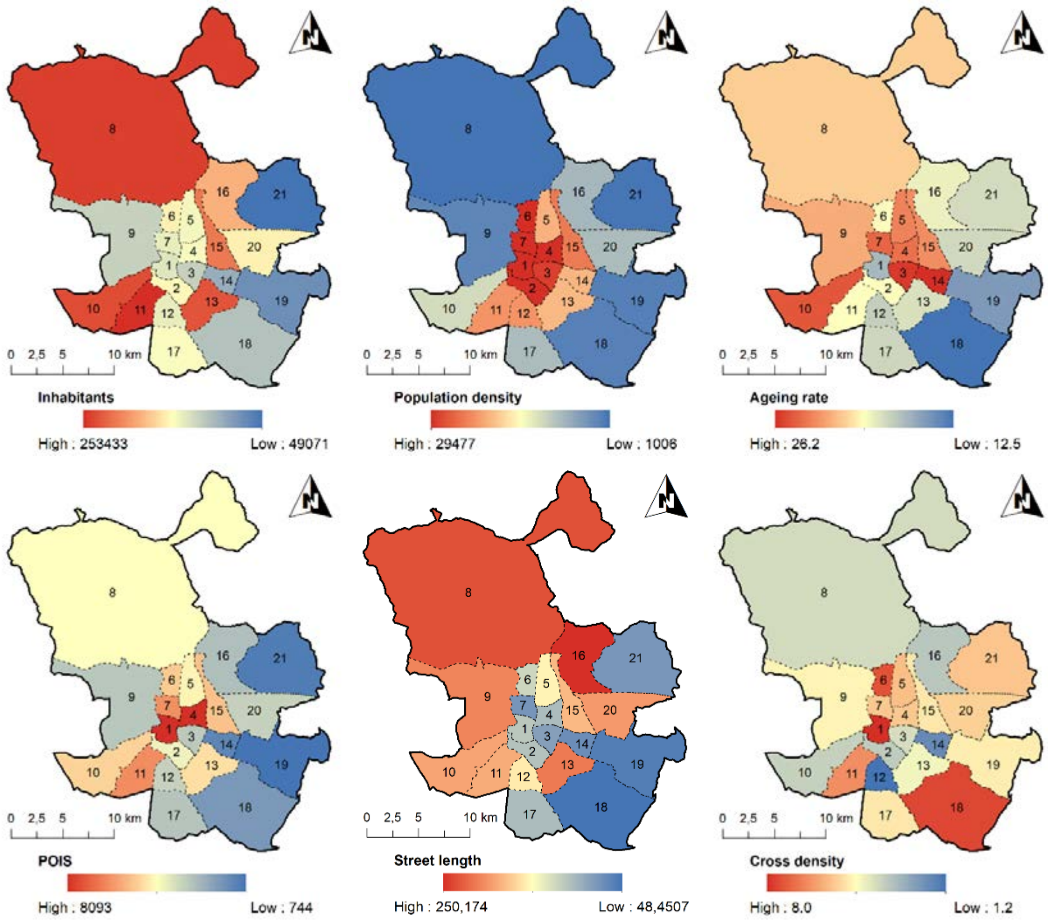

Figure 2: Spatial representation of independent variables.

Group	Variable	Unit	Mean	St. Dev.	Min	Max
Socio-economic	Inhabitants	#	155,834.40	56,436.15	49,071	253,433
	Population Density	#/km2	14,007.85	9,700.58	1,006.00	29,477.78
	Ageing rate	%	20.13	3.78	12.53	26.16
	Average annual income per household	€	39,209.01	11,146.21	24,688.07	60,947.89
	POIS	#	2,844.29	1,637.71	744	8,093
Infrastructure	Road length	km	140.21	62.58	48.45	250.17
	Road density	km/km2	11.67	7.17	0.94	22.74
	Street crossing density	#/km	4.92	1.61	1.18	8.03
	Signalised street crossing	%	18.99	9.69	5.02	43.95

Table 1: Statistical summary of the independent variables.

At this point, the information reunited in this section was ready to construct a statistical model to assess the importance of the independent variables on the number of vehicle-elderly pedestrian collisions per district in Madrid city. These operations are explained in the following sections.

3.3. The Negative Binomial Regression

This study uses a Negative Binomial (NB) Regression, which is widely spread throughout road safety crashes frequency estimation in general and in macroscopic studies (Ziakopoulos and Yannis, 2020). The output of this regression can only have null or positive numbers.

This model is derived from a Poisson-gamma distribution (Hilbe, 2011) and it can handle over dispersed data, on the contrary of the Poisson regression in which the mean and variance of the data are considered to be equal. As overdispersion was present on the crash frequency per district data, a NB was suitable to construct a statistical model. The density function of the NB is as follows (equation 1):

$$\mathrm{P}(Y = y_i) = (\Gamma(y_i + \alpha^{-1}))/(\Gamma(\alpha^{-1})y_i!) \cdot (\alpha\mu_i)/(1 + \alpha\mu_i))^{y_i} \cdot (1)/(1 + \alpha\mu_i))^{\alpha^{-1}} \quad (1)$$

Where P(Y=yi) is the probability of Y being yi, μi is the expected number of events, α is the dispersion parameter and yi is the number of occurrences at i. The expected number of vehicle-pedestrian collisions is given by the following equation (2):

$$\mu_i = \exp(\beta_0 + \sum_{j=1}^{n} \beta_j{}' x_{ij}) \quad (2)$$

Where μi is the expected number of events, β0 is the estimated intercept if it is considered, βj are the estimated parameters and xij are the independent or explanatory variables at i.

3.4. Model Assessment

After collecting the proposed variables for every district, the next step is to formulate a Negative Binomial Regression that returns the best goodness of fit in the operation of calculating the total number of crashes in each district. This process involves constructing and comparing every possible combination of the 10 selected variables. Thus, an exhaustive procedure was performed to test every subset of the candidate variables and approximately 1,000 models where constructed and assessed based on their Akaike Information Criterion (AIC). The AIC (equation 3) is an estimator of the goodness of fit based on the likelihood and the number of parameters of the model. This criterion does not report an overall score on the goodness of fit, but a rating to compare a set of models that are employed on the same data. The final model is the one with the lowest AIC value.

$$AIC = 2k - 2\ln(L) \quad (3)$$

Where L is the maximum of the likelihood function and k is the number of parameters of the model.

3.5. Results

In this section it is presented the model that was found to have the lowest AIC value among all the possible ones. This final model is based on inhabitants, population density, ageing rate, road length and number of POIs. All the variables have a positive effect on the total number of collisions between vehicles and pedestrians over the age of 65. The most significative variable is the population density, followed by inhabitants, POIS, ageing rate, and road length. Every variable has a p value smaller than 5%, which means that the null hypothesis of the estimate being null is rejected.

A greater number of inhabitants in a district is found to have direct effect on the number of crashes in that district. This can be explained if it is assumed that a pedestrian that suffers a collision is an inhabitant of that very same district (i.e., pedestrian flow increases with population) or if it is presumed that it is more likely that a person walking in one district is an inhabitant of that district. This way, the variable “inhabitants” could also be understood as an indicator of pedestrians’ traffic. Also, population density is an indicator of how crowded a district is, and even a sign of how tall the buildings are. This way, population density provides an indicator of how many conflicts could happen in an equal area. Ageing rate parameter is found to be positive. It can be understood by the same argumentation about inhabitants and presuming that the elderly usually transits in their own district.

From the infrastructure perspective, as road length increases so does the number of crashes. This is explained because road length is a measure of exposure and as it improves the probability of a crash occurring increases, too.

Finally, from the land use point of view, the number of Points of Interest also has a positive effect on the number of crashes. This fact can be explained because it can be expected that there would be a higher pedestrians and vehicle traffic where there are more of these special locations. In consequence, exposure would be higher in those districts where the number of POIs is elevated. Also, it is important to note that those points act as attractive nodes to people.

Variable	**Estimate**	**Std. Error**	**z value**	**p-value**	
Intercept	3.103	1.878e-01	16.524	< 2e-16	***
Inhabitants	4.195e-06	8.722e-07	4.810	1.51e-06	***
Population density	2.768e-05	4.775e-06	5.797	6.74e-09	***
Ageing rate	2.354e-02	8.763e-03	2.686	0.00724	**
Road length	2.149e-03	8.456e-04	2.542	0.01103	*
POIs	9.958e-05	2.375e-05	4.192	2.76e-05	***
Significance Codes	0 ‘***’	0.001 ‘**’	0.01 ‘*’		
Log-likelihood	-98.859				
AIC	211.718				
BIC	219.030				

Table 2: Summary statistics of the final negative binomial model.

4. CONCLUSIONS

In this study, a negative binomial regression model was constructed to evaluate the number of collisions between one vehicle and one elderly pedestrian at a district level in Madrid city, considering socio-economic and infrastructure variables to assess their importance. It can be considered a first approach on the subject by the authors. Because of that, mainly direct data has been used to study the phenomenon. A database containing features about Madrid districts was constructed to be the independent variables in this study.

Crashes that were found to be suitable for this study were geolocated using self-designed algorithms to be placed in a GIS software in order to obtain the number of crash occurrences in each city district, that is the dependent variable in this research. Later, these two objects were joined to form the final dataset to construct the regression model. An exhaustive model search was performed to find the model with the lowest AIC, that was the indicator to assess the goodness of fit.

Variables from all groups have been found to be significant. The final regression model in composed by inhabitants, population density, ageing rate, road length and the number of Points of Interest (POIs), being population density the most significant in the model. The small sample size used in this study (21) is due to the lack of direct information about the proposed variables at a smaller spatial level, such as neighbourhoods. This issue can be solved as it is described in the next paragraph.

Further research is considered to be necessary in various respects due to some reasons:

- There is a remarkable heterogeneity inside the districts in some variables. In consequence, the study of the neighbourhoods or using a homogeneous grid is thought to be the next step to follow. Furthermore, some of the candidate variables have not been found to be significant, but in a further analysis at another scale they will be tested again. Also, sample size will be increased if another spatial unit is used. Finally, one of the most time-consuming tasks carried out was to geolocate the accidents. The data obtained in this respect is understood to be valuable and it will be used in further analysis at a smaller spatial level. Because of these main reasons, a similar study on a smaller spatial unit will be carried out, although it will be necessary to measure some already used variables in a different manner.
- New variables that require to be obtained ad-hoc will be employed in further analysis. For instance, it is the case of not available infrastructure data regarding sidewalks width.
- A change in the methodology is also a way to go. In this sense, a significant number of approaches to study the phenomenon could be used. For instance, a multinomial logistic regression to study the severity level or a study based on street segments.

These proposals imply collecting a bigger amount of data and executing more processes than the option of changing the spatial unit to be studied. Therefore, this option will be implemented after the first one.

The ultimate objective of this research is to develop a set of countermeasures to mitigate road safety issues in view of the present population ageing process. Developing criteria and strategies about how cities should be designed is an important subject to reduce elderly pedestrian road accidents. Further research will explore in more detail possible contributory factors that are not found in this paper.

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