Vulnerable Road Users, Prioritization of Urban Sectors with High Accident Rates. Review and Evaluation Of Methods

Usuarios viales vulnerables, priorización de sectores urbanos con altas tasas de accidentes. Revisión y evaluación de métodos.

Usuários vulneráveis nas vias, priorização de setores urbanos com altos índices de acidentes. Revisão e avaliação de métodos

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Abstract

Introduction: This article presents a review and analysis of studies that concern research made into "Road infrastructure design models to improve road safety for vulnerable users, prioritizing the high accident zones in Bogota D.C."

Objective: To understand the interrelationship between the vulnerable road users, natural surrounding factors and buildings, based on the determination of the most representative variables for the analysis using Geographic Information Systems (GIS), applied to the prioritization of areas with high accident rates.

Methodology: It is based on identifying, through review, the known and unknown updated and important results about accident investigations with regards to vulnerable road users.

Results: The use of multivariable correlation – analysis of groupings that are treated with GIS – to identify the main factors associated with the seriousness of traffic accidents related to vulnerable road users, allows for the generation of road infrastructure designs that reduce the risk, based on areas of high frequency of occurrence.

Conclusions: The multi-criteria analysis and Geographic Information Systems (GIS), allow for the prioritization of areas with high accident rates not only through the evaluation of the quantity of accidents but also by the evaluation of their conditions, by which causal factors of greater influence are identified.

Originality: Development of infrastructure plans that reduce the risk of vulnerable road users being struck by a vehicle.

Limitations: The methodology is only applied to urban areas where there is a pre-existing history of accidents.

Key words: vulnerable transit users, pedestrians, cyclists, road infrastructure design, users' behavior, road accident model of occurrence.

Resumen

Introducción: este artículo presenta una revisión y análisis de estudios concernientes a la investigación realizada "Modelos de diseño de infraestructura vial para mejorar la seguridad vial para usuarios vulnerables, priorizando las zonas de altos accidentes en Bogotá".

Objetivo: comprender la interrelación entre los usuarios vulnerables de la carretera, los factores naturales circundantes y los edificios, a partir de la determinación de las variables más representativas para el análisis, utilizando los Sistemas de Información Geográfica (SIG), aplicados a la priorización de áreas con altas tasas de accidentes.

Metodología: se identifica, a través de la revisión, los resultados actualizados, destacados, conocidos y desconocidos sobre las investigaciones de accidentes con respecto a los usuarios vulnerables de la carretera.

Resultados: el uso de correlación multivariable (análisis de agrupaciones tratadas con SIG) para identificar los principales factores asociados con la gravedad de los accidentes de tránsito relacionados con usuarios vulnerables de la carretera, permite la generación de diseños de infraestructura vial que reducen el riesgo, con base en áreas de alta frecuencia de ocurrencia.

Conclusiones: el análisis multicriterio y los Sistemas de Información Geográfica (SIG) permiten priorizar áreas con altas tasas de accidentes, no solo a través de la evaluación de la cantidad de accidentes sino también a través de la evaluación de sus condiciones, así se identifican los factores causales de mayor influencia.

Originalidad: desarrollo de planes de infraestructura que reducen el riesgo de que los usuarios vulnerables de la carretera sean golpeados por un vehículo.

Limitaciones: la metodología solo se aplica a áreas urbanas donde hay un historial de accidentes preexistente.

Palabras clave: usuarios de tránsito vulnerables, peatones, ciclistas, diseño de infraestructura vial, comportamiento de los usuarios, modelo de ocurrencia de accidentes de tránsito.

Resumo

Introdução: este artigo apresenta uma revisão e uma análise de estudos relacionados à pesquisa “Modelos de design de infraestrutura viária para aumentar a segurança viária para usuários vulneráveis, com prioridade às áreas de maior acidentalidade em Bogotá”.

Objetivo: entender a inter-relação entre usuários vulneráveis das vias, fatores naturais do entorno e edificações, com base na determinação das variáveis mais representativas para a análise a partir de Sistemas de Informação Geográfica (SIG), aplicada à priorização de áreas com altas taxas de acidentalidade.

Metodologia: está baseada em identificar, por meio de revisão, os resultados importantes e atualizados, conhecidos e desconhecidos, das pesquisas sobre acidentes com respeito a usuários vulneráveis das vias.

Resultados: o uso de correlação multivariável – análise de grupos que são tratados com SIG – para identificar os principais fatores associados com a seriedade dos acidentes de trânsito relacionados aos usuários vulneráveis permite a geração de designs de infraestrutura viária que reduz o risco, baseado em áreas com alta frequência de ocorrência.

Conclusões: a análise múltipla de critérios e o Sistema de Informação Geográfica (SIG) permitem a priorização de áreas com altas taxas de acidentes não somente por meio da avaliação da quantidade de acidentes, mas também pela avaliação das condições, nas quais são identificados fatores casuais de grande influência.

Originalidade: desenvolvimento de planos de infraestrutura que reduzem o risco de usuários vulneráveis serem atingidos por um veículo.

Limitações: a metodologia se aplica apenas para áreas urbanas onde existe um histórico prévio de acidentes.

Key words:

1. INTRODUCTION

The World Health Organization (WHO), in its reports about global road safety (2013 and 2015)[1][2], affirms that half of the deaths due to traffic accidents correspond to the so-called “vulnerable users of public roads” (pedestrians, cyclists and motorcyclists). This is confirmed by the Country Profiles report data (2015)[3], that when structured for comparison (Table 1), express the impact that accidents have on pedestrians, cyclists and motorcyclists; For example, more than 50% of the fatalities involve individuals that acheive low and middle class economic incomes. Likewise, it is evident that 90% of the deaths due to traffic accidents are generated in the low and middle class economic income countries, even though 54% of the total vehicles in the world are concentrated in these countries. In high-income countries, the percentage of total deaths and of vulnerable users, according to the number of vehicles, does not even reach 1% on average, such is the case of Sweden, the United Kingdom, Japan, Italy, Spain and the United States. Meanwhile, in developing economies such as Brazil, Paraguay, and Ecuador, high death rates of both total road users and vulnerable road users are commonplace.

Table 1. Total number of road deaths and deaths of vulnerable road users due to traffic accidents in countries with high economic development and developing countries, year 2013.

Country	Total numbeer of estimated deaths due to transit (who)	Deaths according to the category of vulnerable user						Total number of registered vehicles	Deaths of vulnerable users according to reistered vehicle (%)	Total deaths according to registered (%)
		Pedestrian (%)	Pedestrian	Cyclist (%)	Cyclist	Motor cyclist (%)	Motor cyclist			
Argentina	5,619	10%	562	2%	112	No Data	No Data	23,120,241	0.3%	2.4%
Bolivia	2,476	32%	792	1%	25	10%	248	1,206,743	8.8%	20.5%
Brasil	46,935	20%	9387	3%	1408	28%	13142	81,600,729	2.9%	5.8%
Chile	2,179	39%	850	8%	174	7%	153	4,263,084	2.8%	5.1%
Colombia	8,107	29%	2351	5%	405	44%	3567	9,734,565	6.5%	8.3%
Ecuador	3,164	30%	949	1%	32	7%	221	1,721,206	7.0%	18.4%
Paraguay	1,408	21%	296	1%	14	54%	760	1,227,469	8.7%	11.5%
Perú	4,234	24%	1016	1%	42	1%	42	4,264,114	2.6%	9.9%
Uruguay	567	15%	85	3%	17	53%	301	1,991,836	2.0%	2.8%
Germany	3,540	17%	602	11%	389	19%	673	52,391,000	0.3%	0.7%
Australia	1,252	13%	163	4%	50	18%	225	17,180,596	0.3%	0.7%
Spain	1,730	26%	450	4%	69	21%	363	32,616,105	0.3%	0.5%
France	3,268	14%	458	5%	163	24%	784	42,792,103	0.3%	0.8%
Italy	3,721	16%	595	7%	260	26%	967	51,269,218	0.4%	0.7%
Japan	5,971	36%	2150	14%	836	17%	1015	91,377,312	0.4%	0.7%
U.K.	1,827	23%	420	6%	110	19%	347	35,582,650	0.2%	0.5%
Sweden	272	16%	44	5%	14	17%	46	5,755,952	0.2%	0.5%
U.S.A.	34,064	14%	4769	2%	681	15%	5110	265,043,362	0.4%	1.3%

Source: Structuring data extracted from WHO (2015) and Country Profiles (2015).

The problem of road accidents in Colombia arises predominantly in urban spaces; 90% of accidents occur in urban areas and the remaining 10% in rural areas. More than 60% of the events occur in the three main cities, Bogotá, Medellín and Cali, close to 30% in urban areas of intermediate size and the remaining 10 % occur on the national road network. With regards to researching the urban area of Bogotá D.C., the problem of road safety means finding most or all of the variables and characteristics that may be presented in the occurrence of traffic accidents in a Latin American metropolis; a condition that determines results with a high representative character (Cerquera 2013) [4].

According to the National Traffic Code (Mintransporte, 2002) [5], a pedestrian is a user who moves on foot on a road and the cyclist is the driver of a bicycle or tricycle, this type of displacement is conditioned by their own efforts. In the context of road safety they are categorized under the concept of vulnerable user. This term refers to all people who, because of the means of transportation or because of their physical characteristics, age or health, have a greater risk of suffering injuries in a traffic accident.

The accident rate on the roads in the urban area of Bogotá is a constant problem, with 11 % to 13% of the total annual accident rate being incidents involving vulnerable road users. This is partly due to factors such as the physical state of the road infrastructure, the behavior of users and the operational conditions of traffic, as well as the growth of the population and the total number of vehicles; all factors that increase the exposure to risk.

The objective of this article is to present a synthesis of the section that concerns the review and analysis of several of the main studies of accidents of vulnerable users that have been developed in several countries and that concern the research of "Road infrastructure design models to improve the road safety of vulnerable users, based on the prioritization of areas of high accident rate in Bogotá DC", in order to guide the understanding of the interrelationships between the internal factors of the vulnerable users involved and the factors of the natural environment and the urban surroundings.

According to a report from the District Department of Mobility of Bogotá D.C. (Week, 2016) [5] [6], between 2011 and 2015, bicycle use increased by 30 % from 441,135 to 575,356 daily journeys. The city has a network of 376 kilometers of cycle paths, which have helped with mobility, the environment and the economy of the users but this data, compared with the data of deaths of cyclists by traffic accidents — that has increased by 16 % — suggest that in the city, despite the promotion of sustainable transport, there is evidence that there are security failures for the so-called group of vulnerable users .

The database that underpins the investigation is the accident rate for 'accidents involving vulnerable road users' of the Mobility Secretariat, SDM, in the years 2014, 2015 and 2016, with 9,409 records that comprise 99% of the total population of occurrences of accidents in Bogotá in the three years analysis. It is considered that this data set provides an adequate level of representation to perform an exhaustive review of the subject.

2. METHODOLOGY

The method is framed by the objective; to identify through the revision of the updated and important results, known and unknown, about accident investigations related to vulnerable road users, with special relevance in the interrelations of the characteristics and physical conditions of the road infrastructure along with other variables, in Spatial Analysis studies. These are standard models that identify and predict the areas of high occurrence of traffic accidents, as well as grouping methods for their prioritization, in user behavior and on the design and operation methods, which affect the occurrence of accidents of vulnerable users. Studies that guide the development to validate the research hypothesis. Figure 1 presents the synthesis of the method followed for the review of the topics.

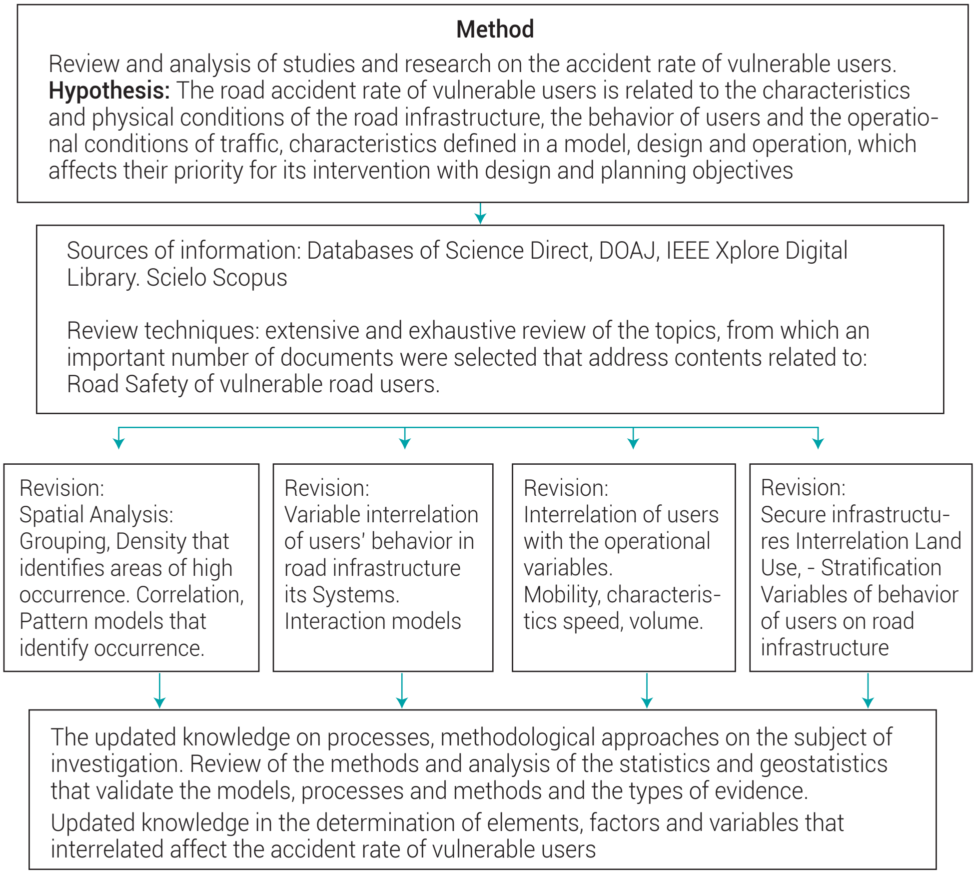

Figure 1. Method and synthesis of the review process
Source: own work

2.1. Review Structure - delimitation of the context

"Road safety should be conceived as a social system, characterized in a holistic way (Pico, González and Noreña, 2011) [7], which includes a variety of activities or processes in which different actors interact with each other in physical environments, through the use of motorized or non-motorized means of transport. Ideally, this social system must have a dynamic, free of conflicts and contradictions, since its purpose is the prevalence of people's lives, in addition to the optimal maintenance of the infrastructure". According to: Nazif, J. Ignacio; Rojas, D.; Sánchez, R. J. and Velasco E. Álvaro (2006) [8], "Traffic safety is the process of preservation of life, health and people's property, through the harmonization of coexistence in transport activities". It involves the life and health of road users as the fundamental aspect in safety, hence the importance of having good traffic management, well maintained road infrastructure and an adequate segregation of it.

Cerquera (2015) [9], in his research on Bogotá DC, stated: "If we look at the probable causes of accidents that cause deaths and injuries, we can see that there is a certain population that is more vulnerable such as pedestrians, being the most exposed in its surroundings, to vehicular flows, with the highest percentage of deaths and injuries. In the country in general, the pedestrian population generally belongs to the communities' least prepared to intervene and interrelate with the other flows and with its surroundings; pedestrians are not aware of their representation in circulation, they are not considered flows that must comply and abide to the rules for their operation and control that will allow them to advance with due security before other flows". He also demonstrated that accidents are not random and their space and time distribution is related to factors that are not only physical-geographical but also socio-economical that manifest differentially in the territory and with a multi-causal character.

In the prioritization of high frequency areas, geographic information systems (GIS) are essential as a support in the determination of accident occurrence models due to the fact that with its application it facilitates the multicriteria analysis, to spatialize and visualize cartographically the attributes of the most frequent and critical areas and sectors of occurrence and through its systemic algorithms allows the geostatistical treatment of the different variables aimed at obtaining results that define the pattern of occurrence. Hence the importance of prioritization with the support of GIS; these identified sectors are highly representative within urban areas.

3. DEVELOPMENT

3.1. Spatial Analysis Studies: Standard models that identify and predict the sectors of high occurrence of traffic accidents for their prioritization

Investigating the pattern or model of incidence in the occurrence of accidents means marking the spatio-temporal regularities in the areas and regions under study, these regularities associate changes and exposure to an intrinsic risk. Through a geospatial analysis it is possible to show the nature of the problem and the way in which traditional solutions may or may not reduce the level of risk of an accident (Whitelegg, 1987) [10], this implies that while traffic accidents occur, there is a clear imperative that's required to perform the spatial analysis in its occurrence, this is a full identifier of prioritization.

In the search for suitable solutions that aim to reduce the accidents of vulnerable road users, it is the analysis of the accidents involving vulnerable road users in the urban area that will serve as the guide to the recognition of the causes of these as well as the use of systems of georeferencing that allow for the analysis of prioritization of critical zones or sectors using multicriteria evaluations that contribute to the identification of the road safety deficiencies of the urban areas of the cities. The identification of these zones and sectors, prioritized by their representativeness, will allow for the continuation of this analysis in determining the variables and parameters that determine a standard pattern of occurrence of accidents of vulnerable users (Cerquera, 2015). [9]

Likewise, Cerquera in his research significantly determines that the occurrence of traffic accidents has a territorial and temporal component that are strongly related to the physical and socioeconomical characteristics of the analyzed space; a fundamental state that visualizes the interrelation between variables to achieve significant predictions of occurrence of accidents to be able to influence their prevention. From there, it menetions that the knowledge of road safety investigations with applications in GIS are widely used to geocode the location, find trends and accident patterns so as to develop maps that visualize the interrelationships and systematize the queries of the attributes that support the locations, which in turn support and describe distribution patterns and multivariate analyzes in their spatiality (Levine et al., 1995 part I and 1995 part II) [11] [12].

Lord, D., Washington, S. P., Ivan, J. N. (2005) [13], provide guidance on how to appropriate accident data for modeling. First, the accident analysis must use the

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theoretical principles and a basic understanding of the process, where it is initially shown that the fundamental process follows a Bernoulli test with unequal probability of independent events (Poisson). It examines the evolution of the statistical models that are applied and present how well they approach the accident process. In addition, they demonstrate that under certain (fairly common) circumstances, the selection of time / space scales for analysis, including a selected set of explanatory variables and / or heterogeneity effects not observed in regression counting models, or the application of small area statistical methods (observations with low exposure), is fairly applicable for data sets with a preponderance of zeros (low exposure).

In the prioritization of sectors with higher accident rate, references should be oriented on the degree of concentration; through spatialization , where the fluctuation of dynamics are shown in response to changing traffic flow patterns, as shown by Affum and Taylor (1995) [14], Austin (et al., 1997) [15], with Kim and Levine (1996) [16] and Miller (1999) [17] in their studies of grouping analysis. Other researchers such as Pulugurtha (et al., 2007) [18] and Cerquera (2015) [19], used important algorithms in GIS for the analysis. They used the concept of 'cell' or 'grid' based on the density calculation analysis – the concentration of collisions to detect the high frequency points –. For this they used the Kernel Density.

Other results from the investigation of Cerquera (2015) [19], using the Kernel Density methodology, determined that in the urban area of Bogotá DC, over a period of five years, that twelve (12) sections and thirty-nine (39) intersections, emerged as the areas that consistently and repetitively, produced the majority of traffic accidents (Figure 2) in contrast to the initial analysis currently developed. Several of these sites continue to suffer high occurrences (Figure 3). This analysis is based on the detection of hot spots, the determination of greater spatial statistical delimitation of sectors, due to its sophisticated mathematical algorithm. In contrast, Greibe (2003) [9] [20], used general linear modeling techniques to relate accident frequencies with explanatory variables and Cerquera (2015) [19], using multicriteria analysis in high-risk areas uses a weighted correlation, identifying variables, though interrelationship models using geographic weighted regressions GWR, with high significance value, that could predict the expected number of accidents at intersections and stretches of urban areas.

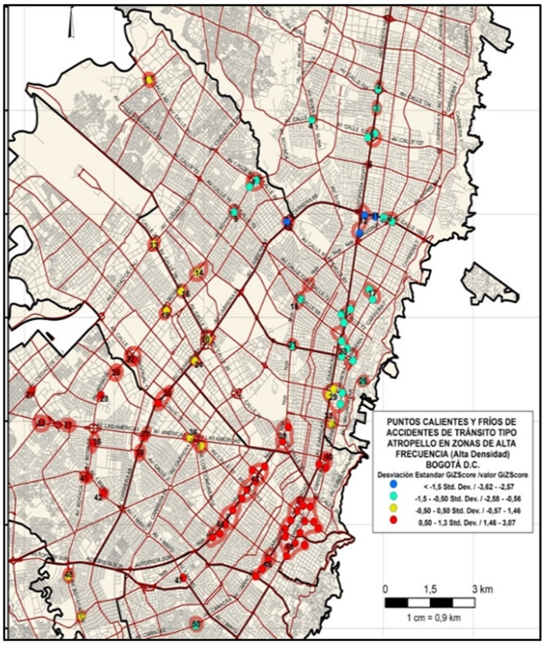

Figure 2. Intersections and Hot Spot streches in run overs (2007-2011) in Bogotá D.C
Source: Cerquera, 2015 [19].

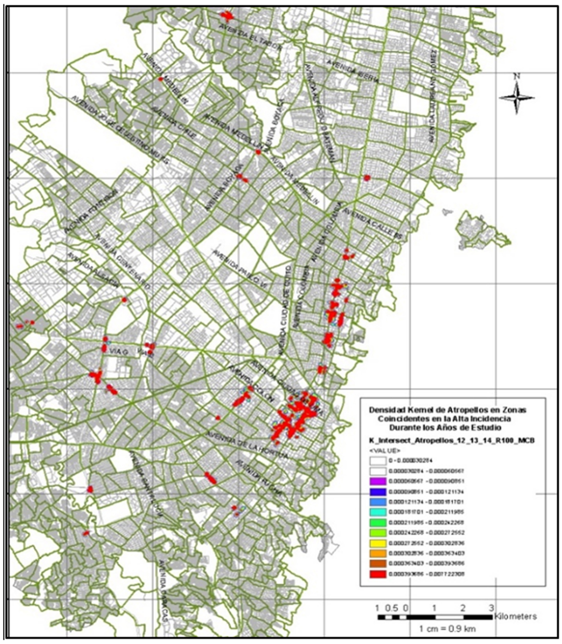

Figure 3. Intersections and streches with high frequence of run over accidents (2012-2014) in Bogotá D.C
Source: Rueda and Cerquera (investigation on development).

Builes, L., and Lotero, L. (2013) [21], used GIS to make an overlay of information layers that allowed them to perform a multicriteria (multivariate) prioritization of zones and thus define by which of these to start the intervention of the dependent variable (in this investigation number of accidents). The most critical areas are those that exceed the national normative ranges in the explanatory variables, referring to: land use, also involving population densities and series of morbidity and mortality rates. Bocarejo (2011) [22], analyzed the characteristics of fatal accidents that occurred in Bogotá, using the K-means algorithm, demonstrating the potential of grouping techniques to identify the specific combinations of the elements that are most affected. The results show that two pairs of interactions characterize the majority of fatal road accidents: public transport and pedestrians, public transport-motorcycle.

3.2. Studies on secure infrastructure

The safety of vulnerable users on urban roads is partly related to the design of these. Efforts of organizations such as the World Resources Institute that provide a vision of road safety through urban road design to achieve sustainable cities through the document " Safer cities through design" (Welle et al, 2016) [23], expose experiences of cities that have dared to make changes in the distribution and management of vehicular flows in order to improve the safety of vulnerable users. Some of these countermeasures modify the widths and length of straight sections of vehicular roads or introduce physical elements: speed reducers, pavement extensions, roundabouts, mini roundabouts, intersections and overpasses. It also suggests that cities implement segregation of flows, improved connectivity and visible road signs, in order to achieve pedestrian and cyclist-friendly streets.

Harry Dupree (1987) [24], understanding the importance of urban design for road safety, developed a document that describes the logical sequence to be employed when implementing a new city. The document includes introductory chapters that provide historical background on the establishment of urban center planning and development of urban transport. Other chapters focus on the master plans, transport plans and the main road network of different cities through a series of illustrative case studies whilst other chapters describe the impacts and responses of ttransportation in residential, commercial and industrial land uses. The last chapters focus on public transport, pedestrian movements, cycling, and parking within cities.

The statistical properties of four regression models, two conventional linear regression models and two Poisson regression models, are investigated (Miaou, SP, Lum, H., 1993) [25], in terms of their ability to model relationships between accidents and the geometric design of roads. The study identifies the possible limitations of these models in relation to their assumed underlined distribution, estimating the procedures of the functional form of the accident rate and sensitivity to short stretches of road. The treatment of vehicle exposure and traffic conditions, and the uncertainties of the data due to sampling and non-sampling errors are also analyzed. It is shown that the conventional linear regression models lack the distributive property to adequately describe accident events of aleatory, discrete, non-negative and typically sporadic vehicles on the road (Miaou, 1994) [26]. As a result, these models are not appropriate for making probabilistic statements about vehicle accidents, and the test statistics derived from these models are questionable.

Tripodi, A. (et al., 2012) [27], worked on the SaferBrain project, where the result is the analysis of the different behaviors of road users for the populations of India and Brazil in accident situations. The system analyzed the road infrastructure giving a corrective approach to the causes of accidents involving vulnerable users (pedestrians and cyclists), as well as giving a preventive focus on new infrastructure.

Ruth Sims (et al., 2011) [28], conducted another study, within the same project, where the objective was to increase the level of safety of the entire road system and its components, focusing on vulnerable users of these and contributing in the reduction of the number of deaths and severity of injuries caused by traffic accidents in emerging economies. This involved analyzing local requirements, and evaluating the transferability of European measures, tools and methodologies adapted to emerging economies, elaborating recommendations, guidelines and tools for the design of safe road infrastructures for vulnerable users under pilot projects and the training of policyholders.

Constanza Martínez (2016) [29], wrote an article that shows five (5) strategies proposed by the National Association of City Transportation Officials (NACTO). These describe different types of elements that can be implemented in different types of intersections of a city in order to improve the mobility and safety of pedestrians and cyclists. The five NACTO proposals seek the appropriate segregation of the circulation at intersections and the reduction in the speed of drivers. For this they propose various modifications to the road surroundings, such as the implementation of pedestrian islands, clear and striking demarcation of transit areas for separation of the circulation, eliminating car turns (left or right), using fences at corners, elevated pedestrian crossings and elevated intersections.

3.3 Vulnerable users by their behavior in the cities

Since 1975, G.M. Mackay [30], published a rigorous study in which he considered that the most vulnerable users of the road were pedestrians, cyclists and motorcyclists. He carried out an analysis of fatalities and serious injuries for each type of vulnerable user according to their age, finding out that the ages in which the majority of the victims were: pedestrians from 2 to 22 years old and over 60 years of age reaching a maximum at ages 7 to 8, cyclists from 5 to 20 years with a maximum at age 15, motorcyclists from 16 to 30 with a maximum at age 16. For some of the causes of accidents, Norton (2007) [31] and Mackay, point to jaywalking emphasizing on the segregation of the circulation of: cars, pedestrians and cyclists, with an insufficiency of lighting as a dominant factor in accidents of pedestrians and cyclists. In another report, he presents the analysis of the types of collisions that may occur and describes what happens to pedestrians and cyclists at the time of being run over by a car. Observing whether the speed is high or low, he found that 60 % of serious and fatal injuries arose from the initial impact of high-speed automobiles.

He also deduced that pedestrians predominantly make errors by omission when they intervene on the road, since they do so without any kind of visual evaluation and prior cognitive recognition. UPCommons [32] (Factors causing accidents) evaluates the behavior of road users as one of the causes of accidents due to the fact that humans are prone to distraction.

V.P. Sisiopiku, D AkIN (2003) [33], conducted a survey on an urban boulevard, located adjacent to the campus of Michigan State University, East Lansing, MI, United States, in order to identify the preferences of pedestrians when crossing the street. This study demonstrated that 41 % of pedestrians cross the street in inconvenient places, which means that 59 % of pedestrians cross the street in the designated area. Rolla Almodfer, Shengwu Xiong, Zhixiang Fang, Xiangzhen Kong, Senwen Zheng (2016) [34] investigated, with probabilistic processes, the relationship between pedestrian waiting time and pedestrian-vehicle conflicts, dividing conflicts into: serious, minor or potential. The results showed that a waiting time of less than 3 seconds, causes 881 situations of conflict between pedestrians and vehicles, and that for times of 30 seconds, the number of serious conflicts decreases (from 194 to 9), which allows us to perceive that patience when crossing the road is appropriate and useful for safety.

Scott A. Bennet, Nikolaos Yiannakoulias, (2015) [35], identified traffic characteristics in pedestrians under the age of 14 when crossing an intersection or being in the middle of the street. It was estimated that to avoid accidents involving children going to school, routes must be proposed in which the number of intersections along the way are reduced. Zohreh Asadi-Shekari, Mehdi Moeinaddini, Muhammad Zaly Shah

(2015) [36], conceptualize the pedestrian safety index (PSI), to evaluate pedestrian safety on several urban streets. By inspecting pedestrian facilities, a points system method is proposed to compare existing conditions to a standard. This allows for the identification of possible improvements and in this way, designers can use these results in the implementation of safe routes for pedestrians. Zheng, Chase, Elefteriadou, Schroeder, Sisiopiku V. (2015) [37], analyzed the behavior of pedestrians when crossing the street in forbidden areas and the drivers' reactions, which proved that the bad habits of pedestrians of not crossings safely and the eagerness of drivers to move faster, are two of the main problems that produce accidents on the roads.

In accordance with the above, the District Department of Mobility of Bogotá D.C. (Mayor's Office of Bogotá, 2016) [38], in its publication: Bogotá invites its citizens to contribute with their ideas to improve child mobility, pointing out that "in the capital, children under the age of 13 make close to 739,000 daily trips, mainly to and from their schools.", and in the Global Guide for the design of safer streets and communities (2014) [39], it tells us that traffic collisions are the leading cause of death of young people between the ages of 15 to 29 years old, and the second worldwide cause of death for children from age 5 to 14; worrying figures that are a guide to the measures that are being taken for the safety of children and young people.

In the analysis of accident rates for pedestrians and cyclists in their nocturnal displacements, Richard D. Blomberg, Allen Hale, David F. Preusser (1986) [40], conducted a field experiment to determine the amount of improvement in the visibility of pedestrians and cyclists who travel at night using various retroreflective materials and lights, in order to measure the distances of detection and recognition. Once the tests were carried out, it was determined that: light colored clothes do not improve the safety of pedestrians and cyclists; The best method to be detected and recognized is by using a flashlight. Additionally, putting on a vest or reflective strips is not as effective as the flashlight but is better than wearing a white shirt.

Alcohol in pedestrians is another factor. Studies by Haddon et al, (1961) [41], Solheim (1964), in which blood samples were taken from fatally injured users and examined to see how many of them had liquor in their system, significant values were found. Being drunk according to Internet Point and Insurance Reduction Program (2016) [42], implies that various functions of the organism lose control, resulting in reduced reflexes, vision and the ability to make decisions; which is indispensable when driving or crossing the street. Other affecting factors according to the UPCommons [32], are mainly, the eagerness to circulate, the mood and distraction by publicity.

3.4. Vulnerable users due to deficiency in the transit operation

Accidents on the road are not only due to factors such as the poor conditions of the design and construction of the road infrastructure, but also due to the operating conditions of the traffic control devices. In 2015, the Pedagogical and Technological University of Colombia, in agreement with the District Department of Mobility of Bogotá DC, performed an analysis on Road Safety Inspections and Audits in the urban area,(Cerquera, Pérez and Guío, 2015) [43]. One of the most frequent findings demarcated as high-risk for accidents involving cyclists and pedestrians, were the intersections operated with traffic lights in which one of its traffic light phases (with turns of vehicles allowed to the right) came into conflict with pedestrian circulation time. This infers that having a coordinated distribution of time in pedestrian traffic lights reduces the risk of run over accidents at the intersections, as this ensures that slower pedestrians cross the street in a safe and prudent time.

Another key to safer operation is the segregation of the circulation of vulnerable road users. This approach is conceived in the service of humanity since 1975 according to Mackay's (1975) [30], yet these days it is still not a priority in the urban design of most of the main Colombian cities. Bogotá D.C. and other capital cities, due to their constant growth, still show weaknesses in urban planning because they do not observe nor delimit the space requirements for the segregation of the different traffic flows.

In 2015, Xiaobao Yang, Mei Huan Mohamed Abdel-Aty Yichuan Peng, Ziyou Gao [44] conducted an analysis of the behavior of cyclists and motorcyclists during the waiting time at a traffic light. The study was carried out at some intersections in Beijing China, with a total sample of 2322 cyclists, 1144 conventional cyclists and 1178 electronic cyclists, who were approaching the intersections during periods of red light. The waiting duration was treated as a continuous aleatory variable T, with a cumulative distribution function. In the study of the cyclists, it is noticed that the selected individuals prepare to make the crossing hastily during the red time due to the long waiting periods. Some cases did not reach 49 seconds and 21% of the sample made the crossing without waiting. It was found that motorcyclists are more impatient than conventional drivers, like male drivers in relation to female drivers. Users tend to wait longer if fewer of them venture out to cross, showing the incidence and impact that their actions have on other people.

Peng Chen (2015) [45] related factors of urban surroundings and accidents of cyclists with cars. In this, a random effects Poisson-lognormal model was used along with a Hierarchical Bayesian estimate, for which variables were used such as: number of displacements by bicycle in relation to the total number of displacements, the zonal average of speed limits, the average gradients by zones, the tree density in the streets and parking signs. Recommendations were obtained that allow for the reduction of collisions between cyclists and drivers, among which there is the reduction of the regular speed limit, driving behaviors in areas of mixed use of the street and building bike lanes separated from motorized traffic.

Tarek Sayed, Mohamed H. Zaki, Jarvis Autey (2013) [46], developed a diagnostic approach to automated security for the assessment of vehicle-cyclist conflicts, using videos for continuous observations at the entrance of the Burrard Bridge in Vancouver, British Columbia. Traffic conflicts were detected and classified according to the time of collision. It also records the violations to the traffic signals by the vehicles. With the previous information, a diagnosis is obtained which allows for the perception of the problem and thereby generate possible countermeasures. The main one of these was to improve the road signs and use higher performance signals.

Roshandeh, A., Li, Z., Zhang, S., Levinson, H., & Lu, X. (2016) [47] simultaneously evaluated the global impacts of vehicle and pedestrian accidents caused by the optimization and synchronization of traffic lights in the dense networks of urban streets. An empirical Bayesian analysis method was introduced to estimate the safety impacts of traffic light optimization at an intersection in a network of urban streets in terms of vehicle collisions with pedestrians at intersections, as well as individual and multiple vehicle collisions in segments of the street. The results show that the vehicle with pedestrian collisions at the intersections are reduced to different degrees and types of severity of accidents. These indicate that the optimization of intersection signal synchronization in dense urban street networks have a potential to improve traffic mobility, vehicle and pedestrian safety at intersections, and the safety of vehicles in the segments of the road.

Peng Chen, Chaozhong Wu, Shunying Zhu (2016) [48]; Agüero & Jovanis (2009) [49], performed a spatial statistical approach that offered the possibility of capturing spatial autocorrelation under precisely estimated parameters that were in-turn related to the Poisson-lognormal conditional autoregressive model and the multivariate Poisson Bayesian logistic model. The investigations explain the interaction between vehicles and pedestrians in pedestrian crossings and half block crossings. The objective of the model is to describe the perception and judgment of pedestrians and drivers when crossing the street, for which it handles parameters with which users must comply when traveling on the road. The spatial statistical approach offers the possibility of capturing spatial autocorrelation with precisely estimated parameters.

Jamroz, K., et al. (2014) [50], test a road safety system equipped with road safety management, road safety inspections and road safety audit tools. It was designed to improve the designs of the roads and provide a treatment (ex-post), which improves the safety conditions of constant users. It suggested that if these tools are applied correctly it could reduce the risks of death and injury of users of the roads.

Gomaa Mohamed, Nicolas Saunier, Luis F. Miranda Moreno, Satish V. Ukkusuri (2013) [51], conducted an analysis that shows how the segmentation of accident databases help to better understand the complex relationship between the results of the severity of the injury and the contribution of the constructed geometric surroundings and sociodemographic factors. Using the same methodology for two different databases, various techniques were tested. Within the New York databases, a latent class with an ordered probit method provides the best results. However, for Montreal it found that pedestrian age, type of location, age of the driver, type of vehicle, K-means with a multinomial logit model is more appropriate. Among other results, the driver's alcoholic behavior, the lighting conditions and various characteristics of the urban surroundings influence the probability of fatal accidents.

3.5. Synthesis modeling methods for the analysis of accident data

Table 2 presents the synthesis of the specific methods applied in the investigations that have been reviewed and that were used for the analysis and to deal with accident frequency data.

4. DISCUSSION

The bibliographical review revealed that the problem of safety for vulnerable road users, is not as recent (of the XXI century) as you might believe. The problems began when the first cars appeared on the roads in the 20s. Back then, the responsibility in case of a crash would not have corresponded to the driver, but to the pedestrian [31]. Since then, especially in the urban areas of cities, it has been determined that the problem is not in the lack of the formulation of strategies, because there are a significant number of studies dealing with the subject, but that it lies in a deficiency of multi-causal, multivariable interrelation analysis. A study to highlight is that of Harry Dupree (1987) [24], who did an excellent analysis, formulating different approaches and spaces with the levels of representation.

The safety of vulnerable road users includes different factors that involve the infrastructure of public spaces, the interaction of users before it, the segregation of roads, the behavior of users before other users and society. The identification of the factors that cause road accidents have taken on strength and importance. Organizations such as the WHO [1], [2] have warned about the problem and have generated strategies for local governments aimed at the mitigation of these and that require great efforts to reduce the threat of accidents in cities [38].

The Bayesiano method is one of the most widely used method in accident frequency models. This estimation method has been gaining popularity due to advances in computer systems (Gilks et al., 1996) [52]. The Bayesiano model has the advantage of being able to handle very complex algorithms, especially those that do not have easily calculated plausibility functions. Thus, it can be deduced that using the Markov Chain Monte Carlo (MCMC) methods, an estimation model based on the appropriate sampling for Bayesiano models can be managed.

Table 2. Summary of the research reviewed and its model used to analyze accident data.

Type of model and method	Some considerations of the model	Some reviewed investigations
Poisson	Most basic model; easy to estimate Since the dependent variable is a whole non-negative number, in the majority of the most recent knowledge in the field the Poisson regression model has been used as a starting point. It has been found that its application is problematic because it cannot handle over and low dispersion.	Miaou, S. P., Lum H., 1993; Miaou, S. P (1994); Lord, D., Washington, S.p., Ivan, J.N. (2005); Chen, P. (2015);Peng Chen,Chaozhong Wu, Shunying Zhu (2016);Aguero-Vlaverde and Jovanis, (2008)
Negative Binomial/ Poisson-gamma	Easy to estimate and may account for over dispersion. The negative binomial model (or Poisson-gamma) is an extension of the Poisson model to overcome possible excess dispersion in the data. The model assumes that the Poisson parameter follows a Gamma probability distribution. The results of the model in a closed-form equation and the mathematics to manipulate the relationship between the average and the structures of the bonding is relatively simple. It is one of the most used models in the analysis of accident frequency, however, the model has its limitations, especially in its inability to handle the low dispersion of data, and presents some problems of dispersion estimation parameters.	Miaou, S. P(1994); Lord, D., Washington, S.P., Ivan, J. N. (2005)

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Type of model and method	Some considerations of the model	Some reviewed investigations
Poisson-lognormal	More flexible than Poisson-Gamma when handling excess dispersion. Recently, some researchers have proposed using the Poisson-lognormal model as an alternative to the negative binomial / Possion-Gamma model to prototype accident data. This is very similar to the negative binomial / Poisson-Gamma model, where only the terms of the Gamma change distributed by the Lognormal.	Miaou et al., (2003); Lord and Miranda-Moreno, (2008); Chen, P. (2015);Peng Chen, Chaozhong Wu, Shunying Zhu (2016); Aguero-Valverde and Jovanis, (2008)
Observations-correlation-indices. Experimental Evaluation	Handles temporal and spatial correlation. There may be reasons to expect a correlation between observations. This correlation could arise from spatial considerations (data from the same geographical region can share unobserved effects), temporal considerations (where data collected from the same observation unit during successive periods could be shared in their unobserved effects) or a combination of the two.	Almodfer, R., Xiong, S., Fang, Z., Kong, X., & Zheng, S. (2015): vi. Bennet, S., & Preusser., D. (1986); Greibe., P (2003); Peng Chen, Chaozhong Wu, Shunying Zhu (2016); Gomaa, M., Saunier, N., Miranda, L., & Ukkusuri, S. (2013); Haddon, W., Valien, P., McCarroll, J.R., & Umberger, C.J. (1961); Jamroz, K., et al. (2014); Mackay, G. (1975); Ruth, S. (etal., 2011); Sayed, T., Zaki, M., & Autey, J. (2013); Zheng Y., etal. (2015); Sisiopiku, V., & Akin, D. (2003).
Bivariate / multivariate, Spatial analysis correlation. GIS application.	You can model different types of accidents in a simultaneous way; functional form more flexible than generalized estimation equation models (you can use non-linear functions)	Cerquera (2013); Cerquera, E.F.A (2015); Builes, L., y Lotero, L. (2013): Affum, J.K., &M.A. P. Taylor (1995); Austin, K., Tight, M. and Kirby, H. (1997); Gomaa, M., Sunier., N., Miranda, L., &Ukkusuri, S. (2013); xix. Greibe, P. (2003); Levine, N., Kim, E. K. and Nitz, H.l. (1995); Kim, E.K.,& Levine, N. (1996);Miller, (1999); Pulugurtha,S.S., Krishnakumar,V.K & Nambisan, S.S (2007); Sisiopiku, V., & Akin, D. (2003); Bocarejo J, Diaz C. (2011).
Bayes parameter estimation methods	The Bayesiano method is one of the most widely used method for accident frequency models. This estimation method has gained popularity due to advances in computer systems. (Gilks etal., 1996). The Bayesiano model has the advantage of being able to handle very complex methods, especially those that do not have easily calculable plausibility functions. Using Markoy Chain Monte Carlo (MCMC) methods, an estimation model based on the sampling that is suitable for Bayesiano models can be managed. It can handle complex forms of functional models.	Chen, P. (2015); Peng Chen, Chaozhong Wu, Shunying Zhu (2016); Roshandeh, A., Li, Z., Zhang, S., Levinson; H., & Lu, Valverde and Jovanis, (2008)

Source: own work

5. CONCLUSION

The studies and analyses reviewed here show, in their generality, the frequency of accidents with an approach to the problems in terms of the attributes of their occurrence. To address these problems, innovative methodological approaches have been introduced to try to improve the level of representativeness of the results. In recent years in particular, this current of innovative procedures and methods has introduced some very important statistical approaches that validate with high levels of certainty the variables that affect the occurrence of accidents; models of aleatory probabilistic parameters of Lognormal, Poisson and Bayes type estimates. Equally important are the grouping and spatial analysis that are then treated with high correlation regression models and geostatistics to identify the main factors associated with the severity of vulnerable users. In addition, the methods of observation are later used to achieve correlation and analysis with simulations to generate deductions under the Experimental Evaluation. There are also others that when applied, are very promising to improve the understanding of the factors that affect the frequency of accidents.

The complexity in the use of these methods requires special training and knowledge in statistical and geospatial analysis which often prevent the application in the practice of these mathematical methods. Additionally, these approaches, are generally combined with spatial tools such as Geographic Information Systems (GIS), and visually display the results, representing an innovative research approach. These methodologies have been hardly used by the administrations of the Colombian cities, unaware of the rational and appropriate application of these.

Research on the clustering regression approach involve a multi-criteria analysis approach that include a wide range of factors; urban surroundings, a geometric design, the interrelationships between vehicles and vulnerable users, studies that support traffic engineering, planners and those who take decisions; all aimed at solving the factors related to accident injuries.

Results of the studies and investigations generally point out the mixture of the different flows in the circulation and the road user as the most recurrent in the accidents due to their behavior. Human beings are prone to distractions which are incident factors that cause accidents. Likewise, they infer that pedestrian predominantly make errors by omission when they use the road, since they do so without any kind of visual evaluation and prior cognitive recognition.

According to the review, it was observed that the integration of GIS, along with multicriteria analysis, is key in the identification of high accident rate zones. They allow for the processing of large amounts of data (Big-data under geodatabases), facilitating its visualization by means of dense images, in a scaled (pixelated) format, established with high levels of significance and representativeness due to their values of standard deviation and which in turn can address the urban design criteria for the most vulnerable users of the road.

6. REFERENCES

[1] OMS, "Informe sobre la situación mundial de la seguridad vial 2013," *WHO*, p. 12, 2014. [Online]. Available: http://www.who.int/violence_injury_prevention/road_safety_status/2013/es/.

[2] Informe sobre la situación mundial de la seguridad vial 2015, *WHO*, p. 16, 2015. [Online]. Available: http://www.who.int/violence_injury_prevention/road_safety_status/2015/Summary_GSRRS2015_SPA.pdf?ua=1.

[3] Country profiles, *WHO*, p. 181, 2015. [Online]. Available: http://www.who.int/violence_injury_prevention/road_safety_status/2015/Country_profiles_combined_GSRRS2015_2.pdf?ua=1.

[4] F. Á. Cerquera Escobar, "Análisis espacial de los accidentes de tráfico en Bogotá D.C. Fundamentos de investigación," *Perspect. Geográfica*, vol. 18, no. 1, p. 9, Jan. 2013. [Online]. doi:10.19053/01233769.2248.

[5] Mintransporte, "Ley_0769_2002," *Diario Oficial,* no. 44.932, 13 de Sep. 2002. [Online]. Available: http://www.secretariasenado.gov.co/senado/basedoc/ley_0769_2002.html.

[6] Semana, Sección Nación, "En Bogotá aumentaron a 16 % las muertes de ciclistas por accidentes," *Semana*, 2016. [Online]. Available: http://www.semana.com/nacion/articulo/bogota-aumentaron-las-muertes-de-ciclistas-por-accidentes/467147. [Accessed: 11-Mar-2018].

[7] M. E. Pico Merchán, R. E. González Pérez, and O. P. Noreña Aristizábal, "Seguridad vial y peatonal: una aproximación teórica desde la política pública," *Hacia la promoción de la salud.*, vol. 16, no. 2, 2011. [Online]. Available: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0121-75772011000200014.

[8] J. I. Nazif, D. Rojas, R. J. S. Álvaro, and V. Espinosa, "Inst rumentos para la toma de decisiones en políticas de seguridad vial en América Latina El Índice de Seguridad de Tránsito (INSETRA) recursos naturales e infraestructura 115 División de Recursos Naturales e Infraestructura". [Online]. Available: https://repositorio.cepal.org/bitstream/handle/11362/6311/S0600581_es.pdf?sequence=1&isAllowed=y.

[9] F. A. Cerquera-Escobar, “Modelo patrón de evaluación de la accidentalidad vial en áreas urbanas de Bogotá (Colombia),” *Carreteras*, vol. 2015, no. 202, pp. 45–62, 2015.

[10] J. Whitelegg, “A Geography of Road Traffic Accidents,” *Trans. Inst. Br. Geogr.*, vol. 12, no. 2, p. 161, 1987. [Online]. doi: 10.2307/622525.

[11] N. Levine, K. E. Kim, and L. H. Nitz, “Spatial analysis of Honolulu motor vehicle crashes: I. Spatial patterns,” *Accid. Anal. Prev.*, vol. 27, no. 5, pp. 663–674, Oct. 1995. [Online]. doi: 10.1016/0001-4575(95)00017-T.

[12] N. Levine, K. E. Kim, and L. H. Nitz, “Spatial analysis of Honolulu motor vehicle crashes: II. Zonal generators,” *Accid. Anal. Prev.*, vol. 27, no. 5, pp. 675–685, Oct. 1995. [Online]. doi: 10.1016/0001-4575(95)00018-U.

[13] D. Lord, S. P. Washington, and J. N. Ivan, “Poisson, Poisson-gamma and zero-inflated regression models of motor vehicle crashes: balancing statistical fit and theory,” *Accid. Anal. Prev.*, vol. 37, no. 1, pp. 35–46, Jan. 2005. [Online]. doi: 10.1016/j.aap.2004.02.004.

[14] J. K. Affum and M. Taylor, “Integrated gis database for road safety management,” 1995. [Online]. Available: https://trid.trb.org/View/464320.

[15] K. Austin, M. Tight, and H. Kirby, “The use of geographical information systems to enhance road safety analysis,” *Transp. Plan. Technol.*, vol. 20, no. 3, pp. 249–266, Mar. 1997. [Online]. doi:10.1080/03081069708717592.

[16] K. Kim and N. Levine, “Using GIS to improve highway safety,” *Comput. Environ. Urban Syst.*, vol. 20, no. 4–5, pp. 289–302, Jul. 1996. [Online]. doi: 10.1016/S0198-9715(96)00022-1.

[17] John S. Miller, “What Value May Geographic Information Systems Add to the Art of Identifying ... - John S. Miller - Google Libros,” *Report VTRC 99-R13*, 1999. [Online]. Available: https://books.google.com.co/books?id=RIifV21Op8sC&pg=PA1&lpg=PA1&dq=What+value+may+geographic+information+systems+add+to+the+art+of+identifying+crash+countermeasures?&source=bl&ots=Mrmm6mR5fK&sig=xLQ-Wf6NkpAD5KcyrFxjZN-EaCg&hl=es&sa=X&ved=0ahUKEwi42fvq--L. [Accessed: 10-Mar-2018].

[18] S. S. Pulugurtha, V. K. Krishnakumar, and S. S. Nambisan, “New methods to identify and rank high pedestrian crash zones: An illustration,” *Accid. Anal. Prev.*, vol. 39, no. 4, pp. 800–811, Jul. 2007. [Online]. doi: 10.1016/J.AAP.2006.12.001.

[19] F. A. Cerquera Escobar (2015) Análisis espacial de la accidentalidad vial urbana: método de investigación con SIG. Universidad Pedagógica y Tecnológica de Colombia, 2015. [Online]. Available: https://www.buscalibre.com.co/libro-analisis-espacial-de-la-accidentalidad-vial-urbana-metodo-de-investigacion-con-sig/9789586602099/p/46874964?gclid=EAIaIQobChMIqZCI3sTl2QIVVFuGCh2ShA2lEAYYASABEgKEpvD_BwE.

[20] P. Greibe, "Accident prediction models for urban roads," *Accid. Anal. Prev.*, vol. 35, no. 2, pp. 273–285, Mar. 2003. [Online]. doi: 10.1016/S0001-4575(02)00005-2.

[21] L. A. B. Jaramillo and L. L. Vélez, "Priorización de zonas geográficas mediante el uso de sistemas de información geográfica: Aplicación a un municipio Colombiano," *Investig. Geográficas*, no. 46, p. ág. 93-112, Dec. 2013. [Online]. doi: 10.5354/IG.V0I46.30285.

[22] D. C. Bocarejo J, "Characterization of Fatal Road Traffic Accidents Using k-Means Clustering: Case Study of Bogotá, Colombia," *Transp. Res. Rec.* no. 11-4026(Session 424), pp. 1–8, 2011. [Online]. Available: https://sur.uniandes.edu.co/index.php/research/publicaciones.

[23] W. Org et al., Ciudades más seguras mediante el diseño. [Online]. Available: http://wrimexico.org/sites/default/files/Cities_Safer_By_Design_Spanish.pdf.

[24] H. Dupree, *Urban transportation : the new town solution*. Gower, 1987.

[25] S.-P. Miaou and H. Lum, "Modeling vehicle accidents and highway geometric design relationships," *Accid. Anal. Prev.*, vol. 25, no. 6, pp. 689–709, Dec. 1993. [Online]. doi: 10.1016/0001-4575(93)90034-T.

[26] S.-P. Miaou, "The relationship between truck accidents and geometric design of road sections: Poisson versus negative binomial regressions," *Accid. Anal. Prev.*, vol. 26, no. 4, pp. 471–482, Aug. 1994. [Online]. doi: 10.1016/0001-4575(94)90038-8.

[27] A. Tripodi, L. Persia, P. Di Mascio, M. V. Corazza, and A. Musso, "A Decision Support System for Analysis of Vulnerable Road Users Safety Issues: Results of the SAFERBRAIN Project," *Procedia - Soc. Behav. Sci.*, vol. 53, pp. 841–850, Oct. 2012. [Online]. doi: 10.1016/J.SBSPRO.2012.09.933.

[28] R. Sims et al. (2011) Innovative guidelines and tools for vulnerable road users safety in India and Brazil [SaferBraIn]: D3.3 Decision Support System functionalities and specifications. [Online]. Available: https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/19151.

[29] C. Martínez Gaete, "5 propuestas de intersecciones más seguras para diversos modos de movilidad | ArchDaily Colombia," *archdaily*, 2016. [Online]. Available: https://www.archdai-

ly.co/co/783659/5-propuestas-de-intersecciones-mas-seguras-para-diversos-modos-de-movilidad#

[30] G. M. Mackay, "Pedestrian and Cyclist Road Accidents," *J. Forensic Sci. Soc.*, vol. 15, no. 1, pp. 7–15, Jan. 1975. [Online]. doi: 10.1016/S0015-7368(75)71019-8.

[31] P. D. Norton, "Street Rivals: Jaywalking and the Invention of the Motor Age Street," *Technol. Cult.*, vol. 48, no. 2, pp. 331–359, 2007. [Online]. doi: 10.1353/tech.2007.0085.

[32] UPCommons (2003) Factores causantes de los accidentes. [Online]. Available: https://upcommons.upc.edu/bitstream/handle/2099.1/6321/06.pdf?sequence=7.

[33] V. . Sisiopiku and D. Akin, "Pedestrian behaviors at and perceptions towards various pedestrian facilities: an examination based on observation and survey data," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 6, no. 4, pp. 249–274, Dec. 2003. [Online]. doi: 10.1016/J.TRF.2003.06.001.

[34] R. Almodfer, S. Xiong, Z. Fang, X. Kong, and S. Zheng, "Quantitative analysis of lane-based pedestrian-vehicle conflict at a non-signalized marked crosswalk," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 42, pp. 468–478, Oct. 2016. [Online]. doi: 10.1016/J.TRF.2015.07.004.

[35] S. A. Bennet and N. Yiannakoulias, "Motor-vehicle collisions involving child pedestrians at intersection and mid-block locations," *Accid. Anal. Prev.*, vol. 78, pp. 94–103, May 2015. [Online]. doi: 10.1016/J.AAP.2015.03.001.

[36] Z. Asadi-Shekari, M. Moeinaddini, and M. Zaly Shah, "Pedestrian safety index for evaluating street facilities in urban areas," *Saf. Sci.*, vol. 74, pp. 1–14, Apr. 2015. [Online]. doi: 10.1016/J.SSCI.2014.11.014.

[37] Y. Zheng, T. Chase, L. Elefteriadou, B. Schroeder, and V. P. Sisiopiku, "Modeling vehicle–pedestrian interactions outside of crosswalks," *Simul. Model. Pract. Theory*, vol. 59, pp. 89–101, Dec. 2015. [Online]. doi: 10.1016/J.SIMPAT.2015.08.005.

[38] Alcaldía Mayor de Bogotá, "Bogotá invita a sus ciudadanos a que aporten sus ideas para mejorar la movilidad de los niños - Secretaría Distrital de Movilidad - simurportal," *Sistema Integrado de Información sobre Movilidad Urbano Regional*, 2016. [Online]. Available: http://www.simur.gov.co/secretaria-distrital-de-movilidad1/-/asset_publisher/7Q43GofwLlxQ/content/bogota-invita-a-sus-ciudadanos-a-que-aporten-sus-ideas-para-mejorar-la-movilidad-de-los-ninos;jsessionid=1ec61c8a0e6438d83d5238fb8f81.

[39] Secretaria Distrital de Movilidad de Bogotá, "Guía global en el diseño de calles y comunidades más seguras," *SDM*, 2014. [Online]. Available: http://www.movilidadbogota.gov.co/hiwebx_archivos/audio_y_video/3. BEN WELLE - PLANIFICADOR URBANO Y DE TRANSPORTE_EMBARQ.pdf. [Accessed: 11-Mar-2018].

[40] R. D. Blomberg, A. Hale, and D. F. Preusser, "Experimental evaluation of alternative conspicuity-enhancement techniques for pedestrians and bicyclists," *J. Safety Res.*, vol. 17, no. 1, pp. 1–12, Mar. 1986. [Online]. doi: 10.1016/0022-4375(86)90002-2.

[41] W. Haddon, P. Valien, J. R. McCarroll, and C. J. Umberger, "A controlled investigation of the characteristics of adult pedestrians fatally injured by motor vehicles in Manhattan," *J. Chronic Dis.*, vol. 14, no. 6, pp. 655–678, Dec. 1961. [Online]. doi: 10.1016/0021-9681(61)90122-9.

[42] Internet Point y Insurance Reduction Progran, "Alcohol y la seguridad de tránsito," *USA Training Company*, 2016. [Online]. Available: https://www.newyorkdefensivedriving.com/course_sample_spanish.html?p=11.

[43] G. P-B., F. G-B. y F. A. Cerquera-Escobar, "Actualización del manual De Auditorías de seguridad vial de Bogotá," *Contrato 20141460. SDM-UPTC.*, 2015.

[44] X. Yang, M. Huan, M. Abdel-Aty, Y. Peng, and Z. Gao, "A hazard-based duration model for analyzing crossing behavior of cyclists and electric bike riders at signalized intersections," *Accid. Anal. Prev.*, vol. 74, pp. 33–41, Jan. 2015. [Online]. doi: 10.1016/J.AAP.2014.10.014.

[45] P. Chen, "Built environment factors in explaining the automobile-involved bicycle crash frequencies: A spatial statistic approach," *Saf. Sci.*, vol. 79, pp. 336–343, Nov. 2015. [Online]. doi: 10.1016/J.SSCI.2015.06.016.

[46] T. Sayed, M. H. Zaki, and J. Autey, "Automated safety diagnosis of vehicle–bicycle interactions using computer vision analysis," *Saf. Sci.*, vol. 59, pp. 163–172, Nov. 2013. [Online]. doi: 10.1016/J.SSCI.2013.05.009.

[47] A. M. Roshandeh, Z. Li, S. Zhang, H. S. Levinson, and X. Lu, "Vehicle and pedestrian safety impacts of signal timing optimization in a dense urban street network," *J. Traffic Transp. Eng.*, vol. 3, no. 1, pp. 16–27, Feb. 2016. [Online]. doi: 10.1016/J.JTTE.2016.01.001.

[48] P. Chen, C. Wu, and S. Zhu, "Interaction between vehicles and pedestrians at uncontrolled mid-block crosswalks," *Saf. Sci.*, vol. 82, pp. 68–76, Feb. 2016. [Online]. doi: 10.1016/J.SSCI.2015.09.016.

[49] J. Aguero-Valverde and P. J., “Bayesian multivariate Poisson lognormal models for crash severity modeling and site ranking,” *trrjournalonline.trb.org*, 2009. [Online]. Available: http://trrjournalonline.trb.org/doi/abs/10.3141/2136-10.

[50] K. Jamroz, M. Budzyński, W. Kustra, L. Michalski, and S. Gaca, “Tools for Road Infrastructure Safety Management – Polish Experiences,” *Transp. Res. Procedia*, vol. 3, pp. 730–739, Jan. 2014. [Online]. doi: 10.1016/J.TRPRO.2014.10.052.

[51] M. G. Mohamed, N. Saunier, L. F. Miranda-Moreno, and S. V. Ukkusuri, “A clustering regression approach: A comprehensive injury severity analysis of pedestrian–vehicle crashes in New York, US and Montreal, Canada,” *Saf. Sci.*, vol. 54, pp. 27–37, Apr. 2013. [Online]. doi: 10.1016/J.SSCI.2012.11.001.

[52] W.R Gilks, S. Richardson, and D.J. Spiegelhalter, D.J. *Markov Chain Monte Carlo in Practice*. Chapman and Hall, London, UK, 1996.