SAFETY AND ROAD INFRASTRUCTURE: A SPATIAL ANALYSIS IN SUBURBS OF BOGOTÁ

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ABSTRACT

The research was focused in a multiple correspondence analysis. We analyzed the relationships between accident rates and road infrastructure variables in a municipality of Soacha (with more than five hundred thousand inhabitants in the suburbs of Bogota-Colombia). In Colombia, the fatality rate is 13 deaths per 100.000 inhabitants. In Soacha municipality the fatality rate is 10 deaths per 100.000 inhabitants. Soacha reports the highest number of deaths in the region (ANSV, 2020). In this research we performed a spatial analysis using a Kernel density graph to identify the areas with the highest concentration of fatal crashes.

We found that five dimensions explain 70% of the variability of data. We made a cross-dimension analysis by pairs, to obtain information on all possible combinations between that dimensions and used them as an input of a spatial distribution analysis of crashes in the municipality. We also calculated the contour curves for density modeling. We found that higher concentration of fatal crashes is around the highway “Autopista Sur”. These crashes were associated whit crash hypothesis variables, immediate cause of the crash, crash class, crash severity and type of vehicle.

1. INTRODUCTION

The Global Report on Road Safety 2018 (World Health Organization – WHO, 2018), highlights that the number of annual deaths from crashes has reached 1.35 million. More than a half of the fatalities and serious injuries in crashes occurs on 10% of the road infrastructure and the most affected actors are pedestrians, cyclists, and motorcyclists. In addition, according to this report, 13% of fatalities occurs in low-income countries.

In order to reduce the rate of accidents, the WHO adopted the road safety factors based on the Haddon Matrix (1968) and proposed to the countries the implementation of programs and the introduction of the main pillars of road safety in their safety plans: safe infrastructure, human behavior, safe vehicles, institutional, environment and victim care. WHO emphasizes in the systematic analysis of accident data and the use of maps to locate accident hotspots in order to focus resources more effectively and efficiently in at-risk road infrastructure (WHO, 2019).

In Colombia (2020) there were 5,458 deaths in crashes, 82% of these fatalities correspond to vulnerable road actors: pedestrians, cyclists and motorcyclists. In the state of Cundinamarca occurred 6% of the total fatalities in the country (327 deaths in crashes), and the municipality of Soacha, located in this department, presented 53 fatalities and 189 injured. This municipality had the highest number of deaths in crashes in this department.

According to information from the *Agencia Nacional de Seguridad Vial* - ANSV, 84% of the fatalities in this municipality occurs on the national road that crosses the urban area of the municipality of Soacha (ANSV, 2020).

Moreover, the annual report of the Transport Ministry (2019) , define that primary roads correspond to 9.3% of the national network, 44% are concessioned roads. The “Via 40 Express”, a road under private concession cross the municipality and it has 144, 8 kilometers long and eight Functional Units – UF, and in the municipality of Soacha is located in UF-8 (Ministerio de Transporte, 2019).

The literature review presents models and techniques for the identification, analysis and assessment of crashes, involved with analysis in Geographic Information Systems (GIS) and spatial statistical methods. In our research, a descriptive statistics process was carried out to define accident patterns, in a second step a multiple correspondence analysis and a GIS analysis were performed. We found that the categories pedestrian, rollover, road, infrastructure, hit-and-run, according with original names of variables in database related to the hypothesis, immediate cause and accident class, that variables have the major contribution in the road accident rate. The multiple correspondence analysis together with the spatial analysis support the evaluation of the variables involved in the accident to generate prevention measures. These results contribute to improve current and future public policies in municipalities, departments and road safety agencies (Forigua, et al., 2020).

The purpose of this paper is to present the methodology based on spatial analysis to identify the areas with the highest concentration of crashes in Soacha and the main variables involved. The databases of crashes in the municipality and secondary information provided by the ANSV and other government organizations for the period 2014-2018 were used. The methodology proposes a multiple correspondence analysis in order to identify the relations between variables, and the variability in the information. We also applied an analysis of the spatial distribution of accident points using a Kernel density graph focused on localization of areas with the highest concentration of fatal crashes for spatial modeling.

2. LITERATURE REVIEW

In general, the models identified in the literature review for the analysis of road infrastructure and its impact on accident rates are from the temporal point of view, such the Accident Prediction Models (APM) that allow to consider road safety problems, identifying safety improvements and estimating the potential effect in terms of reduction of crashes (Kustra 2019, Raheel 2019, Wang 2017, Yannis 2016). Other researches include variables to define geometric and traffic characteristics with statistical analysis such as Loglogistic and Gamma distribution (Negative binominal), the variables of these models are related to traffic volume, distance, type of road, number of crashes, crash costs, crash density and the probability of occurrence according to the severity of the crash (Kustra, Żukowska, Budzyński, & Jamroz, 2019).

Velloso and Prudéncio (2012) in their study on pedestrian fatalities on rural roads passing through urban areas, perform a basic statistical analysis of the risk of crashes, since they have a mixture of the characteristics of a rural road with those of an urban road, where high speeds, wide roadways, high vehicle capacity can be observed and with heavy vehicle traffic, lack of facilities for vulnerable road users, high number of accesses on both sides of the road, cyclists and motorcyclists riding on the road, pedestrians crossing at any point of the road, among others, which is a very common feature in middle and low income countries where the suburbs of the cities are located.

Some authors (Galgamuwa 2019, Liu 2018, Erdogan 2015, Zhou 2015) propose spatial models, these analysis are performed by integrating quantitative methods with a Geographic Information System (GIS), identifying crash hotspots (crash frequency, crash rate and crash severity) with spatial statistical methods such as Moran's I Estimation, GetisOrd G and Kernel Density Estimation to apply actions to reduce the probability of road crash. Spatial road safety models consider crash data, traffic data and road infrastructure design variables. These models are generally developed as a simple regression equation (Safety Performance Function - SPF) where the spatial correlation considers multiple variables at the same location (Yannis, et al., 2016).

Based on this literature review and considering the scope of this research, a multiple correspondence analysis and a spatial analysis using a Kernel density plot are applied to identify the areas with the highest concentration of fatal crashes in the study area.

3. METHOD

According to the official data provided by the ANSV, the information was validated and processed. The road accident rate of the department of Cundinamarca and specifically for the municipality of Soacha for the period 2014-2018 was analyzed. A descriptive statistics analysis was performed with the statistical software RStudio® and we define the variables that have an impact on crashes, making groups to standardize the information. Subsequently, an extensive process of organization and georeferencing of the data was carried out to guarantee the accuracy of the information used for the study, from which the preliminary description of the road accident rate in the municipality was obtained (Forigua, et al., 2020).

The next step continues with the analysis of the points and periods with the highest concentration of crashes in the road network of the municipality, and we apply the multiple correspondence analysis of the variables that affect the response of crashes. After this analysis a Geographic Information System (GIS) was implemented to represent the spatial behavior of road accident rates by creating and designing base maps that illustrate the accident hotspots in different scenarios.

Based on these results, we propose a field inspection in the points with the highest concentration of crashes, followed by a new spatial analysis including variables on traffic, geometric design, signaling and other road infrastructure in order to suggest preventive and corrective recommendations to reduce the number of crashes in these areas and, consequently, contribute to the reduction of accident rates in the municipality.

4. RESULTS

For the development of this research, data from the Police Crash Report - IPAT collected by the National Crash Registry – RNAT, providing 100 attributes associated with each of the crashes presented in the country for 12 years. The distribution of the databases is shown in Table 1.

RNAT	**Observations**	**Variables**
RNAT_A	2,451,804	24
RNAT_H	2,692,050	2
RNAT_ML	4,331,376	8
RNAT_S	2,569,877	35
RNAT_V	7,858,013	31
TOTAL	**19,903,120**	**100**

Table 1. Observations and variables of road accident databases.

All the information was rigorously treated and a database was consolidated with the information of 4598 crashes between the years 2015 and 2018 for the municipality of Soacha. The distribution of these crashes according to the year of occurrence and the composition comparisons for 2015 to 2018 is shown in Table 2.

Year	Crashes	Passenger Car Occupants	Small-Truck Occupants	Heavy-Truck, Buses	Motorcyclists
2015	1,427	38%	34%	15%	12%
2016	1,141	39%	34%	11%	16%
2017	1,105	41%	33%	11%	14%
2018	925	41%	30%	14%	15%
TOTAL	4,598	40%	33%	13%	14%

Table 2. Crashes composition per year

According to the analysis of these information the following relevant aspects are identified:

- Regarding the severity of the accident, 65% present only economic damages, 32% injured, and 3% are with fatality.
- According to the type of accident, 81% correspond to collisions between vehicles, 18% to pedestrian collisions and 1% to vehicle rollovers.
- In terms of the type of vehicle responsible for the accident, 40% are trucks, 24% are buses, 13% are motorcycles, 13% are passenger cars, 6% are bicycles and 4% are taxi.
- In terms of the type of road infrastructure where the accidents occurred, 85% occurred on a stretch of road and the remaining 15% at intersections.
- In the area where road accidents occurred, 61% occurred on the “Autopista Sur” corridor and 39% in the urban area.
- In terms of the weather conditions when the accidents occurred, 97% occurred in normal weather and 3% in rainy weather.
- In the time of the week when the crashes occurred, 55% were on weekdays and 45% on weekends.
- In terms of the time of day when the crashes occurred, 32% occurred in the afternoon, 28% at night, 27% in the morning and 13% in the early morning.
- In the age ranges of people involved in road crashes, 36% were young people under 29 years of age, 28% were people between 30 and 39 years of age, 24% were people between 40 and 59 years of age, and 11% were people over 60 years of age.
- In terms of the gender of the people involved in the crashes, 92% were men and 8% were women.
- In terms of the agent that caused the crashes, 89% were caused by drivers, 9% by pedestrians and 2% by road infrastructure.
- In terms of the causes of road crashes, 92% were related to the behavior of people, 4% are related to the consumption of substances, 2% to the infrastructure, and 2% with excessive speed.

With the georeferencing of the crashes, it was possible to establish spatially the points where road accidents are occurring in Soacha, taking into account the severity of the accident. The spatial density of the crashes is shown in Figure 1.

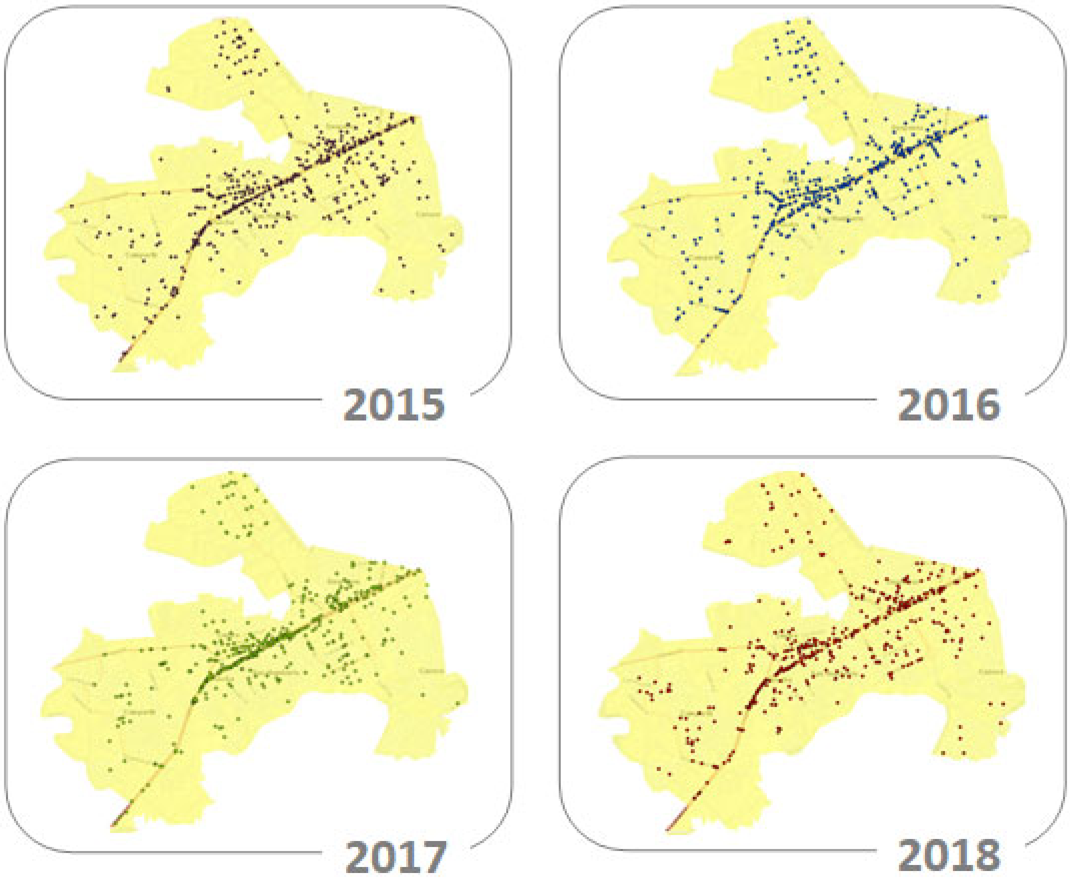

Figure 1. GIS crash localization per year. (Bermudez, Sanchez, Forigua, & Lyons, 2021)

5. ANALYSIS AND DISCUSSION

According with the statistical results, we observed that there are severity features in 35% of the crashes, 40% involves trucks and 61% occurs on the highway, these results confirm that the greatest risk is on the rural roads crossing the urban area particularly for freight vehicles.

We identified in the municipality of Soacha that main crashes do not occur at intersections, 85% of the infrastructure risk is found in continuous segments of roads, which is different from study cases in literature review.

Analyzing the immediate causes defined by the traffic police who report the crash, 98% of the responsibility for the accident corresponds to human factor and 2% to the infrastructure, however, the report does not identify the root cause of the crash.

According to the multiple correspondence analysis, the normal weather variables, throughout the day, during all days of the week do not contribute to the behavior of the accident rate in the municipality of Soacha.

In the spatial analysis of crashes with a GIS, it was possible to identify that the severity of road accidents occurs on the national road that crosses the urban area, confirming the argument of the authors Valenzuela and Burke (2020), where they state that the greatest risk of accidents occurs on this type of roads, because they have characteristics of national roads, but integrating characteristics of urban roads. Figure 2 shows the concentration of fatal crashes on the highway in the municipality of Soacha, while crashes with injuries occur in general throughout the urban area, but with a higher concentration on the national road.

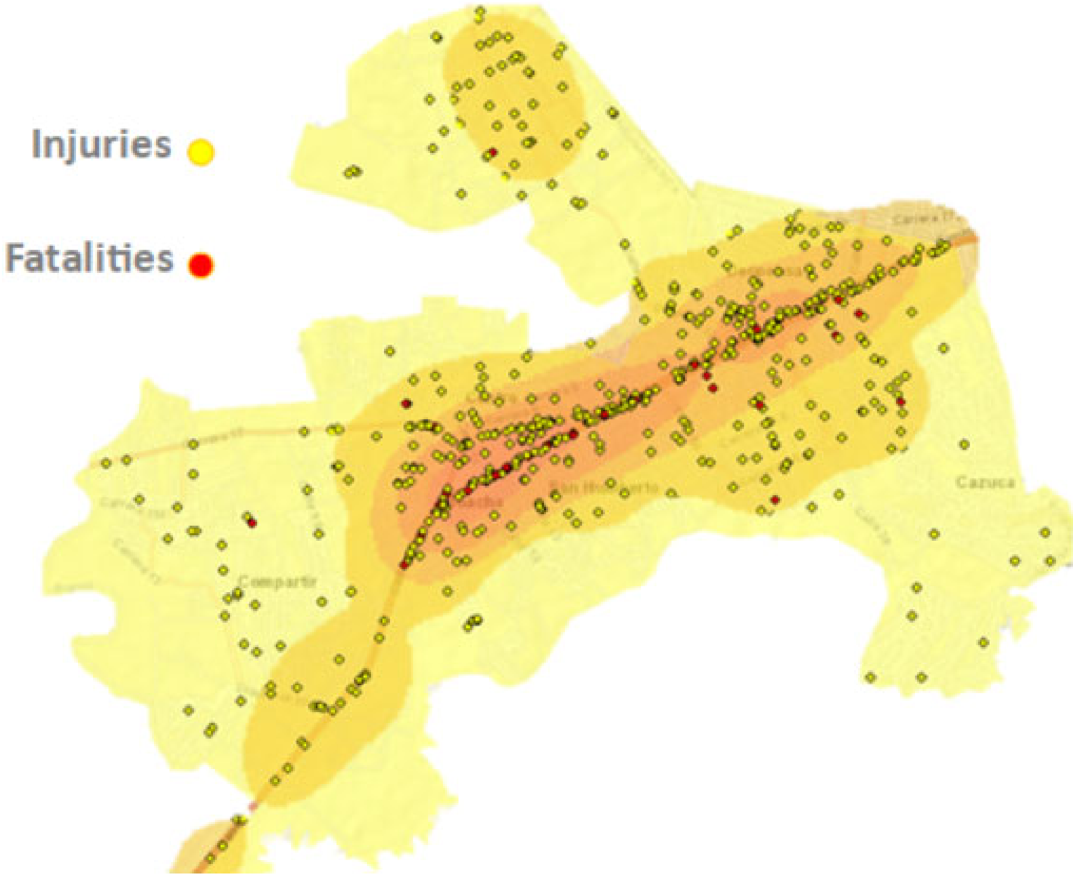

Figure 2. Severity GIS crash localization. (Bermudez, Sanchez, Forigua, & Lyons, 2021)

In the multiple correspondence analysis between the different variables mentioned in the descriptive statistics, it was possible to estimate the behavior of the variables due to the contribution of each one in the road accident problem. The crash hypothesis variables (HIP), immediate cause of the crash (CAU), crash class (CLA), crash severity (GRV) and type of vehicle (VEH), mainly denote a greater contribution to the behavior of the crash rate in the municipality of Soacha, Cundinamarca. The contribution of the variables is shown in Figure 3.

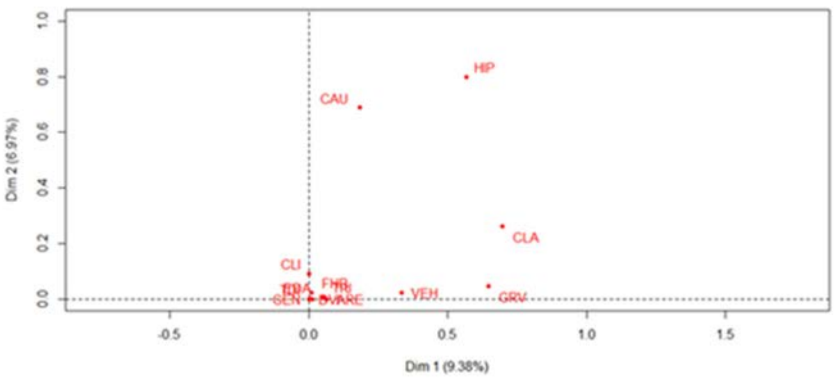

Figure 3. Contribution of variables in the multiple correspondence analysis. (Forigua, et al., 2020)

Variables related to the seasonality of accidents, weather conditions, age and gender characteristics do not contribute to the explanation of road accidents in the municipality of Soacha. Five dimensions explain 70% of the variability of data.

6. CONCLUSIONS

The traffic in rural roads that cross urban areas of conurbation municipalities represent a higher risk of crash severity.

The literature identifies studies that have shown that the use of different hot spot detection models leads to different results. In this research, multiple correspondence analysis together with spatial analysis supports the evaluation of variables involved in crashes.

These research continue with spatial analysis including variables on traffic, geometric design, signaling and other road infrastructure in order to propose preventive and corrective recommendations to reduce the number of crashes in these areas and, consequently, contribute to the reduction of accident rates in the municipality.

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