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Spatial Analysis with Weighted Kernel Groupings to Determine Risk Sectors Due to Traffic Accidents in Urban Area. Tunja Analysis, Colombia

Análisis espacial con agrupamientos kernel ponderados para determinar sectores de riesgo por accidentes de tráfico en zona urbana. Análisis Tunja, Colombia

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Abstract

A method is presented to identify and determine groups with risk sectors due to the greater occurrence of traffic accidents in urban areas as an integral component in road safety management. The methodology was framed in Spatial Analysis with geographic statistics based on Exploratory Data Analysis (AED), Kernel Density Estimation (KDE), and the application of correlation and geoprocessing techniques. The accident data collected between 2015 and 2018 from the urban area of Tunja, Boyacá, Colombia, were the basis for the study of the distribution of events, characterization of clusters, occurrence dynamics and pattern modeling. The definition and delimitation of risks depended on the dispersion or grouping (Hotspots) found with weighted Kernel together with the socio-spatial interrelation of underlying processes due to the territorial dynamics of the sector. The results reveal patterns of events in concentration foci with different levels of risk, in which land uses of opposite characteristics coexist according to their activities [commercial and residential], socioeconomic sectors of low strata with a mixture of arterial road network that by its functionality mobilizes high vehicular and pedestrian flows. Although the analysis is limited to a case study, the findings show a promising perspective in road safety by delimiting risk sites for traffic accidents through the incidence of territorial variables.

Key words: Spatial Analysis; Exploratory Data Analysis-EDA; Concentration, weighted kernel clustering; Determination of risks due to traffic accidents

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Resumen

Se presenta un método para identificar y determinar agrupaciones con sectores de riesgo por mayor ocurrencia de accidentes de tránsito en áreas urbanas como un componente integral en la gestión de seguridad vial. La metodología se enmarcó en el Análisis Espacial con estadística geográfica fundamentada sobre el Análisis Exploratorio de Datos (AED), la estimación Densidad Kernel (KDE), y la aplicación de técnicas de correlación y geoprocesamiento. Los datos de accidentes recopilados entre 2015 a 2018 de la zona urbana de Tunja, Boyacá, Colombia, fueron la base para el estudio de la distribución de eventos, caracterización de agrupaciones, dinámica de ocurrencia y la modelación de patrones. La definición y delimitación de riesgos dependió de la dispersión o agrupamiento (Hotspots) hallados con Kernel ponderado junto con la interrelación socioespacial de procesos subyacentes por la dinámica territorial del sector. Los resultados revelan patrones de eventos en focos de concentración con diferentes niveles de riesgo, en el que coexisten usos de suelo de características opuestas de acuerdo con sus actividades [comercial y residencial], sectores socioeconómicos de estratos bajos con mezcla de red vial arterial que por su funcionalidad moviliza altos flujos vehiculares y peatonales. A pesar de que el análisis se limita a un estudio de caso, los hallazgos muestran una perspectiva prometedora en seguridad vial al delimitar sitios de riesgo por accidentes de tráfico a través de la incidencia de variables territoriales.

Palabras clave: Análisis Espacial; Análisis Exploratorio de Datos-AED; Agrupamiento Kernel ponderado; Riesgos por accidentes de Tráfico.

1. Introduction

The planning and operation of traffic in urban centers includes road safety by government administrations. Over the last decade, for socioeconomic and public health reasons, this has become a priority requiring the attention, allocation, and intervention of sufficient resources in the sectors identified as at risk for the occurrence of traffic accidents (TA). Road safety programs should support research with a spatio-temporal analysis of the distribution on how events occur in these sectors. Statistics including damages and deaths and/or injuries are of great interest since they represent high social and economic costs for the population. Spatial analysis refers to the spatio-temporal research carried out to understand the dynamics of incidents in the occurrence of events with the objective of building representative profiles of risks based on reliable data. Spatial analysis makes it possible to identify and define, qualify and quantify the characteristics of how accidents happen and the probability of their trend (increasing or decreasing). This is determined using risk profiles and measuring the associated impact or damage since the results support the planning and operation of transport and traffic in cities.

Spatio-temporal analysis concerns the investigation of the structure of TAs, groupings, and especially the repetitive nature of traffic accidents in urban areas that characterizes it as a risky sector (Ouni, & Belloumi, 2018). These factors combined with its repetitive dynamics (including elements, factors, and variables), determines its predictability, especially when events due to their frequency (location and time) generate an impact on risk perception and prevention within communities during everyday life. The creation of TA risk profiles that occur over an area requires the creation of methods (Rueda et al., 2019) that include the structuring of processes aimed at determining visible and understandable patterns as a representation of a geographic profile. This information can then be input into a Geographic Information System (GIS) to facilitate the intervention of territorial variables under significant statistical correlations that differs when classical quantitative statistical procedures used, which seen as periodic data.

Over the last five years in Colombia, 83% of registered accidents have been concentrated in urban areas, and the remaining 17% in rural areas. This confirms that communities in urban areas must establish conditions for the prevention or mitigation of risks of traffic accidents (National Road Safety Agency-ANSV, 2019). Figures revealed by the National Road Safety Observatory show that in the period from 2015 to 2018, road accidents represented the second leading cause of death among young people (under 24 years of age) and vulnerable users such as pedestrians, cyclists, and motorcyclists. As result of these statistics, the Decade of Action for Road Safety plan and the implementation of the Sustainable Development Goals (SDG), a goal of reducing the death rate to 8.35 per 100,000 inhabitants by 2030 has been set (DNP-CONPES 3918). This is a challenge as the current death rate is approximately 13.7 per 100,000 inhabitants for 2017 (Forensis, 2017), and lowering this rate will be difficult in order to fulfill the global objective.

Tunja, as the case study city, is located in the Cundiboyacense plateau, central region of Colombia (5° 31’56.95” N, 73° 21’41.71” W). Its configuration, like the road network, extends longitudinally over the department of Boyacá. This road network is classified according to its functionality and capacity as arterial, collector, pedestrian and internal. It consists of an area of 121.5 km2, which is 87% urban (POT, 2014). In the last ten years it has undergone spatial processes with transformation of uses, land occupation with distribution of equipment, road infrastructure and vehicle fleet, and densification of various areas of the city. This has caused changes in the dynamics of the activity within the system that affects a growth in mobility, generating conflicts that increase the exposure to risk for TA to occur, hence the justification for this study.

Accepting the guidelines that promote the safe system approach is ordered in the world report on the situation of road safety published by the WHO (2018), which specifies a management and investment framework that includes practical procedures with profile designs aimed at achieve greater effectiveness in the transfer and visualization of knowledge aimed at populations in urban areas, hence the importance of conducting rigorous studies to determine the spatio-temporal interrelationships that, due to their visible attribute, facilitate the understanding of how events occur on the territory.

The research is an applied type developed under the epistemological framework of Transportation Geography, based on Spatial Analysis and Exploratory Data Analysis-EDA. Its main objective was to find patterns of occurrence of traffic accidents on sectors of the urban area of an intermediate type of city such as Tunja-Colombia (IDB, 2015), and which, due to their frequency of occurrence, constitute critical and risky. The framework involves investigating the concentrations and groups that are formed together with the interrelation of elements and factors that affect and characterizes them as risky so that they continue to occur and that makes it possible to generate a methodical, systematic space-time structure that facilitates knowledge of the phenomenon as a programmatic strategy. comprehensive road safety management. Its geographical, spatial, territorial component conceives its treatment with the support of Geographic Information Systems-GIS (Shafabakhsh et al., 2017; Dereli & Erdogan, 2017; Kuo et al., 2013; Mohaymany et al., 2013; Lassarre, 2012)

Since 1989, Legendre and Fortin in Maestre (et al., 2008), expressed that “within a generic framework, spatial analysis encompasses a set of techniques aimed at qualitatively and quantitatively analyzing spatial data explicitly grouped in their location ". In 1995, Bailey and Gattrel, defined spatial analysis as the quantitative study of phenomena that are located in space, hence the spectrum is open to validation when approached from a thematic perspective (Raghad and Hussein, 2020; Kuo et al., 2013; Shafabakhsh et al., 2017). The study refers to the generation of processes applying a series of statistical and mathematical techniques for the analysis of geographical data distributed in the territory using GIS and based on the spatial relationships of the entities contained in the thematic layers of a database.

The method begins with the planning and development phase of the process for the selection of information sources, collection, ordering and structuring of data matrices, which includes evaluating them with the objective of having reliable, validated and statistically significant data to address geospatial analysis. and that they reflect the magnitude and characteristics of the phenomenon (PAHO, 2010). The second phase corresponds to the Spatial Analysis that refers to the investigation of the distribution of the events that occur in the urban territory, an objective established as the challenge that leads to the clarification of the context of the variables that affect the occurrence of the TAs.

The study and analysis of the distribution of events gives way to the definition of clusters and concentrations, Hotspots (Briz-Redóna et al., 2019; Thakali et al., 2015; Kundakci and Tuydes-Yaman, 2014; Cheng and Washington, 2008; Xiao-Qin et al., 2007; Griebe, 2003). These events are repetitive in their occurrence at the same locations or with relatively short distances between one and another and have similar severity, type, and class resulting from the underlying dynamics studied in the territory. The repetitive nature determines the establishment of patterns of occurrence within urban areas where the application of geospatial methods supported its definition and delimitation. An analysis of significant groupings (Nearest Neighbors, VCM) and Kernel density estimation (KDE) calculated based on sectors, sections, and intersections of the road network. The repetitive groupings and concentrations of events weighted according to severity, type and class, as they constitute the reason for the existence of a permanent risk. Subsequently, these elements are analyzed structurally and in a scalar way using geographic units with a predominance of territory and functionality of the environments (Mazurek, 2018; Lorda et al., 2005), in order to determine the indicator appropriate to limit analysis of problem imbalances

The results are evaluated from a spatial pattern of distribution that reveals the levels of risk based on the grouping of events with incidence of the interrelation of variables such as land use, stratification, and road network that, due to their functionality, prioritize mobility with less accessibility. Likewise, as a support tool for institutions and organizations, the design of a type of scheme is presented that contains the synthesis of results, especially of detected risks; tool for local observatories, with the aim of facilitating communication and transfer of information to the communities. The investigation mainly uses the comprehensive database of TA from the Tunja Traffic Directorate-DITT, the Traffic Police-DITRA and the National Institute of Legal Medicine and Forensic Sciences-INMLCF, as well as data from the Office Planning Advisor established through the Territorial Ordering Plans (POT) of the city under study.

2. Methodology

Part of the investigative value of the methodology is declared on the basis of the Spatial Analysis referring to the quantitative and qualitative development established on the Exploratory Data Analysis – EDA, the analysis of correlations and the geospatial modeling under densities, geostatistical groupings (Wang et al., 2020; Dall'erba and Chen. 2020; Saffet, 2009; Wise et al., 1999), all focused on finding and generating knowledge about elements and strategies that allow achieving the objective of defining risk sectors of the urban area where TAs occur repetitively, defined on the validation of territorial patterns.

2.1. Selection of sources of information and databases

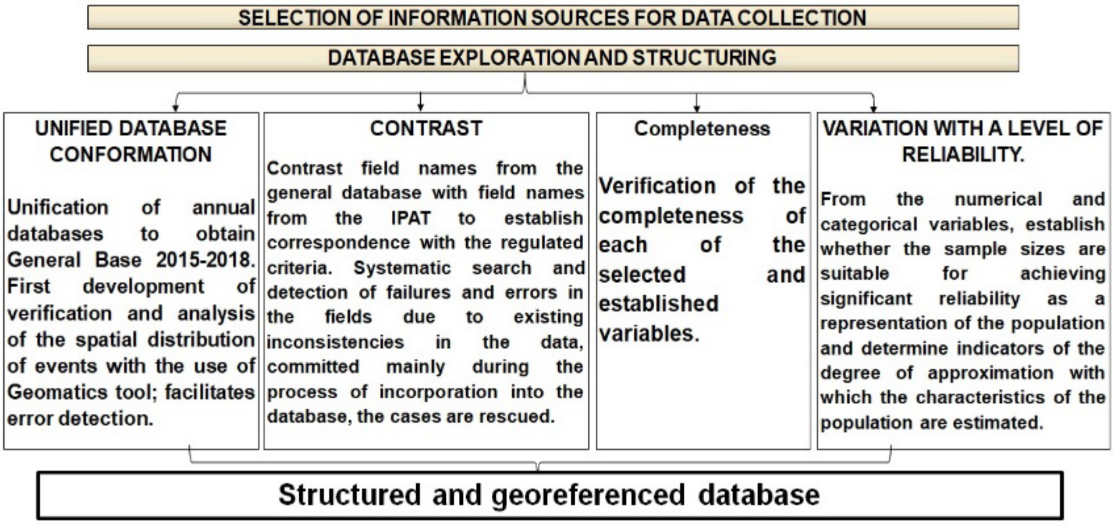
The development of the research based on the Spatial Analysis required structuring a methodical process of evaluation and reduction, both generalities and particularities of the occurrence of the events. This process first led to the selection of suitable sources to obtain the information; These sources correspond to the institutions with functions of road safety and urban planning of the territory in Colombia. For the selection, the elements that prevailed were, the performance of the function of operation in mobility, road safety, the competence in capture, the collection and storage of traffic accident data (function regulated and controlled by state institutions) and the competence in land use plans.

According to the institutions that have the competence to collect and capture the data attributable to the occurrence of accidents in the urban area of the case study city (Tunja-Colombia), it is highlighted that the selected ones have different competences in the capture and collection of TA. The events of only material damage are raised by the local transit institution (DITT), with the support of the regional traffic police (DITRA; when the accident registers deaths and injuries, it is the regional one of the National Institute of Legal Medicine and Forensic Sciences (INMLCF) , with logistical support from DITRA and DITT Data are available from the local Planning Advisory Office, which guides urban development through the Land Use Plans (POT) of the city under study There is a state entity (ANSV), rector of road safety in Colombia that collects with its National Road Safety Observatory (ONSV), the total number of TA records throughout the country, but in the development of its function they present technological difficulties for the same collection and transmission of data to other entities and thus achieve the effective state unification of the databases; therefore, in the country, among the greatest limitations for TA statistics and investigations are, the non-existence of a unified database structure among all the institutions that perform the function, and the lack of sufficient logistics, technique, and training to efficiently achieve the highest quality standards in the studies.

The second step required greater rigor to obtain the conversion of field data to representative data with a pattern. This consisted of the treatment and structuring of the information under the EDA (Figure 1), to achieve sufficient conditions oriented to its geostatistical application and thus reliably reveal the results outlined in the objectives. The selected analysis period was 2015 to 2018.

The EDA is statistically validated on four principles: the treatment of data towards the structuring of statistically significant bases, the Spatial Analysis of descriptive and exploratory events, and the development of geospatial modeling, which aimed to achieve the objectives in the definition of risk sectors and their transfer for purposes of planning, design, and safe operation of traffic, directed towards the prevention and control of the occurrence of TA on urban sectors.

Figure 1. Base method Exploratory Data Analysis – EDA



Source: own elaboration

The databases were treated and structured as matrices where their fields became the variables or attributes of each event (TA record). The homogenization of the data from the period 2015 to 2018, initially required “Unifying” the databases of the selected institutions, under quantitative and qualitative review of place, time and number of accidents, deaths, and injuries according to the competence of each institution, verification that determined to make corrections for repetition of events between institutions. Then the “Contrast” the names of the variables and categories of the general and unified base of TA, with the names of the variables and categories established in the Police Report of TA (IPAT), to determine the correspondence with the normative criterion and State regulated by the Ministry of Transportation (MINTRANSPORTE, 2012). This regulation applies to the entire country and is the basis for decisions in the trial of civil or criminal responsibilities when involved in an TA.

The analysis of frequencies on the variables of the general unified and contrasted base was carried out under filtrations. This procedure detected errors in categories (fields), due to excess and defect of data and due to differences in the types of formats within the same variable and in the different years of the analysis period, also errors were found in records, the result of failures that they are made in the processes of transcription and incorporation of data in the database, corrections that are made through rigorous filtrations with the ease that the accessibility, flexibility and management of the already unified database should provide.

The “Completeness”; It was based on establishing how complete each of the variables selected and established in the fields of the general database are filled out, a correction that is also achieved through the comparison of the bases of the three competent institutions in capturing information. (DITT, DITRA and INMLCF). Likewise, the restitution of data is carried out from the “Consistency” value that the variable presents during the action of review, unification and in the historical behavior that the attributes have had within the same events, knowledge that is acquired by consultations and inspection on the sectors where the accidents have occurred to recover the missing data. The development of the processes described leads to obtaining a structured and homogenized matrix, the basis for space-time analysis, the definition of risk sectors and their representativeness and significance.

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2.2. Spatio-temporal Analysis

The focus is on identifying, quantifying, and characterizing the distribution of accidents over the urban area. During the first analysis, establishing distribution in order to spatialize the events to determine the level of correlation and the significance of their grouping on the sectors, neighborhoods, and road network (intersections and sections) as well as establish a pattern of occurrence is vital. Spatialization requires georeferencing by visualizing the distribution of events over the territory. This phase helps in the detection of location errors, which is generated by a detailed verification of the IPAT and/or the sector of occurrence.

Establishing the significant groupings in the distribution in order to demonstrate a representative pattern requires the geostatistical treatment of the data to determine the delimitation of its level of risk. It has also led to the exploration of training on the influence of socio-spatial and temporal factors. Among the bounded geostatistical principles is the Average Nearest Neighbor (Kuo et al., 2013) and Kernel Density, KDE (Shafabakhsh et al., 2017; Thakali et al, 2015; Xie and Yan, 2008; Silverman, 1986).

Average Nearest Neighbor is an index based on the average distance from each event to the nearest neighbor event; it is, used to check if the TAs are clustered significantly. It returns a general value that represents the concentration ratio of all events and is defined (Equation 1), by:

$$ANN = \frac{\bar{d}}{\bar{\delta}} = \frac{\bar{d}}{0.5 * \sqrt{A/n}} \quad (1)$$

Where *ANN* is the average distance between the closest event, $\bar{d}$ is the average random distance, *A* is the area of the study, and *n* is the number of events within the study area. If ANN is less than 1 and the observed average distance is less than the expected average distance, the character of the events is grouped. The ANN value is only interpreted as significant when the Z-score is significant (large or small enough and within the significant normal curve area), otherwise if the Z-score is not significant, the ANN value is not grouped, and they are random events in the location of their occurrence.

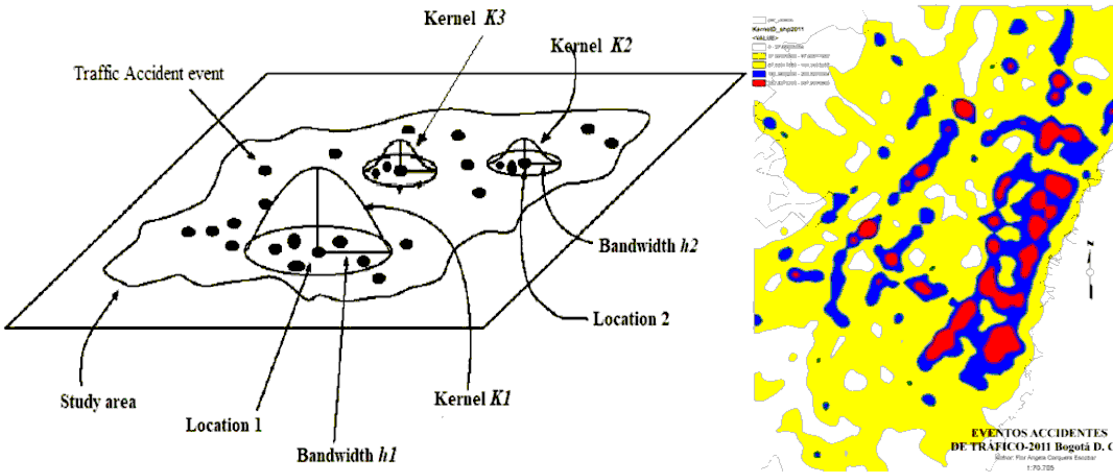
KDE transforms the distribution of the "events" into a discrete point in a continuous scan surface. Based on the quotient between two types of values that include TA in their significant grouping, and the reference surface. Then with the support of the GIS, traces a bandwidth (circumference radius), from the center of a master cell until the surface is raised according to the weighted kernel value (gravity value and type of TA), tracking the number of events inside (Figure 2), a statistical principle originally proposed by Rosenblatt (1956). The estimation is based on Tukey's Biweight or the Quartic Kernel function (Silverman, 1986), (Equation 2):

$$K(u)= \frac{15}{16}(1-u^2)^2, \text{ for } u\leq 1 \quad \text{Where: } u=(x-X_i)/h \quad (2)$$

Where *x* is point at which the density is estimated, is the amplitude of the band (interval, radius in circumference of 500 to 600m), X_i value of the variable in the case of i = 1, … , n., and *K(u)* is the function of the weighted Kernel.

KDE is estimated from the distribution of the total georeferenced events that occurred in each of the years during the analysis in which the spatial variability of the concentration pattern of investigated events is inferred (Ouni & Belloumi, 2018; Pulugurtha, 2007). This vision is both punctual and precise on the constant and repetitive occurrence year after year. The delimitation that defines the critical and risk sectors (Raghad and Hussein, 2020; Mohaymany et al., 2013; Afshin et al., 2013) of the studied urban area.

Figure 2. Principles of Kernel analysis, applied in TA in Bogotá D.C.



Source: KDE, adapted from Sabel (et al., 2005), and Kernel TA in Bogotá D.C. (Cerquera, 2015).

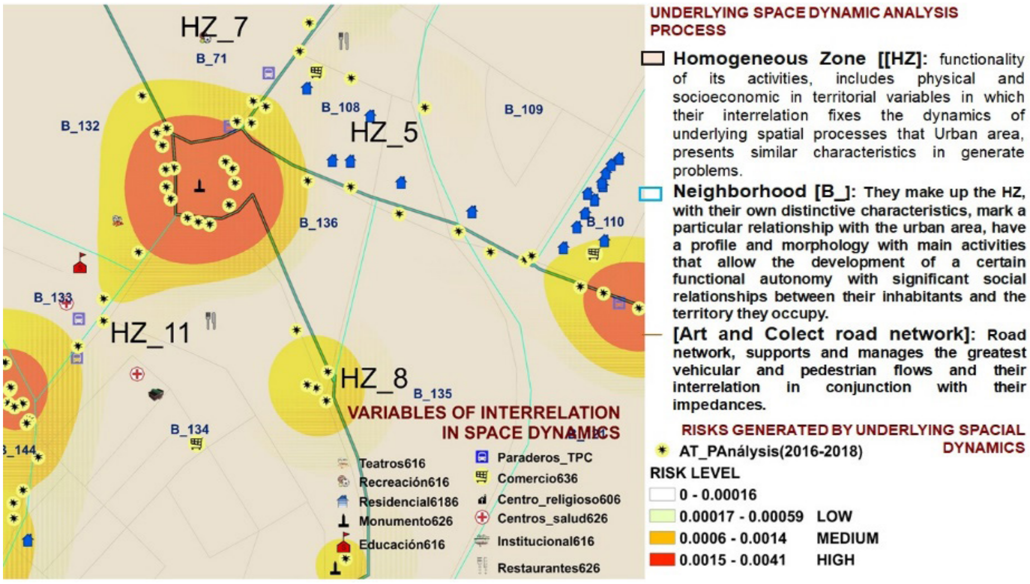
2.3. Socio-spatial dynamics in risk-generating interrelationships.

The territory is made up of articulated structures that make up dynamic systems due to the underlying interrelationships of physical and socioeconomic variables. The environment that constitutes the perceptible part of this set of underlying relationships, involving social and economic actors, are the source of information detected as resources, potentialities, impacts, conflicts and risks; problems that guide the approach of management guidelines in the planning of any urban area. On the other hand, the territory has different functions in each sector and at different times, however, in each of these one function predominates according to the socioeconomic, cultural and political decisions of the group that occupies it, that appropriates and uses it. in its potentialities; they are the key to determining the causality of TA-type conflicts. result of that dynamic.

These configuration and function characteristics are the basis of the study, since it allows it to be divided into tangible sectors or geographical units that (Lorda, et al., 2005; et al., 2018; Mena et al., 2018; Saadat et al., 2019), constitute a construction from the theoretical base to the empirical, even more, with the support of cartography as a means to use information from the geographical environment and convert it into new knowledge with a practical purpose. Thus, the identification, delimitation and characterization of the geographical units is accepted as the appropriate instrument to delimit the problem of the occurrence that generates risks due to TA, approached from the analysis of the socioeconomic interrelationships, their conflicts and imbalances resulting from the underlying dynamics of the sector. The main difficulty in establishing geographic units was defining their limits along with their resolution scales due to the permanent changes they undergo due to the acceleration and deceleration of the same underlying processes. The delimitation required knowledge of the area to identify and define the incident variables, due to the large number of main components that can make it up in its context as a territory.

Within the framework of an initial methodological theoretical construction and for the delimitation in the study, the principles of socio-spatial interrelationships proposed on two structural elements are taken: the human, based on the behavior of individuals under a territorial socioeconomic status; and the physical, based on the set of functional circulation variables that operate in the area. Of these structural elements, three geographical units prevail (Figure 3), over the urban and socioeconomic area (POT, 2014) : the Homogeneous Zone [ZH_], established as the main unit of the urban area, defined as an area subject to development in its functional urbanization with similar characteristics in the socioeconomic (POT, 2014), which involves type variables such as land use, population density and in which their interrelation affects and fixes the dynamics of the underlying spatial processes that may be incident in the risks of TAs. The neighborhood [B_], geographically conceived as the second territorial unit that makes up the homogeneous zones, endowed with its own characteristics with priority socioeconomic activities based on its stratification and road network that allow it some functional autonomy under safe coexistence (Tapia et al., 2009), this determines that it stands out in the conformation of a distinctive profile with functionality and appropriation of significant risk-generating social relationships and the Arterial and Collector road network [Art and Collect road network], as a geographical, physical unit that Due to their functional classification of mobility (speeds) and accessibility, they support the largest vehicular and pedestrian flows, and where their interrelation with the field of human activities and their impedances characterize a component that generates risk.

Figure 3. Method, delimitation of Geographical Units for risk analysis in TA.



Source: own elaboration

Each of these units comprise geospatial functions that, through their interrelation, determine the causal and risk problems of the occurrence of TAs. Likewise, in order to achieve a better transmission and a greater understanding, by the population exposed to the risks by AT, the formulation of schemes is proposed (which presents results in synthesis such as that of Figure 3), aimed at forming local observatories of institutions that exercise control and planning of traffic and road safety.

The existence of the interrelationships between the socioeconomic variables extracted from their predominant structural elements, such as ZH_ and B_ (as geographical units delimited for analysis), and the physical, operational variables faced on the critical sectors of TA occurrence, is validated. through stepwise and hierarchical multiple regression analysis, which with its results (significant statistical indices), shows that both the area is a pattern or model in the generation of conflicts and risk for the occurrence of TA. Table 1 presents the territorial and operational variables that underlie as structural elements of the sectors determined as critical of the corresponding ZH_ and B_ that they comprise. Likewise, the main significance indices that validate the power of correlation, explanation of occurrence and generalization of the interrelated variables that statistically prove the existence of a pattern (model) of TA incidence are identified.

Table 1. Operational and socioeconomic variables extracted from structural elements in ZH_ and B_, with indices of statistical significance that validate their interrelationship and incidence in the occurrence of AT.

Structural elements	Geographical Unit	Variable(Un)	Class - Name
		Dependent: AccidentsNo.	Variable to be predicted through a repetitive, significant pattern
		Independent:	
Socioeconomic: Human Behavior Foundation	Homogeneous Zone [ZH_]	LandUse(km2)	Land Use (Area): 1.Free Lots; 2.Residential; 3.Government or institutional education; 4.Mixed; 5. Parks, squares, green or sports areas; 6.Commercial; 7. Services; 8.Industry
		DensPob(Hbtes/km2)	No. Hbtes por área
	Neighborhood [B_]	Stratum(km2)	Stratum (Area): 1.Very Low; 2.Low 3.Medium 4.Medium High; 5.High; 6.Very High
Physical Operational	Art and Colect road network	Independent: Speed(Km/h)	Speed
		Flow(Veh/h))	Volumen (Flow)
		RedCarril(km)	Lane lenght: Local; Collector; Arterial
Índices de significancia: D-W - Durbin Watson: Generalization Power of Correlated Data to Predict R2 – Prediction value of the variables as a whole F(Anova) – Factor predictor P: Significance of value F(Anova) f2 : Statistical Power Effect Size: Value or power explanation of variables in the occurrence of TAevents VIF and Tolerance: Collinearity or Multicollinearity: Existence or not of high correlations between factors of the model			

3. Results

3.1. Spatial and temporal analysis. Structuring databases Distribution and groups.

The structuring and purification of the databases required the “Unification” and “Contrast” processes, in which missing location and vital data (deaths and/or injuries) were identified in 47% with respect to the data registered in the IPAT and INMLCF reports. The process to correct this deficiency required crossing the data between entities, DITT, DITRA and INMLCF, as well as carrying out direct restitution processes from the sites of occurrence and health centers in order to achieve 92% of the “Completeness” of the initial information of the base. The duplication of records was another of the errors detected which gave rise to the phase of verifying through the number of IPAT and INMLCF reports, an action that served to verify the “Consistency” of the data through contrast tests between the basis and the same reports. With the processes developed, a 96% data purification of the base was achieved, made up of 39 variables considered essential for the analyzes and that represented a significant population size available for the study.

The analyzes of the absolute and relative results of the TA in the study period 2015 to 2018 (Table 2), show a trend of constant occurrence with minimal differences between one year and another; the year 2016 marks some difference, in total accidents and in accidents with injuries and deaths [975, 287 and 11], in relation to the other years of the period [2015, 2017 and 2018] (Figure 4).

Table 2. Traffic accidents (TA), analysis period in Tunja

Year		2015	2016	2017	2018
Total TA		796	975	833	817
Total TA with injuries		171	287	192	228
Total TA with deaths		9	11	8	8
Total TA with just property damage		616	677	633	581
Total TA x 100.000 hab.		422.5	507.8	426.2	409.9
Population		188 395	191 987	195 440	199 297
DEATHS	Deaths among men	19	18	14	14
	Deaths among men x 100.000 hab.	21.09	19.59	14.94	14.64
	Deaths among women	6	5	4	3
	Deaths among women. x 100.000 hab.	6.11	5.00	3.93	2.9
	Total deaths among men and women	25	23	18	17
	Deaths among men and women x 100.000 hab.	13.27	11.98	9.21	8.53
INJURIES	Injuries among men	141	150	122	135
	Injuries among men x 100.000 hab.	156.48	163.21	130.16	141.21
	Injuries among women	96	89	95	100
	Injuries among women x 100.000 hab.	97.69	88.98	93.31	96.51
	Total injuries among men and women	237	239	217	235
	Injuries among men and women x 100.000 hab.	123.45	124.53	110.98	117.96
Total deaths and injuries among men and women		262	262	235	252
Deaths and injuries x 100.000 hab., men and women		136.72	136.51	120.18	126.49

Source: Created using data from DITT, DITRA, and INMLCF.

In mortality and morbidity, the trend is similar, with minimal differences between 2015 and 2018, but 2016 marks a majority, and it is men who are more involved due to their greater participation in driving, but it is observed that women presents involvement with a growing trend. In summary, it is highlighted that there is a state between repetitive growth and decrease in the study period (Figure 4).

In relation to gender and age of those involved in TAs in the period, it is men who present a greater pattern of involvement [89%, 91%, and 88%]. Furthermore, in each of the age ranges (Figure 5), the population between 20 and 30 years of age predominate. The age groups of women mark some differences between the years, constituting the range of ages between 30 to 40 the most involved with an important participation of those between 20 to 30 years of age.

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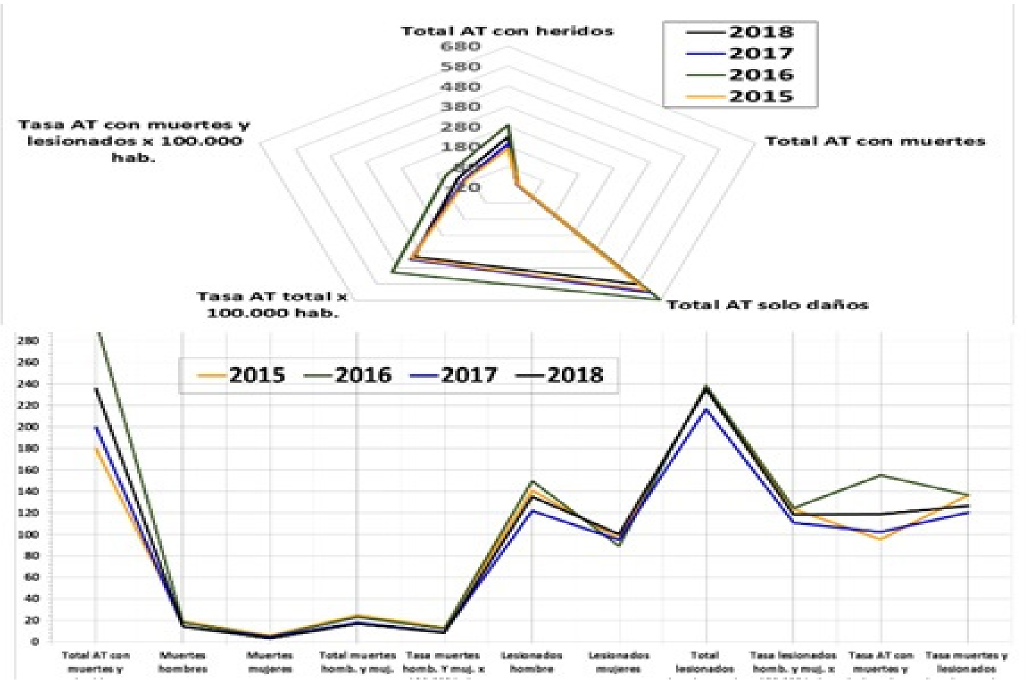
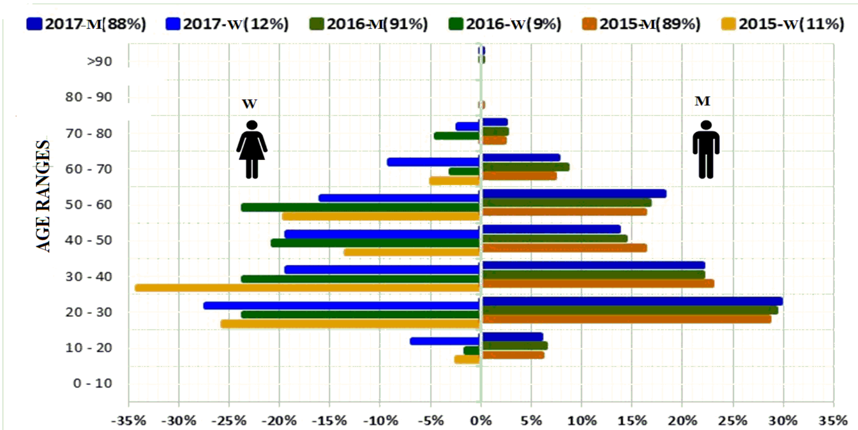
Figure 4. Comparative TA analysis period



Source: own elaboration

Figure 5. Gender and age groups involved in TA



Source: own elaboration

The temporal dynamics (Figure 6), reveals the detailed analysis of the behavior of the hourly occurrence of a day [Thursday]. It is representative of the study period, identified based on the behavioral trends and with the variability associated with the dynamics of the total of events [determination coefficients (R2), between 0.78 and 0.85, which result from significant adjustment with actual behavior]. Early in the morning until 4:30 AM, the trend appears with low but constant frequencies. Then it grows until 7:00 AM, where it behaves constant but high [11:00 AM to 5:00 PM], reaching frequencies up to 32 accidents, then decreasing until 10:30 pm before returning to a constant low behavior in the early hours of the morning [frequencies between 2 to 5 events]. This trend is repetitive, which is why it constitutes the base pattern for setting planning and prevention strategies with technical and systematic processes aimed at officials and users who intervene in the mobility of urban areas

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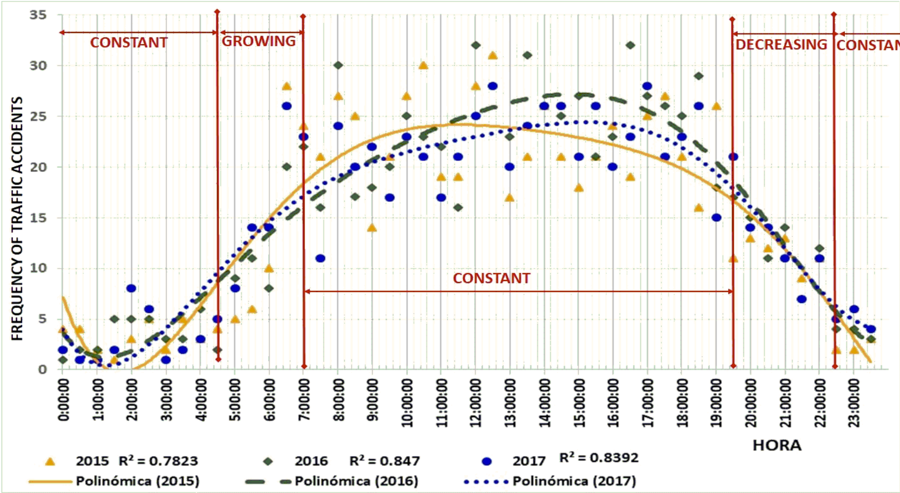
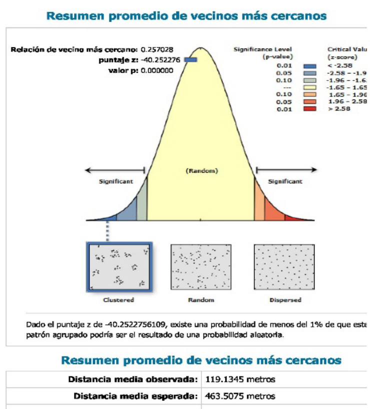
Figure 6. Risk pattern for time of day per TA, representative day



Source: own elaboration

The determination of the concentrations and groupings of events for critically high-risk sectors as result of TA frames their representativeness and level of significance. Using the geostatistics of grouping, correlation (Flahaut et al., 2003), and density value times for the repetitive frequency in the analysis period. The results in Table 3 indicate that the events occur under a repetitive grouped distribution pattern with characteristics of proximity and density weighted by severity [deaths and injuries], significance, and prioritizing hit-and-run accidents to assess the vulnerability of the sectors involved.

Table 3. Geostatistical validity, definition of the clustering pattern and TA concentration, period of analysis

Period	Average Distance	ANN	Z-score	p	
Patter Period	Observed(m):119.1 Esperad.(m): 463.57	.25703	-40.252	0.001 There is a probability of less than 1% that this clustered pattern is random in nature	
2015	Observed(m):86.2 Esperad.(m).: 249.01	.34619	-34.048	0.001 There is a probability of less than 1% that this clustered pattern is random in nature	
2016	Observed(m):120.7 Espected.(m).: 434.72	.28932	-39.271	0.001 There is a probability of less than 1% that this clustered pattern is random in nature	
2017	Observed(m):107.4 Espected(m): 347.78	.37673	-37.324	0.001 There is a probability of less than 1% that this clustered pattern is random in nature	
2018	Observed(m):99.9 Espected(m): 297.57	.32753	-32.432	0.001 There is a probability of less than 1% that this clustered pattern is random in nature	

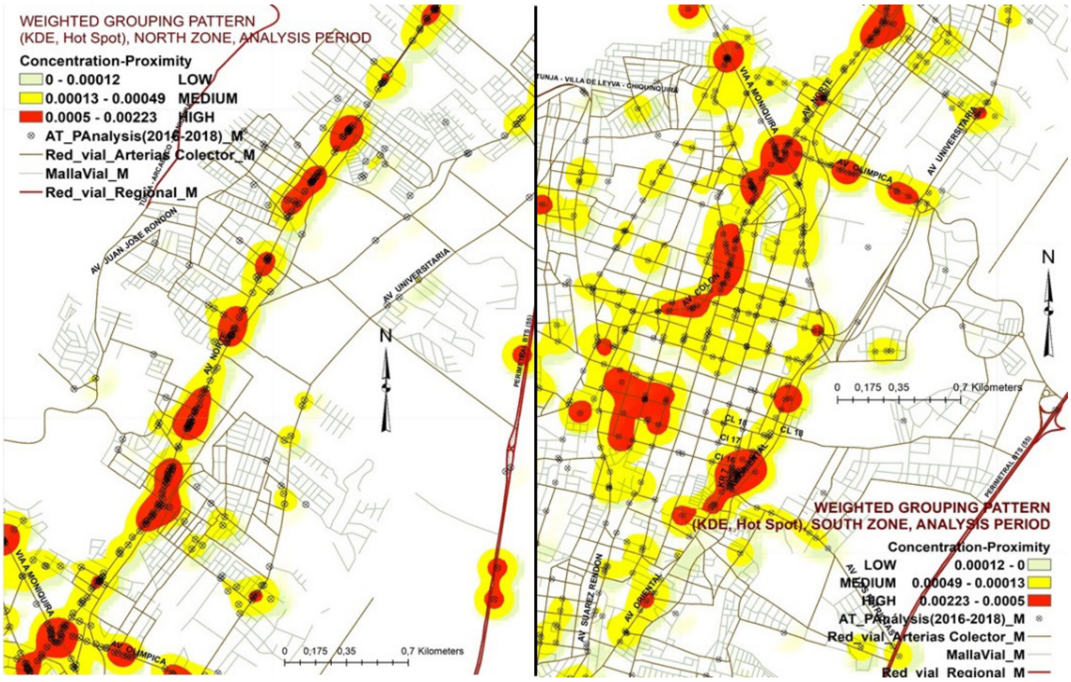
Source: own elaboration

The representative pattern of the period shows foci of significant concentration (clustering), with an observed mean distance of 119.1 m, less than the expected mean distance of 463.6, with

Z-score [-40.252276] and p [.001], as well as the other years of the analysis period, groupings that demarcate the sectors designated as critical with characteristics that determine the existence of a structure with underlying processes in its concentration dynamics.

The KDE analyzes (Figure 7, Northern and Southern zone of the urban area in the study), determine the delimitation of the risk area in the sectors with high concentration (clustering). These are dense sectors that are repetitive in their occurrence within the analysis period, and that presented the following ranges of density in their indices by area and severity: Low [.00001 to .00012], Medium [.00013 to .00040] and High [.0041 to .00223], are also identified as critical. The result is twenty (20) sectors with the greatest grouping and density, between stretches and intersections, which respond to being critical and which impact 3.7% of the total urban area [4.5 km2], with 65% of intersections located on four main arterial connectivity sections (from south to north and from east to west and vice versa), which support the largest vehicular flows in the city [Av Norte, Av Oriental, Av Maldonado and Av Colón], and where 89% of the traffic occurs. the TA with 77% of deaths and injuries. These critical sectors must be a priority for intervention in development and mobility plans.

Figure 7. Critical sector patterns with clusters and weighted density in TAs, Northern and Southern zones during the analysis period



Source: own elaboration

The definition of the critical sectors (clustering) was the basis for the analysis of the dynamics of the underlying geospatial processes that characterized the risk states that trigger TA. This risk dynamic is configured on consolidated areas of the city: historical, educational, institutional, commercial, and residential [treated as geographical units], which in their functionality include important mobility axes, arterials and collectors, where flows of traffic are regularly mixed. pedestrians with light and heavy vehicles that affect not only road safety, but also the fluidity, transfer, and integration of the urban-regional mobility system.

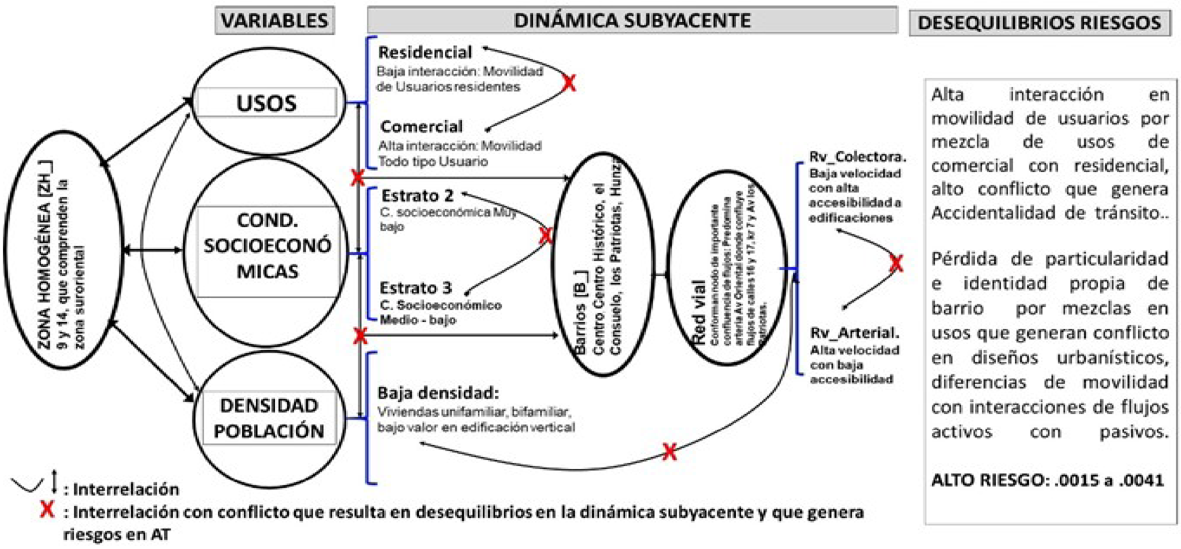
3.2. Risk-generating interrelationship dynamics in geographic units.

The determination of the imbalances of the socio-spatial interrelationships that triggers the risks for the occurrence of TA required a detailed analysis, an analysis that guided the definition of the variables and elements that intervene and affect the underlying dynamics of the critical or risk sector). The process approach was structured and developed as a Principal Components Analysis to identify representative risks across sectors. The analysis of the three geographical units extracted, in their potentialities, limitations and imbalances revealed the interrelationships and correlations between variables involved, generators of conflicts as determinants in the causal problems and risks of the occurrence of TAs.

Figure 8 shows the synthesis of the imbalances detected by the interrelationships of the three geographical units together with their variables and elements that generate conflicts and therefore risks, rooted in the urban planning of the city of analysis. One of the main ones detected is the non-compliance with urban and socio-economic regulations determined in the mix of uses (with opposite types of activities carried out by residents and transit population), in the area, as well as the loss of appropriation and identity of the neighbourhoods, the non-homogeneity in the walls of platforms and buildings and the mixture of layouts in the designs of the physical infrastructure of sidewalks and roads.

Figure 8. Underlying dynamics in risk incidence. Multilayer network model graphical representation

Critical Sector: Old transport terminal. B_168 and B_169 ....Homogeneous Zone ZH_9
Characterization: Its grouping and concentration with statistically significant correlation defines it as a representative pattern of occurrence of High Risk TA over the .14 km2 sector.
Variables: high rate of TA predominates, outrages and shocks with high morbidity and mortality. Confluence of road network Collector on Arterial. No. HIGH RISK TA Equivalent = .0015 to .0041



Source: own elaboration

The ZH_, presented as a predominant, representative, and critical unit, prevails: the mixture of Commercial use [6, short trips with dynamics of active and high mobility activities, especially pedestrian], with Residential use [2, imposes short trips with dynamics of passive mobility activities and behavior]. Likewise, the existence of some vacant lots determines a low density of population and housing, which has affected a lack of delimitation of the neighborhoods, generating a loss of integration and identity, a condition that has resulted in a low appropriation for the management and implementation of urban projects that motivate a growing development in the socioeconomic dynamics of its residents. The prevailing socioeconomic condition is low, stratum level 2 and in some sectors in 3, which respond to neighborhoods with deficiencies in services, in physical accessibility and where low-income families reside with fewer possibilities of accessing permanent education on behaviors in Mobility. The Rv_ Arterial Road network of high mobility (speed), with poor design in accessibility and connectivity for users, where there are no traffic network links to manage the speed transition, which produces untimely decelerations that trigger TA; the capacity and service of the pedestrian circulation network is deficient, which affects road signs, regulations, prevention, and information), it is deficient and insufficient.

The demonstration and statistical validation of the existence of interrelation, correlation between territorial variables (social, physical, and operational), generator of conflicts (previously described), and therefore risks for the occurrence of TAs, is carried out through multiple linear regression by Steps and Hierarchical. The results in Table 4 present the variables together with the indices of significance, statistical power and effect size, selected as the most appropriate to declare the incident relationship for the occurrence of TAs and which in turn validate the existence of a TA prediction incidence model.

Table 4. Interrelation models of variables that predict the occurrence of TA. Statistical validation

Modelos	F(Anova)	P(Sig_F)	R2	ΔR2	B	Error Stand	β	1- β	f2	Colinealidad Tolerancia	VIF
MODEL1	6.36(1.49)	.015	.121	.097	64.558			.554	.138		
Speed(Km/h)					.704	.279	.339			1	1
MODEL2	65.417(2.48)	.001	.732	.720	-9.776			1	2.731		
Speed(Km/h)					.475	.157	.229			.981	1.020
ArtCarril(km)					.024	.002	.793			.981	1.020
MODEL3	235.966(3.47)	.001	.938	.934	20.814			1	15.129		
Speed(km/h)					.454	.076	.219			.980	1.020
ArtCarril(km)					.010	.002	.320			0475	2.106
LandUse6(km2)					322.663	25.865	.657			.478	2.093
MODEL4	173.301(4.46)	.001	.939	.933	21.114			1	15.393		
Speed(Km/h)					.453	.077	.218			.971	1.029
ArtCarril(km)					.010	.002	.318			.458	2.185
LandUse6(km2)					324.208	28.066	.660			.414	2.413
Stratum2(km2)					-5.563	36.813	.006			.852	1.173
MODEL5	154.59(5.45)	.001	.945	.939	17.567			1	17.181		
Speed(Km/h)					.322	.091	.155			.632	1.582
Art/Lane(km)					.010	.002	.317			.458	2.185
LandUse6(km2)					324.305	26.681	.660			.414	2.413
Stratum2(km2					3.449	35.192	.004			.843	1.187
landUse2(km2)					146.865	60.462	.107			.633	1.580
MODEL6	133.42(6.44)	.001	.948	.941	6.078			1	18.230		
Speed(Km/h)					.331	.090	.159			.630	1.588
ArtCarril(km)					.009	.002	.286			.397	2.520
LandUse6(km2)					337.909	27.652	.688			.374	2.676
Stratum2(km2)					13.090	35.175	.014			.817	1.224
landUse2(km2)					150.273	59.543	.109			.632	1.582
Flow(Veh/h)					.001	.001	.060			.800	1.250
D_W (1.871)											

Modelos	F(Anova)	P(Sig_F)	R2	ΔR2	B	Error Stand	β	1- β	f2	Colinealidad Tolerancia VIF
Accidents_No = 6.078+.331*Speed(Km/h)+ .009*ArtCarril(km)+ 337.9*LandUse6(km2)+ 13.09* Stratum2(km2)+ 150.2*landUse2(km2)+ .001* Flow(Veh/h)										

Source: own elaboration

The results validate the representativeness of the incident variables in the risks for the TA, when the set of variables [model 6] are interrelated, since it predicts 94.8% of the occurrence. The analysis also shows that the interrelationship of the operational variables speed and flow, by themselves, present a value of explanation of the occurrence from low to medium [effect size f2=.138]; where with the incorporation of the variables [land uses 6 and 2, stratification 2 and arterial road network], the explanatory power of the occurrence increases to a high statistical level [effect size f2=18.23], (Faul et al., 2009). Likewise, the multicollinearity indicators VIF (Variance Inflation Factor) [>10] and the tolerance values [<.20] indicate that there are no high correlations between the factors of the model, and finally the Durbin Watson indicator [1.871], located within the established range [1.5 to 2.5], allows a generalization of the data for its prediction. It is noted that population density was excluded from all relationships.

4. Discussion

Similar to the WHO report (2018), this study points out the great differences between low and middle-income countries with respect to high-income ones, in terms of quality and coverage in the collection and transfer of data on TA. This is contrasted with the current study which found a lack of quality in important databases where there are significant gaps in records, consistency, and homogenization of entry fields. The problem is not only in Colombia, but in several countries as confirmed by studies on the analysis of TA databases of 46 countries in the world (Chen, 2020; Ashar et al., 2017; & Mandacaru et al., 2017; Haagsma et al., 2016; Zhao, 2009). Deficiencies were found in the records of location and type of victims. This is problamatic since TA research requires reliable data to determine the scope of the problem, provide solutions, and permanently evaluate the effectiveness of intervention measures.

Drivers between the ages of 20 and 40 are involved in the majority of traffic accidents. According to gender, men are involved in 89% of accidents and more often it is younger people between 20 and 30 years old which is similar to other research results from other countries (Johnsson et al., 2018; Olszewski et al., 2018; Cioca & Ivascu, 2017; Cheng et al., 2015; Kar et al., 2016; Cerquera, 2015b; Blazquez and Celis, 2012; Lassarre, 2012). Women have shown to be involved in a stable to increasing amount of TA.

Estimating the effect size responds to the magnitude of the differences found in the study with the standardized ranges and statistical power. This should express the degree of validity of the research findings which is important and increasingly becoming a requirement for ethical and technical reasons (Murphy et al., 2014; Kelley & Preacher, 2012; Hedges & Rhoads, 2010; Murphy et al., 2014; Cohen , 1988). It is unethical to carry out studies without sufficient rigor to determine with a greater approximation the effect of the incidence of territorial variables in the occurrence of TA. Likewise the use of inappropriate techniques due to the expenditure of unnecessary resources when recruiting more personnel than required to verify the objectives of the study is also a problem.

Although the results of the current study are consolidated with the studies of Blazquez and Celis, (2012), Cerquera (2015b), in Bogotá D.C. It is necessary to deepen and consolidate the knowledge of the variables of the underlying dynamics of the territory that impact the problem. The density of inhabitants, dwellings by area, and population make it difficult to define sectors as risky. Likewise the continual mix of commercial and residential land use related to reduced social conditions (strata 2 and/or 3) and the intervention of the arterial road network result in sectors with the highest occurrence of TA. The results of the statistical correlations suggest that circulating flows (demand that circulates through the arterial and collector road network) should be studied in in high-risk sectors.

From the current research cycle, the behavior of users as a factor that produces accidents (Olszewski et al., 2018; Pérez and Cerquera, 2017; Laureshyn et al., 2017) is directly related to the appropriation of the territory. This reduces the influence of the randomness of human error through the forgiving effect of the factors related to each other and under the grouped Kernel character, which has shown its ability to limit TAs in risky sectors.

5. Conclusions

There are twenty (20) sectors between arcs and intersections defined by having a high concentration of TA, constantly, repetitively during each of the years of the analysis period. Their statistical correlation values were significant, which were determined with a great approximation to consider them as critical risks for users who circulate through the corresponding urban sectors. Acting on this information requires increasing the priority in risk prevention and mitigation policies. This would only represent an intervention of 3.7% of the urban area and result in a 67% decrease in TA of the case study city.

The pattern of repetitive character of the critical sectors of permanent risk of occurrence reveals the representativeness of territorial and operational variables that, interrelated, affect the occurrence of TAs. The mixtures of Commercial and Residential uses, the low socioeconomic level (stratum 2), with high incidence, and the operational variables volume, speed, and arterial road network with little incidence if they are related to the territorial variables land use and stratification. The model showed that population density is not incident in the occurrence of accidents. The results of the underlying dynamics together with those of spatial distribution and representativeness in the concentration and occurrence of TA, define with greater certainty the specificity and particularity of the risks that appear by sector that can be declared as critical, but with the particularity of know the variables to influence to clean up their road insecurity.

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