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Analysis of the Risk Factors Affecting the Severity of Traffic Accidents on Spanish Crosstown Roads: The Driver's Perspective

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Abstract: Globally, road traffic accidents are an important public health concern which needs to be tackled. A multidisciplinary approach is required to understand what causes them and to provide the evidence for policy support. In Spain, one of the roads with the highest fatality rate is the crosstown road, a particular type of rural road in which urban and interurban traffic meet, producing conflicts and interference with the population. This paper contributes to the previous existing research on the Spanish crosstown roads, providing a new vision that had not been analyzed so far: the driver's perspective. The main purpose of the investigation is to identify the contributing factors that increment the likelihood of a fatal outcome based on single-vehicle crashes, which occurred on Spanish crosstown roads in the period 2006-2016. In order to achieve this aim, 1064 accidents have been analyzed, applying a latent cluster analysis as an initial tool for the fragmentation of crashes. Next, a multinomial logit (MNL) model was applied to find the most important factors involved in driver injury severity. The statistical analysis reveals that factors such as lateral crosstown roads, low traffic volumes, higher percentages of heavy vehicles, wider lanes, the non-existence of road markings, and finally, infractions, increase the severity of the drivers' injuries.

Keywords: single-vehicle crashes; contributing factors; driver injury severity; multinomial logit; latent class cluster analysis; crosstown roads

1. Introduction

Living in urban areas can offer advantages in terms of road safety when compared to rural areas [1]. Some authors [2] have demonstrated that most of the inhabitants who live in urban areas have less risk of death on the road than those who live in rural areas. Additional literature [3,4] provides the justification for this: rural residents travel approximately 33% more than urban residents and as well, are more dependent on private transport, due to the limitations or even absence of public transport services. Although there is a general consensus on the research needs on rural road safety, the complexity of this research is high because there is a range of rural road types with different functions: accessibility provision, inter-urban mobility and crosstown roads.

Crosstown roads in Spain constitute a "dangerous type" of rural road, being a mixed type of urban and inter-urban road, where the main street of a small town becomes part of an inter-urban route. The town population is far more exposed to road crashes and there are competing speed requirements: urban mobility needs low speeds and measures to encourage pedestrians' flows, while car inter-urban traffic demands higher speeds and continuous flows (without the interruption of traffic lights or zebra crossings). As a result, crosstown roads register higher fatality rates than pure urban roads. The convergence of roads of different administrative ownership in this nucleus of population is also another problem to tackle, leading to complex situations. The role performed by a crosstown road inside a road network is shown in Figure 1, with a Spanish road example, as well as some photographs of the types of road sections that can be found in this particular type of road. Literature shows that this type of road infrastructure has received little investigation, in which speeding is supposed to be the first cause of accident [5]. Traffic calming measures are, a priori, the first tools implemented when the Administrations start to register road accidents in urban roads, but more research is needed on the causal variables. In Spain, crosstown roads have recently experienced an increasing number of fatalities (2011–2016), currently reaching 2% of all deaths and serious traffic injuries [6]. The case fatality rate (defined as the number of fatalities per 100 affected victims) for 2018 was 2.1 for this type of road, while on other urban roads the rate was 0.6. This alarming data have aroused interest in Spain for territorial issues in the analysis of crosstown roads [7,8].

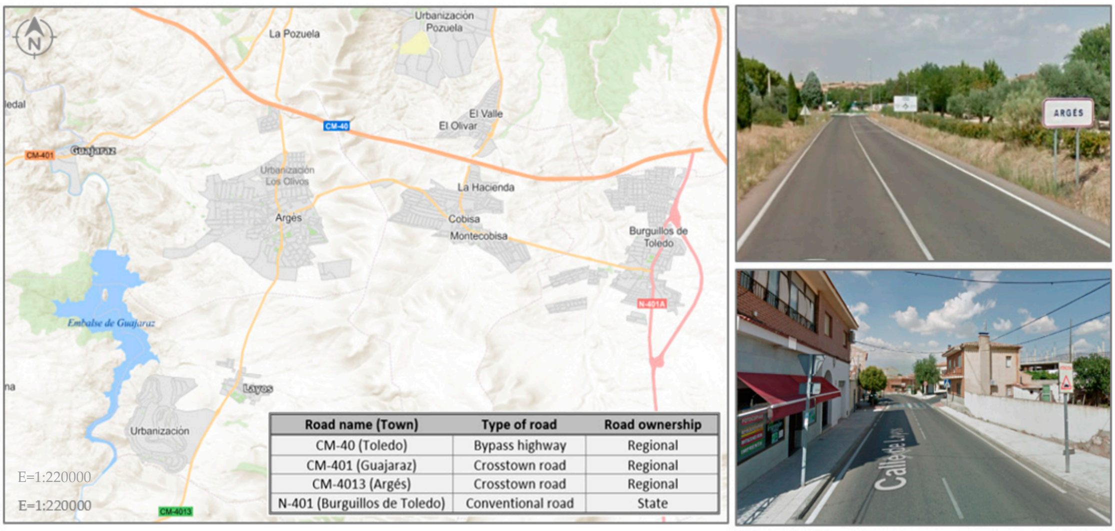

Figure 1. Map of an example of the road layout of a crosstown road in Spain (Argès) inside a road network (left). Example of the road section of one of the crosstown roads under study (right).

Statistically, the database on crosstown road accidents shows a greater number of severe injury accidents involving pedestrians. Pedestrians are the most unprotected road user group (because of their limited tolerance to a vehicle collision and absence of protection) and for this reason, in case of urban roads, the scientific research has always focused on the identification of causes concerning pedestrian accident severity applying a modeling methodology that implies an initial segmentation of the sample of accidents [9,10]. Previous work on the Spanish crosstown roads, using official databases, have demonstrated [11] that there are clear risk factors related with pedestrian injury severity like offences committed by the pedestrian (such as not using pedestrian crossings, crossing illegally, etc.) or the driver (such as distracted driving and not respecting a light or a crossing), as well as the visibility limited by atmospheric factors or dazzle. Subsequent studies on elderly pedestrian accidents on crosstown roads [12] show the need to incorporate ad hoc variables to the road safety analysis, variables that are not usually collected by the official databases (such as the traffic flows, the road layout or territorial factors). This process is very costly, especially where the sample of accidents is extensive and there are no alternative official databases to link the information in a spatial manner. Some authors [12] found that the territorial variables associated with the location of the accident (for example, the physical severance defined by a crosstown road) help to understand the pedestrian risk to suffer a more severe accident. All these complementary variables are necessary to achieve a holistic analysis and studies should not be limited to the road infrastructure, the victim and the vehicle data, but also to the scenario where this infrastructure is territorially implemented.

Within this holistic analysis, as the accidents involving pedestrians are more frequent, studying the driver perspective has been mostly ignored. Questions regarding the driver perspective therefore remain unanswered. What are the principal risk indicators concerning the driver injury severity when passing through a crosstown road? Are territorial factors also a determining variable in the driver injury severity? The main contribution of this paper is to incorporate the driver perspective to the analysis of the accident injury severity in Spanish crosstown roads. Latent cluster analysis and multinomial logit models have been applied to a total sample of 1064 accidents involving one vehicle that have occurred on Spanish crosstown roads in the period 2006–2016.

To explain in detail and in a structured way the current research study, this article has been separated into the following sections: First of all, a preface with the background and the major objectives of the study; second, a literature review focused on publications considering crash severity. Section 3 provides the accident database used in this study and an exploratory analysis of it. Section 4 gathers the methodology applied. Then, the discussion and the results of the analysis are exposed in Section 5. Section 6 compares the results obtained in the road safety analysis of crosstown roads carried out, until now, from different perspectives. Lastly, the major research conclusions are defined in Section 7.

2. Literature Review

Crosstown roads are usually located in rural areas but share some features with urban areas because they usually constitute the main road of the town, with a high number of pedestrian crossings and high traffic flows compared to the rest of the local road network. According to Zwerling, Peek-Asa, Whitten et al. [13], rural areas have suffered much higher fatality rates due to traffic accidents than in urban areas. As mentioned in the previous section, rural areas are usually populated by a higher number of elderly drivers and this age group generally has a greater fragility, making their chances of dying in a traffic accident much higher. Rural areas are provided with less public transport services and, over time, this has generated a greater dependence on private cars. In the US, research developed by Zwerling, Peek-Asa, Whitten et al. [13] found that drivers in rural areas use seat belts much less, may also drive older cars at higher speeds and even at times of high crash risk. In the rural context of the Spanish crosstown roads, Casado-Sanz, Guirao and Gálvez-Pérez [12] demonstrated the influence of age on the severity of accidents involving pedestrians and a single vehicle. In fact, most of the fatal and seriously injured victims in the reported accidents were pedestrians.

From the driver's perspective, it is not clear whether fatal and serious injury accidents that take place in rural areas are caused by drivers older than 65. Rural areas are usually populated by older inhabitants, with a greater dependence on private cars, but this fact does not mean that they generate car accidents as drivers. Thompson, Baldock, Mathias et al. [14] pointed that, generally speaking, drivers over the age of 65 have a lower number of crashes than all other age groups. Older drivers also drive less kilometers per year on average than drivers from other age groups, and if we work with absolute indicators, low crash figures are obtained. Indeed, when referring to the number of kilometers driven, literature has demonstrated that older drivers have a raised crash risk on a per kilometer driven basis, which is second only to the very youngest age groups. Teen drivers' behavior have been widely studied in the US, and literature shows that this group of users is more likely to be involved in angular and rear-end accidents than in crashes with fixed objects [15]. Generally, the principal cause of accidents with teens involved are usually the driver's error to a greater extent, as opposed to other users' groups in which the most common causes are environmental or vehicle factors. According to Curry, Hafetz, Kallan, et al. [16], among crashes with a driver error, a teen driver makes the error 80% of the time. Amarasingha and Dissanayake [17] studied the variables affecting young drivers that were more likely to be involved in crashes. Driving at night on weekends, driving with a not valid license, not wearing seat belts and driving on wet roads (or gravel/brick-tops) were revealed as the most significant variables. Carney, Harland and McGehee [18], using data collected with vehicle event recorders, analyzed over 400 rear-end collisions involving teen drivers. The research revealed that the use of a mobile phone and attending to occupants were the leading causes for the high frequency of rear-end crashes involving teen drivers. The use of the mobile phone is also higher among younger drivers and this variable will start to be studied in road safety studies.

Coming back to crosstown roads, which are the type of road infrastructure analyzed in this paper, the majority of accidents that take place on Spanish crosstown roads without pedestrian involvement are single-vehicle crashes. According to the literature [19], single-vehicle collisions are often related with a high number of serious and fatal accidents and, for that reason, there is a need to better understand the variables that have an influence on these types of accidents and, in consequence, influence the injury severity. Many authors [20] have demonstrated that two vehicles and single-vehicle crashes should be modeled separately. The profile of injury severities in single-vehicle crashes also differs from rural to urban crashes. Wu, Zhang, Zhu et al. [19] demonstrated through a study conducted with traffic accident data from New Mexico in the period 2010–2011, that in rural and urban areas, female and senior drivers, alcohol-impaired driving, or drivers involved in overturned or fixed object collisions are more likely to suffer serious injuries. In rural areas, there were only five factors that are found to be significant, including animal-involved crashes, rainy conditions, crashes in no passing zones and crashes involving pickups. However, crosstown roads are a mixed type between rural and urban roads and no conclusions can be extrapolated from this research to the Spanish case study.

Single-vehicle crashes can result in fatal and non-fatal injuries, and all of them have to be used in any investigation on factors affecting severity. Road safety databases should contain all fatal and non-fatal accidents during the period studied but under-reporting is the main barrier that inhibits the development of a thorough and complete database of non-fatal accidents. When many non-fatal accidents are not collected/represented in a database, this can lead to slanted results, providing mistaken identification of the significant variables that condition crash severity. Under-reporting levels vary across countries [21–24] and usually are due to the risk, once the insurance companies are involved, of the increase in vehicle insurance premiums over the following years [25]. Non-fatal accident injuries are more common in urban areas (where the regulated speed is lower) than in inter-urban roads. Non-fatal accidents can result in seriously injured individuals or slightly injured individuals; this latter group being the most affected by under-reporting.

Apart from non-fatal accident under-reporting, official databases on road safety show problems derived from the type of accident variables recorded, which usually focuses on the victims´ information. Casado-Sanz, Guirao and Gálvez-Pérez [12] classified in groups, all the possible factors that contribute to accident severity that should be considered in a holistic road safety database: infrastructure factors (layout variables, road width, presence of pavement, shoulder width, road marking, etc.), exposure indicators (traffic flows at the accident point, climate and visibility conditions), socio-economic variables (related to the point of the accident), victim and vehicle variables and territorial indicators. Territorial and socio-economic indicators are also interesting in the study of urban road safety, where the urban structure can condition speed limitations, pedestrian itineraries or on-line street parking locations. In cases of crosstown roads, these latter variables have a great importance for road safety research, although they are not registered in the official databases.

Official road safety databases are provided by the Public Administrations, and the vast majority of the studies on road safety depend on their quality and the level of disaggregation [26]. Casado-Sanz, Guirao, Lara Galera, et al. [11] described the Spanish framework within an international framework, comparing and contrasting analysis of the variables collected in the most important databases of different countries (US, New Zealand, and Australia, along with the requirements of the Directive 2008/96/EC of the European Parliament). As expected, none of them included territorial or socio-economic variables, but even some exposure variables (traffic flows) were also missing in all databases. The identification of the location of the accident is also very important: in the US and New Zealand, GPS coordinates are collected and this fact eases the estimation of other variables, but Spain still registers only the road name and a reference point (kilometer point) which hinders proper road safety investigations. The tendency to use GPS coordinates to identify the location of road collisions is growing in the last years. Depending on the type of road infrastructure, the study of accidents can require indicators and variables not collected by official road safety data. In these situations, researchers should not stop using these indicators but try to develop ad hoc procedures to measure them (although they are costly and time consuming). In cases of crosstown roads, the physical severance (territorial variable), the length of the crosstown road and the sequence of the layout radius along the crosstown road needs to be studied as factors that can condition accident severity. For example, the level of severance generated by a crosstown road can be estimated measuring the area of the two built-up areas divided by the crosstown road. These areas can be identified with Computer Added Design (CAD) software (e.g., AutoCAD) utilizing orthophotos of the affected municipalities. With these measurements, an index can be designed to evaluate the physical barrier impacts generated by the linearity of the transport infrastructure [12]. However, severance in a crosstown road is not only physical but also depends on the location of the main activities (e.g., hospitals, schools, supermarkets, council offices, etc.). The activity severance index can be estimated by calculating the ratio between the types of activities located at the right and left of the crosstown road and the total number of activities in the area being studied or town. ESRI offers the locations of main activities (defined as POIs—Points of Interest) through open access map collections called *Living Maps*. This information provides for an alternative and systematic study of the road safety, taking into consideration territorial variables [12]. Figure 2 shows an example of one of the crosstown roads under study, where the principal points of interest can be observed.

Traffic flow is another important variable to be considered in road safety studies. Traffic flow levels near the accident location can be obtained manually through information provided by the nearest AADT (Annual Average Daily Traffic) stations. In the case of infrastructure variables (slope, minimum radius, layout consistency, road width, lane width, etc.), when not provided by official road safety databases, their collection depends on the level of disaggregation and digitalization of the road inventory in each country or Administration. For example, in a case of the study of crosstown roads, Casado-Sanz, Guirao and Gálvez-Pérez [12] used AutoTURN software (a CAD-based measurement software that realistically simulates low-speed turn maneuvers for road vehicles) to measure the sequence of the road layout radius in the Spanish crosstown roads. Other authors have also successfully investigated the use of CAD in the road safety analysis [27,28]. Loprencipe, Moretti, Cantisani, et al. [27] carried out a study that consisted of designing an innovative methodology that permits calculating and analyzing a numerical risk factor of a road, considering geometry design consistency, among other numerous variables. On the other hand, in other research, Demasi, Loprencipe and Moretti [28] proposed an analytical methodology for the estimation of urban branch road safety, in which they also considered road geometry layout.

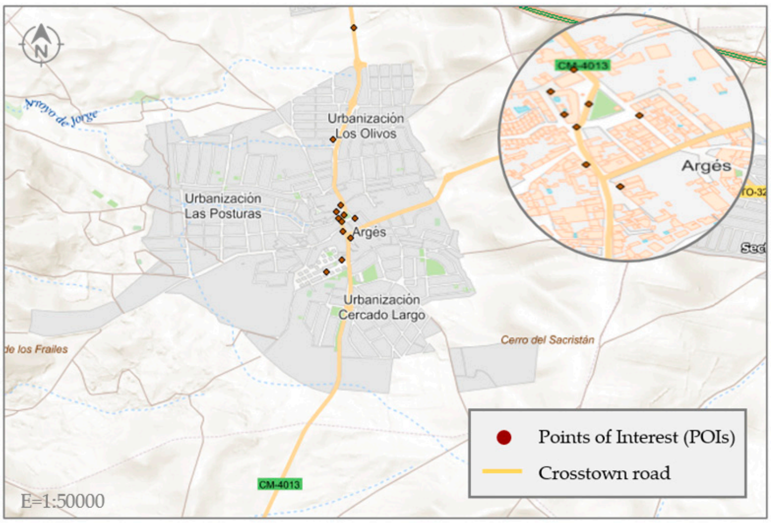

Figure 2. Example of the locations of the Points of Interest (POIs) of one of the crosstown roads under study.

Once an extensive database has been obtained, literature offers a wide variety of the methodologies to analyze crash severity: multinomial logit models [29], binary logit models [30], ordered logit or probit models [31,32] or mixed logit models [33] could be developed. However, safety data is deeply heterogeneous, and an initial segmentation of accidents provides a good solution to obtain better results from the modeling. As a consequence of this, data mining methods such as clustering, and classification techniques have been implemented and combined with classic statistical methods. There are many examples in the literature of using clustering techniques to analyze accident severity [9,34–36]. Clustering is based on taxonomy that attempts to maximize the likeness within the components within the group and the difference between the factors between groups [37,38]. Latent Class Clustering (LCC) [39,40] is a cluster analysis method based on probability models that offers prominent benefits over the conventional cluster, and for this reason, it has been recently implemented in the analysis of road accident severity [9]. LCC supposes that there is a latent variable that divides the data into reciprocally unique homogeneous subgroups and also supposes that the data is from a mixed model of different probability distributions [41]. Under these assumptions, LCC provides the following advantages: Firstly, allows different statistical criteria, which can be used to identify the most suitable number of groups. Secondly, one can use different types of variables (counts, continuous, categorical, nominal or a combination of them) and they can be analyzed without a standardization process [9,39,42]. The results will be the same, regardless of whether the variables are normalized or not. This is one of the advantages over standard non-hierarchical cluster methods, where scaling is always a problem. Furthermore, latent cluster yields a probabilistic clustering approach, that is, it is taken into account that there is uncertainty about an object's cluster membership, making this method conceptually similar to fuzzy clustering techniques. Additionally, class-membership probabilities are calculated form the estimated model coefficients and its observed scores, making possible to classify other objects belonging to the population from which the sample is taken [39]. This is another of the benefits of this technique, which is not possible with the standard fuzzy methodology.

The main aim of this paper is to analyze the factors affecting the driver injury severity of single-vehicle accidents on a specific type of infrastructure: the crosstown roads. This research work complements the previous studies on Spanish crosstown roads that were only focused on accidents involving pedestrians [11,12]. Beyond effectively incorporating the driver´s perspective, the database has also been enlarged including non-fatal accidents with slightly injured victims and the respective ad hoc variables associated with crosstown roads (territorial, infrastructure and exposure indicators). Latent cluster analysis has been incorporated in the methodology instead of traditional clustering tools [11], due to its added notable advantages, and as a second stage, Multinomial Logit Models (MLM) have been applied to the whole dataset and to each cluster obtained. In addition, to perform the multinomial logistic regression analysis, the driver injury severity was considered as a dependent variable with three possible values: slightly injured, severely injured, or fatally injured.

The subsequent section describes the procedure used to select the set of accidents that make up the research database and their key attributes. Furthermore, an exploratory analysis has been performed to obtain an in-depth understanding of the main characteristics of the data to be analyzed, prior to any application of statistical tools.

3. Database and Exploratory Analysis

The accident data used in this investigation were obtained from the Spanish Accident database provided by the Spanish Directorate General of Traffic (DGT), which contains all the crashes that took place in the national territory. The initial step consisted of extracting the crashes located on crosstown roads for a period of 11 years (2006–2016). After selecting the sample single-vehicle accidents were filtered obtaining a total sample of 3531 accidents. Then, the general accident data was cross-referenced with the victim's data and only those accidents in which the driver has been fatally injured, seriously injured or slightly injured were selected. In the final data set, a total of 2355 crashes were contemplated after eliminating the accidents with incomplete data. Each observation of the sample represents the severity of the injury of each driver involved in an accident along with a set of parameters that include driver data, vehicle attributes and road infrastructure characteristics.

As pointed out in Section 2, despite the fact that the Spanish database is one of the most consolidated in the framework of road safety compared to other countries [12], it does not contain information about traffic exposure (traffic flow), road layout variables or territorial factors (such as community severance factors) related with the crash location. Analyzing the causality of traffic accidents is a complex task due to the heterogeneity of traffic crashes and it is important to address as many variables as possible to take into account all possible influencing factors. Regardless of this, collecting these variables is a very laborious process and requires extensive and considerable resources since they need to be gathered manually. This is considered as the only way to study road safety in a holistic manner. For this reason, the authors of this research have decided to select only a representative sample (over the 2355) based on the cost, time or convenience of collecting the data, offering sufficient statistical power. The expression used to obtain a sufficiently representative sample size has been the following:

$$N = \frac{N \cdot Z_a^{\mathbf{2}} \cdot p \cdot q}{d^{\mathbf{2}} \cdot (N - \mathbf{1}) + Z_a^{\mathbf{2}} \cdot p \cdot q} \quad (1)$$

where N = population size; Z = confidence level (1.96 in this case, considering a 95% confidence level); p = probability of success or expected proportion (0.50 in this case, due to the expected proportion being unknown a priori); q = probability of failure (1-p); D = precision (maximum permissible error in terms of proportion. In this case, it was selected the value 0.04).

Taking into account all these values, a figure for n of 479 individuals was obtained. However, due to the fact that a higher number of values of these ad hoc variables were obtained in a previous study [12] and also due to fact that the results obtained in this study revealed the great significance of non-official variables (including territorial, layout and exposure indicators), the database to study the driver´s perspective was enlarged through the same ad hoc procedures. Thus, the final sample consisted of 1064 accidents, a figure much higher than the minimum calculated for the sample to be representative. This final sample contained 396 accidents in which the driver was deceased (37.2% of the total sample), 193 crashes in which the driver was seriously injured (18.1% of the total sample) and 475 accidents in which the driver was slightly injured (44.7% of the total sample). The location of these accidents is shown in Figure 3 and they correspond partly to crosstown roads (832 towns) already studied in previous research developed by Casado, Casado-Sanz and Gálvez-Pérez [12]. All variables used in the statistical analysis of the current study are shown in Table 1.

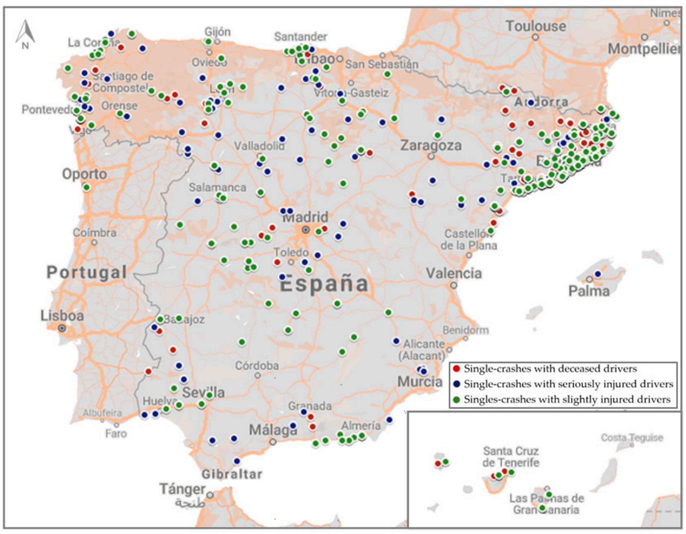

Figure 3. Geographical distribution of the accidents under study on Spanish crosstown roads for the period 2006–2016.

In relation to drivers' ages, as can be seen in Table 1, half of them were between 26 and 64 years old (55.0%). Likewise, a quarter of the drivers involved were young people below 25 years old (about 24%). As can be seen in Figure 4, the least affected group was the elderly (21% of the total accidents). In relation to drivers' gender, 70% were male, compared to the remaining 30% who were female. Regarding the type of accident, Figure 4 shows that most accidents have been caused by collisions with pedestrians (33% of the total sample) and running off the road with or without collision (30% of the total sample). Concerning the atmospheric factors, practically all accidents (86%) have been triggered under good weather conditions. Moreover, as regards to the day of the week, 71% of the accidents occurred from Monday to Friday, and 52% of them were on a working day. In relation to the accident time, 30% of the accidents have occurred in the afternoon (12–6 p.m.) and another 30% in the morning (6–12 a.m.).

Table 1. Descriptive statistics of single-vehicle crashes on crosstown roads grouped by severity.

Variable	No. of Crashes	Fatal Injury	Severe Injury	Minor Injury
Accident type				
Fixed objects collision	72	2.80%	12.50%	84.70%
Collision with pedestrian	353	85.80%	2.60%	11.60%
Collision with animals	7	0.00%	57.10%	42.90%
Vehicle rollover	174	2.30%	12.60%	85.10%
Run off road with or without collision	316	13.00%	33.50%	53.50%
Other	142	32.40%	30.30%	37.30%
Age of the drivers involved				
Youth (< 25 years old)	257	23.30%	21.00%	55.70%
Adults (26–64 years old)	585	32.10%	20.70%	47.20%
Elderly (65 and over)	222	66.70%	8.10%	25.20%
Driver's gender				
Male	742	28.40%	22.40%	49.20%
Female	322	57.50%	8.40%	34.10%
Atmospheric factors				
Good weather	917	37.60%	18.20%	44.20%
Light rain	84	33.30%	16.70%	50.00%
Heavy rain	19	36.80%	15.80%	47.40%
Fog	14	14.30%	28.60%	57.10%
Snow	11	54.50%	9.10%	36.40%
Heavy wind	19	42.10%	21.10%	36.80%
Day of the week				
Beginning of week (Mon)	159	39.00%	14.50%	46.50%
Weekday (Tue, Wed, Thu)	429	40.10%	15.90%	44.10%
End of week (Fri)	166	40.40%	19.80%	39.80%
Weekend (Sat, Sun)	310	30.60%	22.30%	47.10%
Type of day				
Holiday	206	28.20%	22.80%	49.00%
Working day	559	40.80%	16.10%	43.10%
Eve of holiday	161	34.80%	22.40%	22.40%
Day after a holiday	138	39.10%	14.50%	46.40%
Lighting				
Daylight	678	40.60%	16.20%	43.20%
Dusk	64	45.30%	20.30%	34.40%
Insufficient lighting	64	29.70%	28.10%	42.20%
Sufficient lighting	229	30.60%	17.90%	51.50%
Without lighting	29	10.40%	37.90%	51.70%

Table 1. *Cont.*

Variable	No. of Crashes	Fatal Injury	Severe Injury	Minor Injury
Restricted visibility by				
Buildings	144	45.10%	19.40%	35.50%
Terrain	46	43.50%	21.70%	34.80%
Vegetation	14	57.10%	14.30%	28.60%
Weather conditions	44	59.10%	6.80%	34.10%
Glare	19	47.40%	21.10%	31.50%
Without restriction	797	33.60%	18.30%	48.10%
Time				
Early morning (12–6 am)	158	13.90%	26.60%	59.50%
Morning (6–12 am)	320	41.30%	15.30%	43.40%
Afternoon (12–6 pm)	324	38.30%	17.60%	44.10%
Evening (6–9 pm)	184	51.10%	15.20%	33.70%
Night (9–12 pm)	78	30.80%	21.80%	47.40%
Lane width				
< 3.25 m	415	41.40%	13.50%	45.10%
[3.25–3.75] m	542	32.30%	21.20%	46.50%
> 3.75 m	107	45.80%	20.60%	33.60%
Shoulder type				
Does not exist or impractical	667	41.20%	13.90%	44.90%
< 1.5 m	274	25.90%	26.30%	47.80%
[1.5–2.5] m	115	42.60%	22.60%	34.80%
> 2.5 m	8	12.50%	25.00%	62.50%
Sidewalk				
Yes	240	17.10%	26.70%	56.20%
No	824	43.10%	15.70%	41.20%
Road markings				
Does not exist or was deleted	52	38.50%	13.50%	48.00%
Separate lanes only	55	21.80%	32.70%	45.50%
Separate lanes and road margins	947	38.40%	17.10%	44.50%
Separate margins of roadway	10	0.00%	60.00%	40.00%
Number of injuries				
1 injury	834	40.20%	17.60%	42.20%
2 injuries	177	30.50%	20.30%	49.20%
3 injuries	30	20.00%	10.00%	70.00%
> 3 injuries	23	4.30%	30.40%	65.30%
Number of occupants involved				
1 occupant	901	39.50%	17.10%	43.40%
2 occupants	107	28.00%	29.00%	43.00%
3 occupants	25	20.00%	4.00%	76.00%
> 3 occupants	31	16.10%	22.60%	61.30%
Driver infraction				
Distracted or inattentive driving	140	10.00%	40.70%	49.30%
Join the circulation without caution	2	0.00%	100.00%	0.00%
Driving on the wrong side	2	0.00%	50.00%	50.00%
Not respecting a stop signal	1	0.00%	0.00%	100.00%
Not respecting a traffic light	2	0.00%	0.00%	100.00%
Not respecting a pedestrian crossing	6	0.00%	16.70%	83.30%
Partially invade the opposite direction	5	0.00%	0.00%	100.00%
Incorrectly rotate or change direction	1	0.00%	0.00%	100.00%
Reversing wrongly	8	0.00%	12.50%	87.50%
Crossing in a zig-zag manner	2	50.00%	0.00%	50.00%
Braking action without due cause	2	0.00%	0.00%	100.00%
Other infraction	207	27.10%	38.60%	34.30%
No infraction	686	47.40%	6.40%	46.20%

Table 1. *Cont.*

Variable	No. of Crashes	Fatal Injury	Severe Injury	Minor Injury
Driver speed infraction				
Inadequate speed for existing conditions	309	47.60%	19.10%	33.30%
Exceeding the established speed	150	60.00%	20.00%	20.00%
Slow circulation hindering traffic	23	8.70%	8.70%	82.60%
No infraction	582	27.00%	17.50%	55.50%
Road length				
0.0–2.0 km	567	34.00%	20.60%	45.40%
2.0–4.0 km	375	43.70%	16.00%	40.30%
4.0–6.0 km	88	28.40%	12.50%	59.10%
6.0–8.0 km	5	60.00%	0.00%	40.00%
> 8.0 km	31	38.70%	16.10%	45.20%
Ratio Rmin/Raverage *				
0.0–0.2	921	37.00%	17.00%	46.00%
0.2–0.4	102	41.20%	24.50%	34.30%
0.4–0.6	14	28.60%	42.80%	28.60%
0.6–0.8	8	0.00%	12.50%	87.50%
0.8–1.0	19	47.40%	21.10%	31.50%
Annual average daily traffic (AADT)				
0–2500	230	36.50%	26.10%	37.40%
2500–5000	100	30.00%	24.00%	46.00%
5000–7500	75	25.30%	24.00%	50.70%
7500–10,000	69	31.90%	26.10%	42.00%
> 10,000	590	40.80%	12.40%	46.80%
Percentage of heavy vehicles				
0.0–2.5 %	62	37.10%	16.10%	46.80%
2.5–5.0 %	262	36.90%	14.10%	49.00%
5.0–7.5 %	334	37.50%	14.70%	47.80%
> 7.5 %	406	38.40%	21.90%	39.70%
Physical severance index *				
0.0–0.2 (Central crosstown road)	331	42.60%	16.00%	41.40%
0.2–0.4 (Lateral crosstown road level 1)	224	32.60%	14.70%	52.70%
0.4–0.6 (Lateral crosstown road level 2)	204	34.80%	24.00%	41.20%
0.6–0.8 (Lateral crosstown road level 3)	187	34.20%	19.30%	46.50%
0.8–1.0 (Outskirts)	118	39.80%	18.60%	41.60%
Activity severance index *				
0.0–0.2 (50% POIs zone A–50% zone B)	188	48.40%	17.00%	34.60%
0.2–0.4 (60% POIs zone A–40% zone B)	134	31.30%	17.90%	50.70%
0.4-0.6 (75% POIs zone A–25% zone B)	267	40.10%	11.20%	48.70%
0.6-0.8 (90% POIs zone A–10% zone B)	137	33.60%	19.00%	47.40%
0.8-1.0 (100% POIs zone A–0% zone B)	338	32.50%	24.00%	43.50%

* The methodology used to calculate these indexes and the meaning of each range of values can be consulted in the study carried out by Casado-Sanz, Guirao and Gálvez-Pérez [12].

Furthermore, in terms of driver infraction, it should be noted that the most committed infractions by the driver turned out to be distracted or inattentive driving (13% of the accidents). Besides, in relation to the speed infractions, one third of the drivers were driving with an inadequate speed for existing conditions and only 14% were exceeding the established speed.

With respect to infrastructure factors, it should be mentioned that 51% of the accidents took place in crosstown roads with a lane width between 3.25 and 3.75 meters. Forty per cent of them occurred on crosstown roads with a lane width under 3.25 meters. Furthermore, in 63% of the crosstown roads where accidents took place there was no hard shoulder or had insufficient width. Twenty-six per cent of the crashes occurred in crosstown roads with a hard shoulder of less than 1.5 meters. Other relevant information relates to the fact that 77% of the crosstown roads have no sidewalk. Figure 5 shows that 53% of crosstown roads considered in the sample have a road length of less than 2 km.

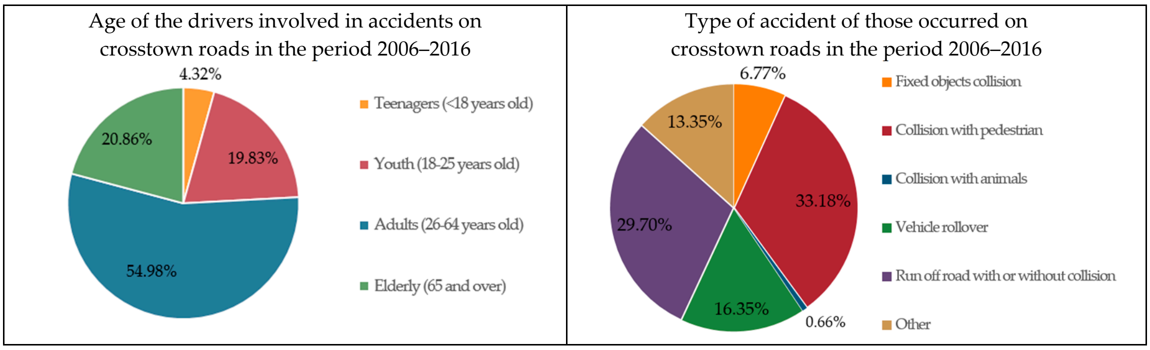

Figure 4. Characterization by age and type of accident associated with traffic accident victims on Spanish crosstown roads in the period 2006–2016 (only single-vehicle crashes).

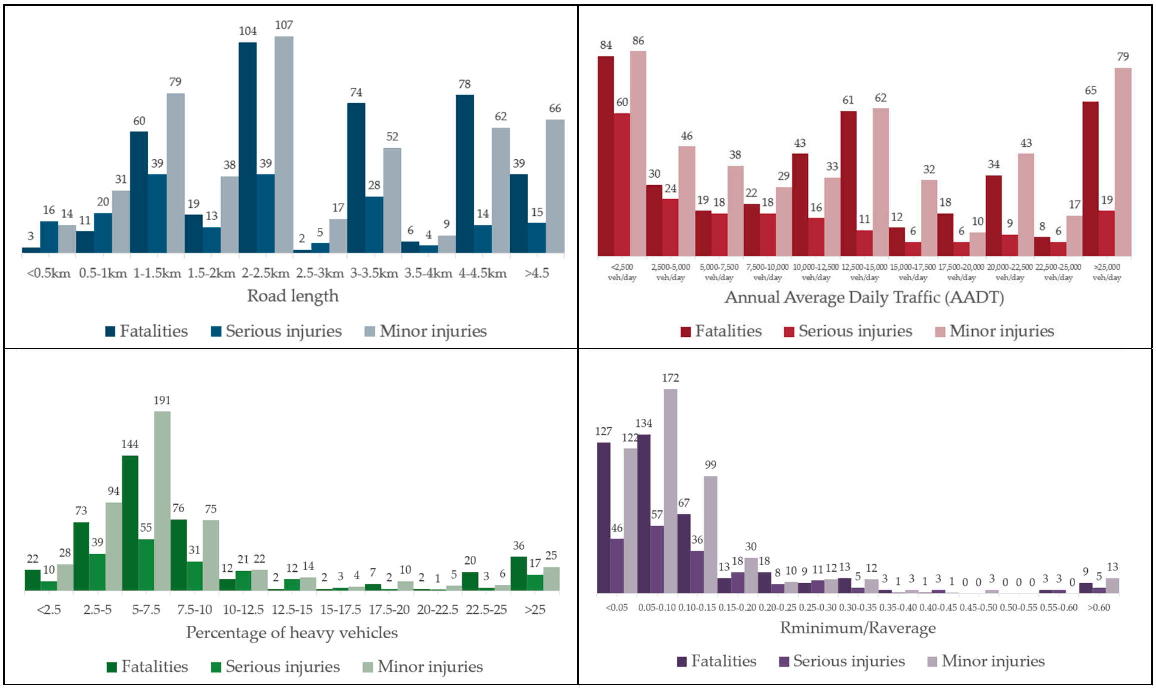

Figure 5. Values of the new variables gathered (road length, AADT, percentage of heavy vehicles, minimum radius), versus the number of crashes occurred on Spanish crosstown roads (2006–2016).

Another interesting conclusion that is obtained from the exploratory analysis is with respect to the territorial variables. This section explains how these variables were gathered and the meanings of values obtained. As can be seen in Figure 6, 31% of the crosstown roads where an accident with a driver injured have occurred, are central crosstown roads cutting across the middle of the town. This could be, a priori, the most unfavorable situation. Until now, there is a tendency to think that crosstown roads with more traffic, that are central to the town or village and are longer in length, are more dangerous. In contrast, approximately 40% of these accidents have taken place on roads that cross the population with one third of the territory on one side and two thirds of it on the other side (lateral crosstown road). It is only one third of accidents that occur on crosstown roads that do not divide the population, but pass very close to it, leaving the majority of the buildings on road margin (peri-urban crosstown road). However, not only the barrier effect must be taken into account, but also the location of the different activity centers in the community affected by the crosstown road. For this reason, the location of all the points of interest and activity centers were included in the analysis to evaluate the impact of a location's attractiveness to people living in a particular location. This analysis could supply knowledge about pedestrian walkability in the area and the potential barrier effect of the crosstown road on the town or village. The exploratory analysis revealed that 32% of the crosstown roads where the accidents took place have attractions (points of interest or activities) concentrated on one roadside. In this sense, it could be supposed that the conflict would depend on the number of people residing in the margin of the road where there are no activities.

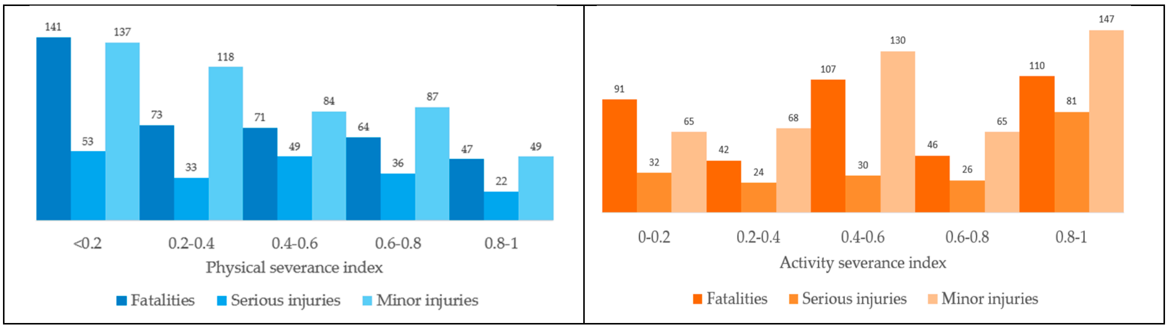

Figure 6. Distribution of values of the physical and activity severance index in the sample. Spanish crosstown roads with single-vehicle accidents (2006–2016).

Finally, regarding the exposure traffic data, the exploratory analysis supports that 55% of the accidents took place on crosstown roads that have an AADT of more than 10,000 vehicles per day, followed by another 22% of them which have a value of less than 2500 vehicles per day. These results point towards the fact that more accidents occur on crosstown roads with higher traffic, a result which is inconsistent with that obtained in other studies [10]. However, in this case, the exploratory analysis only indicates that there are a greater number of crosstown roads with high volume traffic, regardless of the severity of the accident or the number of accidents, which will be analyzed later. Additionally, as can be shown in Figure 5, most of the crosstown roads have a large percentage of heavy vehicles.

4. Methodology

4.1. Cluster Analysis

This section describes the statistical techniques applied to the study. Cluster techniques were used for segmenting the data and the multinomial logistic regression model was used to analyze the driver's injury severity. Applying latent clustering techniques, given a set of data of N crashes, measured within a set of different observed variables, $Y_1, \ldots, Y_j$, which are regarded indexes of a latent variable X, and which constitute a Latent Class Model (LCM) with T categories. If each observed value includes a specific number of classes: Yi has Ii categories, with i=1, … , j; subsequently the manifest variables make a multiple contingency table with $P^{j}_{i=1} I_i$ response patterns. If P expresses probability, $P(X_t)$ make reference to the likelihood that a case selected by chance belongs to the latent t class, with $t = 1, 2, \ldots, T$. The expression of Latent Class Model (LCM) is given by [9]:

$$P_{Y_i} = \sum_{t=1}^{T} P_{X_t} P_{Y_i|X_t} \quad (2)$$

where Yi is the response-pattern vector of case i and $P(X_t)$ is the conditional likelihood that a randomly chosen case contains a response pattern $Y_i = (y_1, \ldots, y_j)$. The ulterior supposition of local independence must be verified and hence, the regular expression of LCMs is re-written:

$$P_{Y_i} = \sum_{t=1}^{T} P_{X_t} \prod_{i=1}^{j} P_{Y_{ij}|X(t)} \quad (3)$$

The values are assessed through the use of an expectation maximization algorithm. The posterior membership probability is calculated by upgrading the previous likelihood by using Bayes' theorem:

$$P_{X_t|Y_i} = \frac{P_{x_t} P_{Y_i|X_t}}{P_{Y_i}} \quad (4)$$

The group of likelihoods is estimated for each of the response patterns and the case is assigned to the latent case with the highest probability. Due to the number of groups being unascertained at the beginning, the aim is to determine the model that can best describe the data being used. The software used for this analysis (Latent GOLD v. 5.1) (Statistical Innovations, Belmont, Nashville, TN, USA, 2016) provides several criterions to choose the ideal number of clusters: Bayesian Information Criterion (BIC) [43], Akaike Information Criterion (AIC) [44] and Consistent Akaike Information Criterion (CAIC) [45]. The number of clusters that minimizes these criteria will be the most suitable one. Some authors recommend using the BIC criterion against others [46], but in many cases, incrementing the number of clusters might not always reach a minimum value [47]. The variation of the values of BIC, AIC and CAIC is shown in Figure 7. BIC criterion has been used to select the optimal number of clusters in our case study.

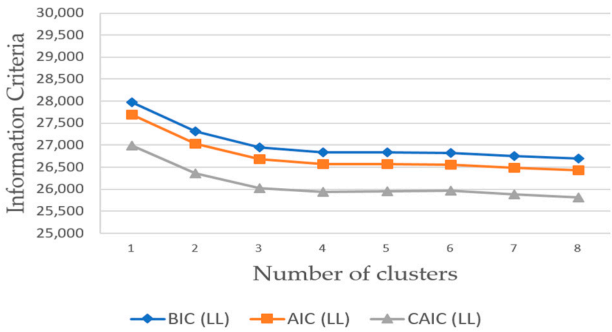

Figure 7. Variation of BIC, AIC and CAIC for number of clusters selection.

4.2. Severity Model

The statistical method used in this study to analyze the accident database has been multinomial logistic regression, which was introduced by McFadden [48]. This methodology is used to predict the probability of belonging to a category in a dependent variable based on numerous independent variables. Unlike a binary logistic regression, in which a dependent variable has only one binary option, the dependent variable in a multinomial logistic regression model can have more than two categorically coded options, and one of the categories is taken as the reference category. Hereafter, the theoretical basis of this statistical method is detailed. The equation of the linear function Q that determines the injury output *i* for observation *n* can be defined as follows:

$$Q_{in} = \delta_i X_{in} + \eta_{in} \quad (5)$$

where δI is a vector of computable coefficients, X_{in} is a vector of discernible features that affect the driver injury severity sustained by observation n. η_{in} is an alteration term that takes into account the no observed effects. In those cases, in which these alteration terms can be distributed independently and are equal to the generalized distribution of extreme values, the model can be represented with the following expression [49]:

$$P_n(i) = \frac{exp(\delta_i X_{in})}{\sum_i exp(\delta_i X_{in})} \quad (6)$$

5. Results and Discussion

5.1. Cluster Analysis

In this section, the discussion focuses on the results of the latent cluster analysis developed to classify single-vehicle crashes into homogeneous groups. As shown in Table 2, accidents were grouped by variables using Latent GOLD 5.1 software (Statistical Innovations, Belmont, Nashville, TN, USA, 2016). Driver injury severity was considered as a dependent variable with three possible categories: slightly injured, severely injured or fatally injured. Eight cluster models were calculated in order to choose the appropriate number of clusters. BIC criterion has been used to select the suitable number of clusters. Finally, single-vehicle crashes' data were grouped into three clusters. Cluster profiles are shown in Table 2. Once the optimal number of clusters had been selected, the next step was characterizing them. For that purpose, the most significant categories for each variable were determined using the highest conditional probability of belonging to a specific cluster. The characterization was based on selecting the variables that allowed distinction between groups. Cluster 1 contains the 37.6% of the sample, Cluster 2 consists of 32.8% of the sample, and Cluster 3 consists of 29.6% of the sample. Their characteristics are detailed below:

Cluster 1. The first group contains 37.6% of the total accidents in the sample. The drivers of 59.7% of these accidents were between 26 and 64 years old. As it is shown in Table 2, the drivers' gender of this group has been mainly male (75.2%). The accidents in this group have been caused by vehicle rollovers in 38.2% of the crashes. The vehicle rollovers took place on business days in 61.1% of the cases and during the afternoon (12–6 p.m.). Further to this, it was noticed that these accidents happened under daylight conditions and with no visibility restrictions. Besides, most of the crashes in this cluster took place in crosstown roads with no shoulder (66.0% of the cases) and without pavement (80.7% of the total collisions in this group). Furthermore, the lane width that is predominant in this first group has been estimated to be between 3.25 and 3.75 m. As reflected in Table 2, the injured drivers involved in these accidents have not committed any significant infraction. Moreover, in relation to traffic volume, these crashes have occurred on crosstown roads with a high volume of traffic and a percentage of heavy vehicles of more than 5%. Finally, regarding territorial factors, this group consists mainly of central crosstown roads where most of the points of interest are located on one roadside. As a result, this group can be called as ´vehicle rollovers on central crosstown roads with no pavement or shoulder caused by drivers between 26 and 64 years old and without infractions committed'.

Cluster 2. The second cluster includes the 32.8% of the total accidents in the sample. The drivers of 40.6% of these accidents were older than 65 years old. Unlike the results obtained in Cluster 1, in this group the gender of drivers was predominantly female (54.2%). The accidents in this group have been caused by collisions with pedestrians in 82.4% of the crashes. The crashes happened on business days in 60.5% of the cases and during the morning (6–12 a.m.). Moreover, results revealed that these accidents took place under daylight conditions and with no visibility constraint. Additionally, most of the accidents of this group occurred on crosstown roads with no shoulder (73.2% of the cases) and with no pavement (92.7% of the total accidents of this group). The lane width that is predominant in this group has been estimated to be < 3.25 m. With regard to infractions, in 38.9% of the accidents, drivers circulated at an inadequate speed for existing conditions. Additionally, these crashes have occurred on crosstown roads with a high volume of traffic and a percentage of heavy vehicles of more than 7.5%. Finally, concerning territorial factors, this group consists mainly of central crosstown roads where most of the points of interest are located on one side of the road. Therefore, this cluster can be defined as ´pedestrian-vehicle collisions on central crosstown roads without sidewalk or shoulder caused by elderly drivers circulating at inadequate speed on working days´.

Cluster 3. The third and final group consists of 29.6% of the total accidents in the sample. The drivers of 51.5% of these accidents were under 26 years old. Similar to Cluster 1, the gender of drivers was mainly male (86.8%). The accidents in this group have been caused by run-off-road with or with no collision in 71.8% of the crashes. These accidents occurred principally on holiday during the weekend in 53.1% of the cases and during the early morning (12–6 a.m.). Besides, it was noticed that these accidents occurred under daylight conditions and without any visibility restrictions. Furthermore, most of the accidents in this group occurred on crosstown roads with no shoulder or with a shoulder of less than 1.5m (45.7% and 42.3% respectively). The lane width that characterizes this group has been estimated to be between 3.25 and 3.75 m. With regard to infractions, in 38.3% of the accidents in this group, drivers circulated distracted or were inattentive and another 33.1% of them committed another infraction. Moreover, 39.7% of them circulated at an inadequate speed for existing conditions. In relation to traffic volume, these crashes have occurred on crosstown roads with a low level of traffic and a percentage of heavy vehicles of more than 7.5%. Finally, regarding territorial factors, this group consists mainly of central crosstown roads where most of the points of interest are located on one side of the road. Hence, this cluster can be defined as ´runs-off-road collisions with a relevant percentage of young drivers on central crosstown roads without sidewalk or shoulder, caused by distracted driving and excessive speed during the weekend late at night´.

As a conclusion to this section, cluster analysis has been used to obtain a brief description for each of the three clusters. This data will be useful in the interpretation of the results of the next stage of the study, where a crash severity analysis will be carried out. First, a multinomial logistic regression model will be applied to the whole dataset and then it will be applied to each cluster individually in order to verify if extra information is obtained.

Table 2. Analyzed variables and percentage of belonging to each cluster.

Variable	Cluster 1 (37.6%)	Cluster 2 (32.8%)	Cluster 3 (29.6%)
Accident type			
Fixed objects collision	13.49%	0.86%	8.08%
Collision with pedestrian	9.20%	82.40%	3.94%
Collision with animals	1.05%	0.00%	0.73%
Vehicle rollover	38.21%	1.34%	6.23%
Run off road with or without collision	22.65%	1.37%	71.80%
Other	15.40%	14.03%	9.22%
Age of the drivers involved			
Youth (< 25 years old)	32.20%	17.80%	51.50%
Adults (26–64 years old)	59.70%	41.60%	39.20%
Elderly (65 and over)	8.10%	40.60%	9.30%
Driver's gender			
Male	75.20%	45.80%	86.80%
Female	24.80%	54.20%	13.20%
Atmospheric factors			
Good weather	87.72%	84.39%	82.17%
Light rain	0.46%	0.48%	0.49%
Heavy rain	0.80%	0.90%	0.95%
Fog	7.23%	8.70%	9.58%
Snow	1.57%	2.04%	2.34%
Heavy wind	0.83%	1.26%	1.57%
Other	1.38%	2.24%	2.90%
Day of the week			
Beginning of week (Mon)	17.46%	16.75%	9.33%
Weekday (Tue, Wed, Thu)	48.23%	45.60%	23.66%
End of week (Fri)	15.30%	18.15%	15.12%
Weekend (Sat, Sun)	19.01%	19.50%	51.89%

Table 2. *Cont.*

Variable	Cluster 1 (37.6%)	Cluster 2 (32.8%)	Cluster 3 (29.6%)
Type of day			
Holiday	12.69%	11.88%	39.75%
Working day	61.10%	60.50%	30.45%
Eve of holiday	11.31%	14.61%	20.59%
Day after a holiday	14.90%	13.01%	9.21%
Lighting			
Daylight	70.49%	72.89%	42.60%
Dusk	5.93%	6.90%	3.94%
Insufficient lighting	14.09%	15.96%	38.12%
Sufficient lighting	4.08%	3.38%	10.23%
Without lighting	9.49%	0.87%	5.11%
Restricted visibility by			
Buildings	13.02%	18.28%	10.12%
Terrain	2.42%	5.49%	5.21%
Vegetation	0.84%	2.16%	2.34%
Weather conditions	2.58%	6.90%	6.45%
Glare	0.75%	2.57%	2.14%
Without restriction	80.39%	64.60%	73.74%
Time			
Early morning (12–6 am)	11.46%	1.93%	35.45%
Morning (6–12 am)	29.94%	36.26%	21.30%
Afternoon (12–6 pm)	36.34%	31.45%	22.60%
Evening (6–9 pm)	17.02%	25.74%	8.26%
Night (9–12 pm)	5.24%	4.62%	12.39%
Lane width			
< 3.25 m	44.40%	45.60%	22.76%
[3.25–3.75] m	48.24%	40.24%	68.20%
> 3.75 m	7.36%	14.16%	9.04%
Shoulder type			
Does not exist or impractical	66.00%	73.20%	45.70%
< 1.5 m	23.75%	15.25%	42.30%
[1.5–2.5] m	8.07%	11.18%	11.42%
> 2.5 m	2.18%	0.37%	0.58%
Sidewalk			
Yes	19.30%	7.30%	44.45%
No	80.70%	92.70%	55.55%
Road markings			
Does not exist or was deleted	5.49%	5.15%	4.37%
Separate lanes only	5.54%	3.46%	9.86%
Separate lanes and road margins	88.16%	91.34%	83.99%
Separate margins of roadway	0.81%	0.05%	1.78%
Number of injured			
1 injured	88.07%	86.24%	59.68%
2 injured	11.09%	12.35%	25.10%
3 injured	0.70%	1.12%	8.35%
> 3 injured	0.14%	0.29%	6.87%
Number of occupants involved			
1 occupant	93.00%	92.50%	62.20%
2 occupants	6.33%	5.60%	22.15%
3 occupants	0.51%	1.49%	6.95%
> 3 occupants	0.16%	0.41%	8.70%

Table 2. *Cont.*

Variable	Cluster 1 (37.6%)	Cluster 2 (32.8%)	Cluster 3 (29.6%)
Driver infraction			
Distracted or inattentive driving	5.85%	0.02%	38.30%
Join the circulation without caution	0.00%	0.00%	0.68%
Driving on the wrong side	0.00%	0.00%	0.68%
Not respecting a stop signal	0.00%	0.00%	0.30%
Not respecting a traffic light	0.41%	0.00%	0.12%
Not respecting a pedestrian crossing	1.35%	0.00%	0.25%
Partially invade the opposite direction	0.86%	0.00%	0.58%
Incorrectly rotate or change direction	0.31%	0.00%	0.00%
Reversing wrongly	1.02%	0.00%	0.94%
Crossing in a zig-zag manner	0.17%	0.00%	0.23%
Braking action without due cause	0.40%	0.00%	0.00%
Other infraction	17.60%	11.25%	33.10%
No infraction	72.03%	88.73%	24.82%
Driver speed infraction			
Inadequate speed for existing conditions	13.40%	38.90%	39.70%
Exceeding the established speed	1.56%	22.45%	21.37%
Slow circulation hindering traffic	4.19%	0.00%	2.19%
No infraction	80.85%	38.65%	36.74%
Road length			
0.0–2.0 km	22.70%	20.85%	60.87%
2.0–4.0 km	46.50%	49.61%	27.25%
4.0–6.0 km	24.31%	26.34%	8.60%
6.0–8.0 km	3.42%	1.14%	1.55%
> 8.0 km	3.07%	2.06%	1.73%
Ratio Rmin/Rave			
0.0–0.2	91.53%	87.14%	79.05%
0.2–0.4	5.35%	9.57%	15.18%
0.4–0.6	0.96%	1.29%	2.16%
0.6–0.8	1.52%	0.00%	0.59%
0.8–1.0	0.64%	2.00%	3.02%
Annual average daily traffic (AADT)			
0–2500	14.67%	15.29%	37.98%
2500–5000	7.73%	8.06%	16.18%
5000–7500	6.72%	5.60%	5.91%
7500–10,000	6.91%	6.26%	9.90%
> 10,000	63.97%	64.79%	41.85%
Percentage of heavy vehicles			
0.0–2.5%	6.66%	6.30%	4.79%
2.5–5.0%	18.86%	18.59%	21.57%
5.0–7.5%	40.90%	36.16%	32.45%
> 7.5%	33.58%	38.95%	41.19%
Activity severance index			
0.0–0.2	8.79%	16.77%	14.97%
0.2–0.4	17.58%	17.06%	14.70%
0.4–0.6	29.86%	28.29%	11.14%
0.6–0.8	16.21%	14.51%	13.67%
0.8–1.0	27.56%	23.37%	45.52%
Physical severance index			
0.0–0.2	23.97%	36.24%	34.22%
0.2–0.4	22.46%	17.60%	22.11%
0.4–0.6	21.64%	19.76%	17.29%
0.6–0.8	21.88%	15.56%	15.16%
0.8–1.0	10.05%	10.84%	11.22%

5.2. Injury Severity Analysis Using MNL

This study used multinomial logistic regression to examine the different contributing causes that increment the probability of a fatal outcome, taking into consideration the fact that a single-vehicle accident has occurred on Spanish crosstown roads. To achieve this objective, four multinomial logit models were developed, one for the whole database and one for each cluster (from Clusters 1–3). Driver injury severity was selected as a dependent variable with the following three possible categories: slightly injured, severely injured, or fatally injured. A total set of 23 variables were contemplated for the statistical analysis, which are shown in Table 1.

The coefficients resulting from the statistical models show the effects that a contributing variable has on the conditional likelihood of a fatal consequence in the event that a severe or fatal accident occurs compared to a minor crash. The estimation results of the multinomial logit models are shown in Table 3. A significance level of 10% was considered in the current analysis. As can be seen in Table 3, only statistically significant variables at the 10% level have been represented. The results of the models revealed that variables that meaningfully increment the probability of fatal and severe accidents, taking into account the whole data set model, are as follows: physical severance index, AADT, percentage of heavy vehicles, day of the week, lane width, road markings, infractions committed by the driver and the type of accident. The results of the physical severance indicator disclosed that the territorial variable is very relevant. The odds ratio calculated for a physical severance index value between 0.4 and 0.6 was 2.370 ($e^{0.863}$). This analysis suggests that the probability of a fatal or severe outcome on a lateral crosstown road is 237.0% higher than the baseline condition, a peri-urban crosstown road. This result may seem, a priori, contrary to what was expected. As mentioned in previous sections and given the evidences found by Casado-Sanz, Guirao and Gálvez-Pérez [12], a central crosstown road could be the most unfavorable situation for a pedestrian. However, the current analysis has revealed that from the driver's perspective, crosstown roads that pass through the outskirts of the town are more dangerous with higher risks of injury severity. This may be due to various reasons that should be analyzed more thoroughly. On the one hand, whilst crossing the city, drivers could encounter more obstacles, narrower sections, less visibility or more urbanized streets that would reduce the driver's speed. On the other hand, if the road borders the city on its outskirts (as a bypass road), the section is generally more generous, there are no obstacles and the speed increases. For the other levels of this variable, the results are not statistically significant and therefore, no firm conclusion can be drawn.

With regard to exposure indicators, the odds ratio decreases as the AADT increases. This result suggests that those crosstown roads with a low traffic volume increase the severity of the driver injury in case of an accident, when compared to higher traffic volumes. A possible explanation could be that higher traffic volumes are generally related to more densely urbanized areas, where the driver expects to find more local traffic and crosstown roads tend to be best signed and with limitations to speeding (more traffic lights in zebra crossings, longer crosstown roads, sidewalks instead of shoulders, etc.). Moreover, these areas are generally more congested, and speeds are also lower due to this reason. Furthermore, in relation to heavy vehicles, the odds ratio estimated for a crosstown road with a percentage of heavy vehicles between 5% and 7.5% is 0.615 ($e^{-0.486}$). This analysis suggests that the probability of a fatal or severe outcome decreases when the crosstown road has a lower percentage of heavy vehicles.

In relation to infrastructure factors, several variables have resulted in being significant. Firstly, the odds ratio obtained for a roadway width of less than 3.25m was 0.501 ($e^{-0.692}$), suggesting that a narrower lane decreases the driver injury severity in case of a crash, compared to a lane width of more than 3.75 m. These results are consistent with previous literature [50,51], which suggest that wider roads may imply higher speeds with the consequent increase in accident severity. Instead, in Cluster 2, the results reveal that crosstown roads with small-sized shoulders are more dangerous than those that have a shoulder greater than 2.5 m. It is importance to mention that broader paved surface usually corresponds to more urban environments (densely-built and populated towns), where the roadway has been enlarged in order to provide space for car parking, for example. Additionally, for several causes, the speeds and severity are lower in more dense urban areas.

On the other hand, considering road markings, results revealed that crosstown roads with no road markings are more likely to cause fatal or serious injuries during single-vehicle crashes.

Regarding infractions committed by the driver, it can be concluded that single-vehicle crashes are more likely to cause fatal or severe injuries when drivers commit an infraction (such as exceeding speed, reversing wrongly or driving distracted). As it can be seen in Table 3, driving distracted or without paying attention is 637% more likely to result in serious injury or fatal injury when compared to the baseline condition (no infraction committed).

On the other hand, it can be observed in Table 3, that numerous variables that have not resulted meaningful in the whole dataset analysis are identified as relevant in some of the clusters. For instance, the variable activity severance index has not resulted significant in the whole database, while the likelihood ratio obtained for a value between 0.6 and 0.8 for Cluster 2 is estimated to be 48.47 ($e^{3.881}$). This value indicates that pedestrian-vehicle crashes with elderly drivers are 4,847% more likely to suffer fatal or severe injuries when the town has all the points of interest (schools, hospitals, grocery shops, etc.) situated on just one roadside. This fact is consistent with previous literature [12], and it may be due to the greater likelihood that residents cross the crosstown road, with the consequent increase in conflicts between vehicles and pedestrians. Another conclusion that can be obtained from the model is that the likelihood ratio of a driver being involved in a pedestrian-vehicle collision with fatal or severe injuries when the crash took place on a central crosstown road without sidewalk or shoulder is 81.6% lower compared to a peri-urban crosstown road.

Further conclusions can be drawn from Cluster 3, which refers to run-off-road collisions caused by young drivers. On the one hand, as can be seen in the previous table, driving at an inadequate speed increases significantly the driver injury severity, as well as visibility restrictions, which is another variable that mostly affects this group. Additionally, accidents caused by the group of young people are much more serious when they occur late at night than in the morning. In relation to gender, accidents have been shown to increase driver injury severity when the driver is male. On the other hand, results of Cluster 1, which refers to vehicle rollovers on central crosstown roads caused by drivers between 26 and 64 years old, reveal that the activity severance variable is very significant. For this particular group, the odds ratio obtained for a value between 0 and 0.2 is estimated to be 18.84 ($e^{2.936}$). This value indicates that vehicle rollovers with adult drivers are 1.884% much more likely to have severe or fatal injuries when the town has all the points of interest distributed homogeneously (50% of them on one side of the crosstown road and 50% on the other side). Moreover, as has happened with the other groups, driver infractions have played a significant role in increasing the severity of this group of accidents. In this case, it has been demonstrated that distracted or inattentive driving increments notably the severity of rollover accidents. Finally, in relation to shoulder size, the results obtained for Cluster 2 reveal that accidents which occur on crosstown roads without a shoulder or with a small-sized shoulder are more serious than those that have a shoulder of more than 2.5 m. Therefore, it can be concluded that a wider shoulder reduces the conditional likelihood of a fatal consequence when a pedestrian-vehicle crash occurs.

Table 3. Statistical results of the Multinomial logit (MNL) regression for one vehicle accidents on Spanish crosstown roads.

Reference Group: Minor Injured	**Whole Dataset**		**Cluster 1**		**Cluster 2**		**Cluster 3**	
Variables	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**
Physical severance index 0.2–0.4 (lateral level 1) [*Ref. Physical severance index 0.8–1.0 (outskirts)]*					−1.695	0.058	−5.157	0.012
Physical severance index 0.4–0.6 (lateral level 2) [*Ref. Physical severance index 0.8–1.0 (outskirts)]*	0.863	0.052			−1.933	0.025		
Physical severance index 0.6–0.8 (lateral level 3) [*Ref. Physical severance index 0.8–1.0 (outskirts)]*							−5.488	0.048
Activity severance index 0.0–0.2 (50%–50%) [*Ref. Activity severance index 0.8–1.0 (100%–0%)]*			2.936	0.056				
Activity severance index 0.4–0.6 (75%–25%) [*Ref. Activity severance index 0.8–1.0 (100%–0%)]*			−2.012	0.006			−4.138	0.052
Activity severance index 0.6–0.8 (90%–10%) [*Ref. Activity severance index 0.8–1.0 (100%–0%)]*					3.881	0.014		
Driver's age < 30 years old *(Ref. Driver's age > 65 years old)*			1.704	0.066			4.579	0.059
Driver's age 31–64 years old *(Ref. Age > 65 years old)*			2.015	0.024			7.628	0.032
Male driver *(Ref. Female driver)*			1.377	0.016			4.090	0.037
AADT < 2500 vehicles/day *(Ref. AADT > 10,000 vehicles/day)*	0.651	0.053			8.290	0.074	5.165	0.005
AADT 2500–5000 vehicles/day *(Ref. AADT > 10,000 veh/day)*			−2.286	0.073				
AADT 5000–7500 vehicles/day *(Ref. AADT > 10,000 veh/day)*	0.743	0.095	1.882	0.032	−16.466	0.000		
Percentage of heavy vehicles 2.5%–5% *(Ref. Percentage of heavy vehicles > 10%)*					15.419	0.002		
Percentage of heavy vehicles 5%–7.5% *(Ref. Percentage of heavy vehicles > 10%)*	−0.486	0.075						
On weekdays (Tuesday, Wednesday, Thursday) [*Ref. During the weekend (Saturday, Sunday)]*	−0.926	0.062					6.131	0.059
In the morning (6–12 am) *(Ref. At night 9–12 pm))*					−8.274	0.061	−5.968	0.083
On holiday *(Ref. During a working day)*							5.794	0.000
Road length 2–4 km *(Ref. Road length 0–2 km)*							−6.087	0.076
Crosstown road with sidewalk *(Ref. crosstown road without sidewalk)*					−13.259	0.003		
Lane width < 3.25 m *(Ref. Lane width > 3.75 m)*	−0.692	0.093			3.778	0.080	−4.867	0.027
Lane width 3.25–3.75m *(Ref. Lane width > 3.75 m)*			−2.117	0.008				
Crosstown road without shoulder *(Ref. Crosstown road with a shoulder > 2.5 m)*					14.183	0.000		
Crosstown road with a shoulder < 1.5 m *(Ref. Crosstown road with a shoulder > 2.5 m)*					11.639	0.003		
Road markings—Separate lanes only *(Ref. Without road markings)*	1.334	0.057					−7.097	0.031
Road markings—Separate lanes and margins *(Ref. Without road markings)*			2.923	0.012			−7.642	0.007
Road markings—Separate margins *(Ref. Without road markings)*	2.324	0.031	4.379	0.094				
Accidents occurred under daylight conditions *(Ref. Without lighting)*							−6.260	0.033
Accident occurred at dusk *(Ref. Without lighting)*			4.431	0.021				
Accident occurred under insufficient lighting conditions *(Ref. Without lighting)*							−5.726	0.026
Accident occurred under sufficient lighting conditions *(Ref. Without lighting)*							−7.316	0.012

Table 3. *Cont.*

Reference Group: Minor Injured	Whole Dataset		Cluster 1		Cluster 2		Cluster 3	
Variables	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**	**Coeff.**	**Sig.**
Restricted visibility by terrain *(Ref. No restriction)*							3.380	0.093
Restricted visibility by weather conditions *(Ref. No restriction)*							14.512	0.002
Restricted visibility by glare *(Ref. No restriction)*							10.430	0.022
Number of victims—1 injured *(Ref. > 3 injured)*			3.977	0.018			19.565	0.000
Number of victims—2 injured *(Ref. > 3 injured)*							11.879	0.012
Number of victims—3 injured *(Ref. > 3 injured)*							9.697	0.035
Number of occupants involved—1 occupant *(Ref. > 3 occupants)*					10.495	0.041	9.693	0.009
Infractions committed by the driver—Inadequate speed *(Ref. No infraction)*					−2.969	0.074	3.815	0.021
Infractions committed by the driver—Exceeding speed *(Ref. No infraction)*	0.702	0.081			−5.114	0.036		
Infractions committed by the driver—Distracted or inattentive driving *(Ref. No infraction)*	1.852	0.000	4.026	0.000				
Infractions committed by the driver—Reversing wrongly *(Ref. No infraction)*	4.210	0.000						
Infractions committed by the driver—Other infraction *(Ref. No infraction)*	2.169	0.000	3.230	0.000				
Type of accident—Rear-end collision *(Ref. Other type of accident)*	−2.695	0.023						
Type of accident—Fixed objects collision *(Ref. Other type of accident)*	−1.848	0.000	−1.929	0.022				
Type of accident—Collision with pedestrians *(Ref. Other type of accident)*	−1.064	0.063			4.557	0.049		
Type of accident—Vehicle rollover *(Ref. Other type of accident)*	−1.796	0.000	−2.389	0.002				
Type of accident—Run off road with or without collision *(Ref. Other type of accident)*	−0.935	0.008	−2.822	0.000				

6. Road Safety Analysis from Different Perspectives: Drivers vs. Pedestrians

In this section, a comparison of the different studies carried out on crosstown roads so far will be carried out. As we just showed in the current paper, the factors influencing the driver injury severity of single-vehicle crashes on crosstown roads have been examined. Additionally, as previously mentioned in the literature review section, this research study complements two preceding works on Spanish crosstown roads that were only focused on accidents involving pedestrians [12]. One of them analyzed pedestrian-vehicle accidents on Spanish crosstown roads considering all age groups, while the other focused only on elderly pedestrians.

Figure 8 shows a summary of the main outcomes of the analysis of the accidents on Spanish crosstown roads from the perspective of two of the intervening users: pedestrians and drivers. The pyramids include the top five most significant predictor variables for each analysis carried out under the driver and the pedestrian´s perspectives. The older pedestrian´s perspective has been also represented by a pyramid. The level of significance increases with the height of the pyramid and the more significant variable for the group is located at the top of the pyramid. As shown in this figure, 'Infractions committed by the driver' and 'Type of accident' are the most important contributing factors on the severity of drivers on single-vehicle accidents on Spanish crosstown roads. The results from this study show that these factors need to be considered in single-vehicle crash studies around crosstown roads and for drivers. As in the previous case, if we take into account the perspective of pedestrians, the variables related to infractions, both pedestrian and driver, are also significant; followed by the pedestrian's age, which also plays a fundamental role in these types of accidents. However, if we only consider the age group of elderly pedestrians, the most significant variables change, being the ones that most affect, in this case, the visibility restrictions and the activity and physical severance.

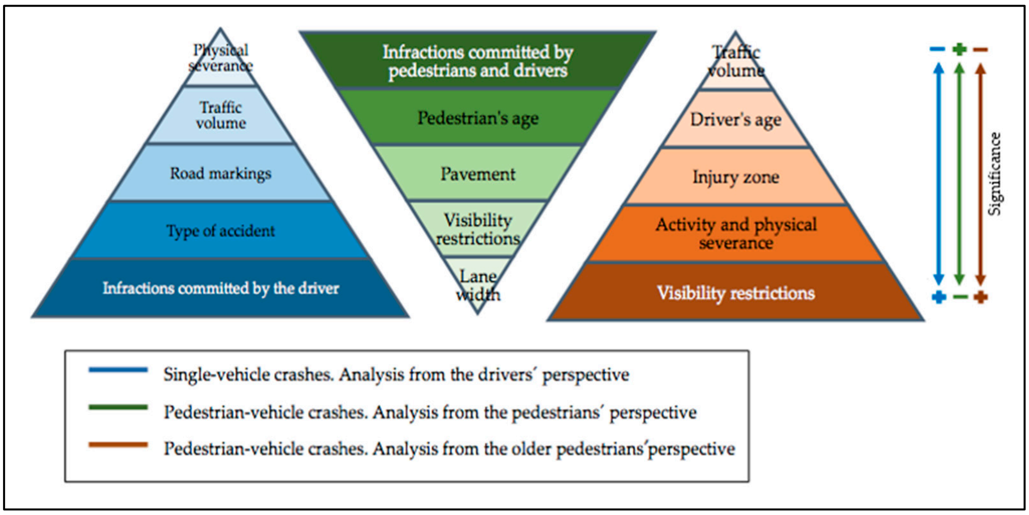

Figure 8. Ranking of significant variables obtained in the diverse analyses carried out to explore the main factors that contribute to accident severity considering different points of view: the driver and the pedestrian.

The results and conclusions obtained from these three sets of analysis can help policy makers to design a set of strategic action plans at the urban level, in particular, for this specific type of road and by user categories. Knowing what the most significant variables are and to what extent they affect the accident severity is a fundamental pillar to better understand and solve existing real road safety problems.

7. Conclusions

In order to incorporate the driver perspective into the analysis of the accident injury severity on Spanish crosstown roads, this study applied a latent cluster analysis and a multinomial logit model to a total sample of 1064 accidents involving only one vehicle in the period 2006–2016. The database was designed through an ad hoc set relying on territorial, exposure and infrastructure factors. The statistical analysis reveals that factors such as lateral crosstown roads, low traffic volumes, higher percentages of heavy vehicles, wider lanes, the non-existence of road markings, and finally, infractions, increase the injury severity of drivers. On the other hand, factors such as a lower percentage of heavy vehicles, accidents occurring on weekdays and a lane width of less than 3.25 m, are associated with less severe injuries. Furthermore, some variables that were not relevant in the analysis of the whole database were identified and found to be very significant in some of the cluster analysis.

In terms of infractions, statistical analysis results have revealed that infractions committed by drivers play a very important role in the accidents on crosstown roads and should be considered when analyzing road safety. In this case, the most common offences committed by drivers have been inattentive driving and exceeding speed. The methodology used in this research and the main outcomes can assist policy makers in transport departments to identify critical accident factors and to apply safety countermeasures.

In view of the results obtained, the following countermeasures are proposed. In the first place, it would be necessary to highlight the concern over crosstown roads with less traffic volumes and those found on the outskirts of towns, since they are more dangerous from the point of view of injury severity. In addition, traffic rules and regulations should be refreshed and enforced for those users who violate traffic regulations, as well as sanctioning processes, which should be stricter in the case of speeding. Another possible solution could be improving and increasing the number of traffic signals along the driver route, or the implementation of alternative traffic calming devices. Another interesting alternative that should be considered is the implementation of roundabouts which can reduce the crossing speed and the waiting times. This type of circular intersection also provides the reduction of driver confusion associated with perpendicular junctions and queuing associated with traffic lights. In the same way, new action strategies are required in order to better integrate crosstown roads into the urban fabric when they become outdated. For example, removing unnecessary fixed objects to reduce the number of fixed object crashes or mowing and clearing vegetation as required in relevant sections of crosstown roads. In addition, another countermeasure could be shoulder widening in dangerous areas of crosstown roads and installing raised pavement markers on longer sections of the road. In regard to the high accident rate of pedestrians, it could be a good measure to consider protected routes and raised crossings, especially close to schools, offices or hospitals, for example.

On the other hand, to address the high accident rate of pedestrians in general, people who commit violations whilst walking should be prosecuted (mandatory crossings for zebra crossings, penalties, awareness raising on the main causes of road crashes at schools and through communication campaigns, etc.). Finally, considering the accidents involving older pedestrians, the actions should focus on studying the pedestrian routes that cross the main town road, paying special attention to the analysis of the levels of physical and activity severance (recurrent trips to hospitals, supermarkets, schools, etc.). Another measure that could be effective is the implementation of traffic lights with a longer crossing time for older pedestrians (frequent itineraries of older pedestrians), and with an auditory signal to better capture their attention. Furthermore, it could be also useful to require driver re-testing and vision testing every few years for senior drivers.

Finally, it is important to mention that further research is needed to analyze other contributing factors in more depth, such as socio-economic indicators or the density of urban environments. In terms of the methodology, it would also be appealing to implement new statistical approaches and methodology, such as Poisson regression models, to examine different indicators contributing to pedestrian accidents and not only the study of injury severity levels. Additionally, more detailed research is required into the cluster characteristics, and patterns determined to analyze in greater depth how these factors can be alleviated to minimize the risk of severe injury. Another interesting point that should be examined could be the existence of differences between the effects that an isolated crosstown road and a series of successive crosstown roads, separated by only a few kilometers, have on accident injury severity. The present conclusions of this research are just the basis for a future line of research intended to examine in greater detail the causality of accidents under different users' perspectives.

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