ISSN 1870-4069

Fatal Cyclist-Car Accidents at Intersections: An Analysis from the Guadalajara Metropolitan Area

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Abstract. Faced with the imminent high fatal cyclist-car accident rate in the Guadalajara Metropolitan Area in recent years, it is necessary to implement mechanisms to improve the safety of cyclist mobility. This research analyzes the principal factors and patterns that cause cyclist-car accidents at intersections in the Guadalajara Metropolitan Area through machine learning algorithms and statistical methods. The data show that the most dangerous intersection consists of one main street and a street. As well the type of vehicle most involved in accidents with cyclists is public transport. The analysis shows that factors such as the speed limit and the lack of traffic lights increase the risk on some roads. It was also found that public transport is hazardous in Street-street type orthogonal intersections. Also, private vehicles are the leading cause of accidents in non-orthogonal intersections consists of one main street and a street where one road involved has three or more lanes.

Keywords. Fatal cyclist-car accidents, intersections, sustainable mobility, statistical analysis, artificial intelligence, pattern recognition, smart city.

1 Introduction

One of the premises of a smart city is generating clean and sustainable mobility where the citizens can move in an agile and safe way. Cyclist mobility can be part of one solution in clean mobility improvement. In the Guadalajara Metropolitan Area (GMA), the governmental and academic authorities are working to transform mobility into smart and sustainable mobility. The city of Guadalajara has more than 100km of bike paths [1], the same ones that are growing. Also, the government, academia, and industry are creating mechanisms to promote bicycle mobility; one of them is the IoP (Internet of People) Jalisco [2]. According to the World Health Organization, bikers are part of the most vulnerable sector of the public via [3].

Therefore, bikers have a high possibility to die or suffer serious harm to their health in a traffic accident. There are three different scenarios for cyclist accidents. A single-bicycle accident, when a cyclist falls or crashes with an object [4]. Bicycle-bicycle accidents [5], and cyclist-car accidents [6].

This work focuses on cyclist-car accidents because those are the most reported and dangerous incidents for the cyclist's community [6, 7]. Despite the continuous growth of cycling infrastructure in the GMA, the biker community has many fatal accidents year by year. The average of lost lives was 23 per year from 2009 to 2019 [8].

Furthermore, when it seemed that the accident rate tended to decrease, the year 2019 compared with 2018 presented an increase of 53.8% of deaths [9] (see Fig. 1). This paper reviews the cyclist-car accident literature, emphasizing the intersections of streets and entrances and exits of car parks and shops.

Since, from different cities globally, the crossroads and intersections are the most frequent places for cyclist-car accidents [6] [7] [10], the main driver of this work is to find factors and patterns with a high impact on GMA fatal cyclist-car accidents at intersections.

We propose, based on historical data, identifying possible factors and accident patterns with three goals. First, to help the government decide better how to allocate their resources to improve the overall safety for citizens moving on bicycles. Second, provide simple but valuable information to citizens to increase their awareness of where patterns of accidents are part of their trip. Third, the possibility of deciding where to place internet of things objects in dangerous crossroads to mitigate as accidents as possible.

This work is organized in the following sections: section two discusses the literature found on bicycle accidents in cities, and the different approaches, datasets used, and results.

Section three relates the GMA problem, explains the primary data to use, and proposes an analysis with contingency tables and correspondence and clustering machine learning algorithms to identify the most common incidents. Section four discusses the approach and found results. Finally, section five concludes and presents the following steps on this work.

2 Literature Review

In a study that the UDV (German Insurers Accident Research) realized, 407 cyclist-car accidents were analyzed [6]. The work shows that when the car travels straight ahead or turns left or right, and the bicycle is coming from the right or left, the car's average speed is 19 km/h to 23 km/h. When the bicycle moves in the same direction before the impact, the average speed is 51 km/h. It can seem that accidents in which the cyclist is

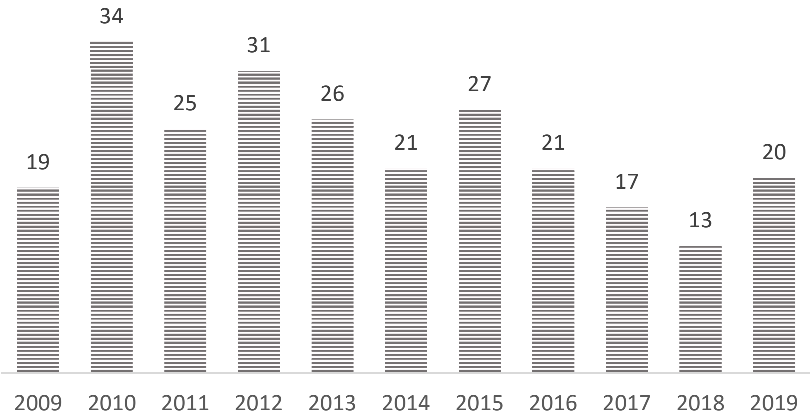

Fig. 1. Death of cyclists on public roads from the year 2009 to 2019 [8].

coming from the right or left usually occur at the entrances or exits of properties or parking lots and intersections of streets.

The accidents were caused for different reasons like vision obstacles or breaking the rules of the road. In Denmark, different bicycle facility layouts in signalized intersections were studied to compare their safety based on 80 hours of video recording for each intersection [11]. The results show that the collision risk is proportional to the traffic intensity. The risk situations occur in the most significant proportion when the driver turns to his right.

The safer layouts increase the distance between the road and the bike path, and car drivers must brake before turning. That situation allows drivers to see the cyclists with more time and a better angle vision. A study analyzed 3350 cyclist-car crashes from New York City to determine the relationship between intersection angle, street width, and accident severity [10]. Approximately 60% of crashes occurred in an intersection, and the rest in a non-intersection part of the street. The intersections with angle orthogonal (85<×<95 grades) are safer than no orthogonal intersections (0<×≤85 or 95≤×<175 grades).

In a no orthogonal intersection, the visual angle is lower, and drivers and cyclists have less time to react and evicted a collision. The streets that have bicycle facilities had more than 50% fewer accidents. Also, the analysis showed that the accidents where a heavy truck or a public transport unit are involved result in a more severe injury compare with small vehicles. Street width was not significant in the severity, but the accidents at night have a significantly higher risk. In the Thomas Richter and Janina Sachs research [12], 873 cyclist-car accidents with turning vehicles and cyclists driving straight ahead were studied.

A third of the accidents correspond to vehicles that turn left, while two parts with a right turn. Three out of every 4 of these accidents occur at intersections with traffic lights. Also, one in 10 turning accidents between vehicles and cyclists happened with the participation of trucks. In the same study with video-recording monitoring, the

Table 1. Structure of database records [8].

variable	class
Sex	M
	F
Type of vehicle	Public transport
	Private car
	Truck
	Unidentified
Age	0-19
	20-39
	40-59
	60+
	Unidentified
Number of lanes per direction	1c
	2c
	3c+
Speed limit	30km/h
	50km/h
	60km/h
	80km/H
Number of directions	1s
	2s
Number of entrances and exits	3e
	4e
	5e+
Cycling infrastructure	Yes
	No
Public transport routes	Yes
	No
Orthogonal intersection	Yes
	No
Roundabout	Yes
	No
Traffic light intersection	Yes
	No
Type of intersection	Main street-main street
	Main street-street
	Street-street

situation that creates most conflicts is when a vehicle starts to drive after the red light, and a cyclist passes through the intersection without stopping. A German Federal Highway Research Institute study analyzed 120 accidents between right-turning trucks and straight driving cyclists [13].

Accidents at crossings and intersections between right-turning trucks and cyclists that move straight are particularly severe if the cyclist is hit and, consequently, overrun. Even though this type of accident is not frequent at intersections, 1 in 10 accidents represents a death.

In this kind of accident, bicycles travel at less than 20 km/h in 80% of accidents, and the trucks travel at less than 30 km/h in 90% of the cases. Bicycles and trucks do not change their speed at the time of the crash. Another study [14] indicates that this type

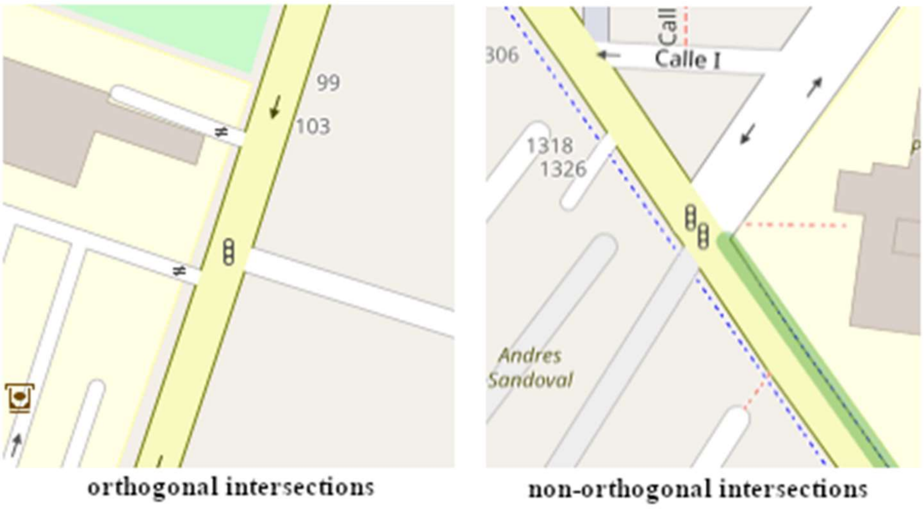

Fig. 2. The intersection is orthogonal when the street angle is between 85 and 95 degrees, and otherwise, the intersection is non-orthogonal. The left side of the figure shows orthogonal intersections, while the right side contains non-orthogonal intersections [9].

of accident occurs mainly at signposted intersections and roundabouts in urban areas. Within urban areas, roundabouts are a type of intersections of particular interest.

For example, a ten-year analysis of reported crashes from 2001 to 2011 in New Zealand showed that cyclists are involved in 28% of roundabout crashes [15]. Furthermore, in an analysis of cyclist risk carried out in Great Britain (2657 individuals were injured at an intersection), roundabouts are the type of intercession with the highest risk index [16]. The factors with the most significant impact on risk in roundabouts were vehicle speed and the streets' width and importance. Also, in a study carried out in the cities of Vancouver and Toronto, where 211 crashes between motorized vehicles and bicycles were analyzed, it confirmed that roundabouts are the type of intersection with the highest risk [17].

In this work, the relevant variables were: the speed of motorized vehicles (more than 30 km/h the risk increases), traffic flow (the more significant the flow of traffic of both vehicles and cyclists increases the risk), the diameter of roundabouts (the smaller the diameter, the greater the risk), the cycling infrastructure (obstacles that separate cyclists from vehicles reduce the chance) and the downward slope of the street on which the driver reaches the intersection.

Finally, an analysis carried out on accidents from 2004 to 2016 about roundabouts in Russia found that the number of exits from a roundabout is highly relevant to the probability that a cyclist suffers an accident with a motorized vehicle [18]. That situation is explained by a higher concentration of conflict points and a relationship with an unfavorable geometry, especially in small roundabouts.

The most common high-risk behavior among bicyclists and motor vehicle drivers at intersections is to ignore red lights or stop signs.

Indeed, cyclists tend to invade other public road areas such as the pedestrian zone to prioritize crossing and thus avoid the red light [19].

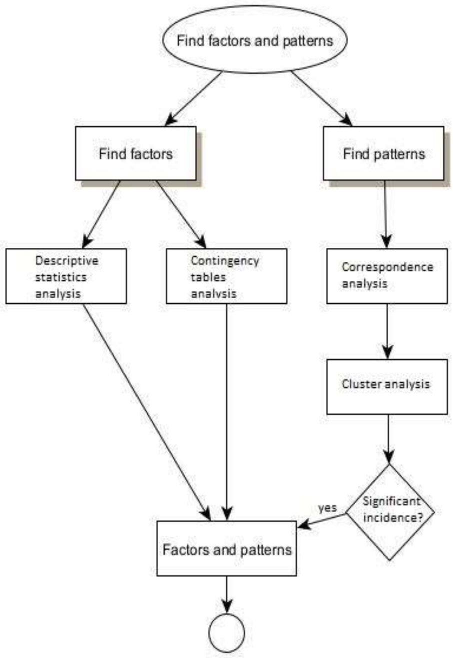

Fig. 2. Diagram of the methodology.

3 Fatal Cyclist-Car Accidents at Intersections Analysis from the Guadalajara Metropolitan Area

From January 2009 to Jun 2021, the White Bicycle organization registered 274 deaths of cyclists in the Guadalajara Metropolitan Area [8]. Two hundred thirty-nine records were identified as a cyclist-car accident, six as falls, two collisions with objects, and 27 where the cause is unknown.

Of the 239 fatal cyclist-car accidents, 56 occurred on a stretch without intersections, five times the location was not identified, and 179 at an intersection. For the analysis, 179 cyclist-car accidents at intersections were used.

The Fatal cyclist-car accidents database initially contains the variables of Sex, Type of road, Age, Type of vehicle, and Location of the accident site.

Then, to obtain the most significant number of variables found in the literature review, the street view of Google maps and the map of the Moovit platform were used for each location. With these tools, the variables Number of lanes per direction, Speed limit and Number of directions of the most significant road involved, and the Number of entrances and exits in each intersection were added.

In addition, the binary variables of the Presence of cycling infrastructure, Presence of public transport routes, Orthogonal intersection (Fig. 2 explains orthogonal intercessions), Roundabout, and Traffic light intersection were also added.

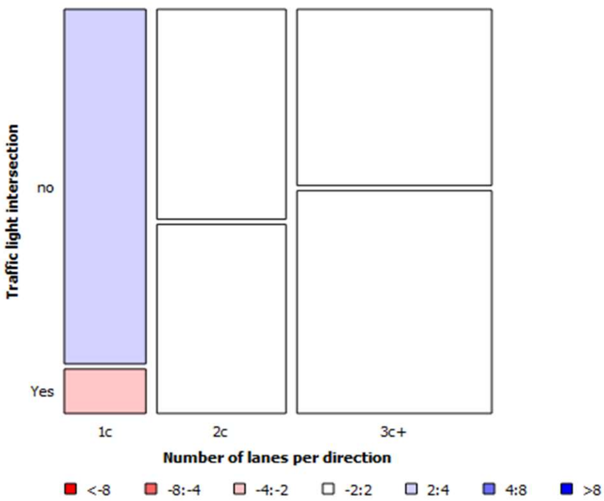

Fig. 3. The blue mosaic shows that there were more accidents than expected between classes no and 1c, while the pink mosaic shows that fewer accidents than expected were found between the same classes. The relationship of these three classes can show that traffic lights influence the number of accidents on one-lane streets per direction.

Finally, the variable Type of road that describes only one road involved in the intersection was modified to express two roads and was called "Type of intersection." Table 1 shows the structure of the database records.

3.1 Methodology

In order to find factors and patterns, the data analysis includes four different techniques. First, a descriptive statistical analysis highlights the main characteristics of fatal accidents at intersections from the GMA. Then a contingency table with Pearson's standardized residual calculation analysis is performed to find relations between the different classes of each combination of two variables. Descriptive statistics analysis and the relationships found in the contingency tables can reveal essential factors of the GMA accidents between cyclists and motorized vehicles.

In the contingency tables, if a class is present in a greater or lesser quantity than expected, it may be a triggering factor in accidents. For example, suppose in the contingency table between the variables Speed limit and Number of lanes per direction, there are more accidents than expected in the 80 k/m class. In that case, this may mean that the speed limit is a factor that affects the occurrence of fatal accidents with cyclists. In the end, correspondence analysis and a clustering algorithm are executed to identify associations between factors.

With correspondence analysis, it is possible to identify strong associations between classes. Subsequently, the presence of said associations in the centroids of the clusters is sought to formulate possible patterns.

To recognize an association of factors as a pattern, this association must show the presence of a phenomenon. Once defining an association of different classes as a

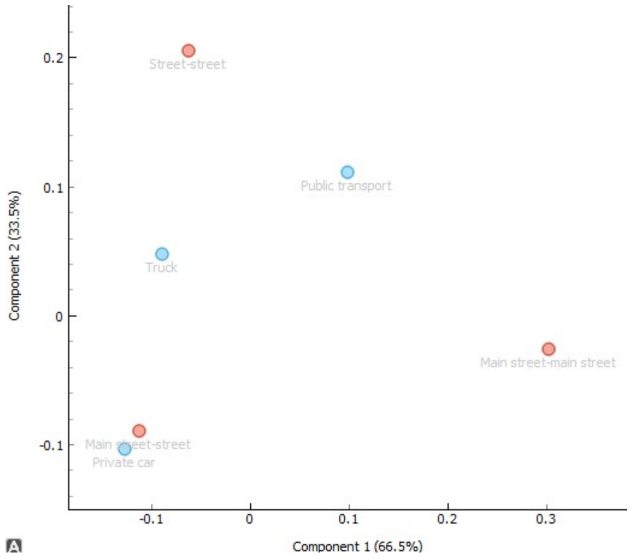

Fig. 4. Correspondence analysis between the Type of vehicle and Type of intersection variables. The red points represent the classes of the variable Type of intersection, and the blue points the classes of the variable Type of vehicle. In the figure, it is possible to see the closeness between the class's Private vehicle and the Main street-street type intersection.

Table 2. Centroids of the variables that present variation in the simple K-means of 2 clusters.

Attribute	Cluster 0	Cluster 1
Number of records	119	60
Type of vehicle	Private car	Public transport
Number of lanes per direction	3c+	1c
Orthogonal intersection	No	Yes
Traffic light intersection	Yes	No
Type of intersection	Main street- street	Street-street

pattern, it is corroborated that the pattern found has at least a 20% higher incidence than any other combination of classes of the variables involved. For example, suppose it is found that Public transport is mainly dangerous in intersections type Main street-street without-traffic light.

In that case, it must be verified that the number of accidents of this combination is at least 20% greater than that of a Private car or a Truck in the Main street-street without-traffic lights type of intersection. The above is in order to find patterns with significant incidence. Fig. 2 shows the process of the methodology.

3.2 Descriptive Statistics Analysis

The descriptive statistics analysis observed that 163 (91.06%) victims are male, and 16 (8.94%) are female [8]. In contrast to what was mentioned in [15, 16, 17], roundabouts

Table 3. Centroids of the variables that present variation in the simple K-means of 3 clusters.

Attribute	**Cluster 0**	**Cluster 1**	**Cluster 2**
Number of records	86	34	59
Type of vehicle	Public transport	Public transport	Private car
Number of lanes per direction	3c+	1c	3c+
Orthogonal intersection	Yes	Yes	No
Traffic light intersection	Yes	No	No
Entrances and exits	4e	4e	3e
Type of intersection	Main street-street	Street-street	Main street- street

are not the most dangerous type of intersection speaking about fatal cyclist-car accidents for the GMA. Because of the 179 incidents, only 7, equivalent to 3.91%, occurred in a roundabout. Furthermore, it was found that, in contrast to [18], increasing the number of entrances and exits from an intersection does not increase the risk of a fatal cyclist-car accident.

The predominant number of entrances and exits at intersections was 4 with an occurrence of 56.42%, followed by 3 with 39.66%, intersections with five or more entrances and exits had an event of 3.91%. On the other hand, it cannot assure that the existence of cycle lanes reduces the number of accidents, as mentioned in [12]. However, the records show that 91.06% of fatal accidents occurred at intersections without bicycle infrastructure.

As mentioned in [10], fatal accidents involving public transport and trucks are more frequent than accidents with small vehicles for the GMA. Accidents with public transport and trucks represent 56.43%.

Thus, public transport is the enemy number one for cyclists with 42.46% of incidents, followed by private cars with 40.78%. Similar to that mentioned in [16], the importance of the streets is of great impact since only 25.14% of the recorded intersections do not contain main roads.

The most common intersection consists of one main street and a street, present in 50.84% of the occasions. In addition, 99% of the intersections with at least one main street have public transport routes, and 98% are two-way traffic. Also, the number of lanes per street increases according to the importance of the streets in the intersection. It is detected that cyclists between the ages of 20 and 39 are most vulnerable to fatal accidents.

3.3 Contingency Tables Analysis

Contingency tables with Pearson's standardized residual calculation were used to identify the events that occur to a greater or lesser extent than expected. A relationship between two classes can show a causal factor in the increase or decrease of accidents, while a relationship of more than two classes of two variables can reflect the existence of a causal phenomenon.

The following deviations were found in the contingency table for each combination of two variables Using Orange software [20]. With a standardized Pearson residual of 3.3, 11.9 more accidents than expected were found in intersections where one street has a speed limit of 80 k/h and three or more lanes per direction. With a Pearson standardized residual of -3.0, 11.9 fewer accidents than expected were found at intersections with traffic lights where the streets have one lane per direction.

Otherwise, with a standardized Pearson residual of 2.7, 12.1 more accidents than expected were found in intersections without traffic lights where the streets have one lane per direction (see figure 3). With a standardized Pearson residual of 8.0, 23.9 more accidents were found than expected in the type of intersection Street-street of one lane per direction.

With a standardized Pearson residual of 3.2, 6.5 more accidents than expected were found in the type of intersection Main street-main street, where the arteries' speed limit is 80 k/m. With a standardized Pearson residual of 6.3, 15.7 more accidents than expected were found in the type of intersection Street-street where the streets are one way.

3.4 Correspondence Analysis

For principal component analysis, the unsupervised visual correspondence analysis of Orange software was used. Correspondence analysis shows the existence of a relationship between classes of two or more variables. The relationship is represented in the form of visual proximity with coordinates of the cartesian plane.

As a result, the following most significant proximity between classes is observed: Private car of the Type of vehicle variable and 3e of the Number of entrances and exits variable; Public transport of the Type of vehicle variable and 4e of the Number of entrances and exits variable; Private car of the variable Type of vehicle and Main street-street of the variable Type of intersection (see in figure 4); 2c of the variable Number of lanes and Yes of the variable Presence of public transport routes; 1c and 2c of the variable Number of lanes with Yes of the variable Orthogonal intersection; 3c+ of the variable Number of lanes with No of the variable Orthogonal intersection; Yes of the variable Presence of public transport routes with 2s of the variable Number of directions; Yes of the variable Orthogonal intersection with 4e of the Number of entrances and exits variable; No of the variable Orthogonal intersection with 3e of the Number of entrances and exits variable.

3.5 Cluster Analysis

Finally, a couple of grouping was made with the simple k-means unsupervised algorithm of the Weka software. It was chosen to work with 2 and 3 clusters since most of the variables involved are nominal categorical of two or three classes. With this, it was possible to observe how the factors of each variable are distributed and associated in the centroids of the clusters. Statistical results of the distribution and centroids of the variables with variation are shown in Tables 2 and 3.

4 Results and Discussion

Based on the descriptive statistics analysis, the analysis with contingency tables, the correlational analysis, and the cluster analysis, the following patterns and principal factors could be found:

1. The closeness in the correspondence analysis between the classes Private car and the Main street-street, three or more lanes with non-orthogonal and the presence of these four classes as centroids in cluster 0 of the grouping in two clusters and cluster 2 of the grouping in 3 clusters indicate that: in the type of intersection Main street-street non-orthogonal where a road has three or more lanes per direction, the private car is the main one causing fatal accidents with cyclists.
2. In the grouping in 2 and 3 clusters, the classes' Public transport, Orthogonal intersection, type of intersection Street-street, and one lane per direction are centroids of a cluster for each grouping. In addition, in the correspondence analysis, the class two lanes and the presence of public transport show closeness, which indicates that: Public transportation is the most dangerous vehicle for cyclists who circulate at orthogonal Street-street intersections with one and two lanes per direction.
3. By finding more accidents than expected in intersections with one-lane streets without traffic lights and fewer accidents than expected in intersections with one-lane streets with traffic lights, and the presence of classes one lane and intersection without traffic lights as centroids in clusters 1 of the grouping in two clusters and cluster 1 in the grouping in 3 clusters indicates that: The presence of traffic lights at intersections where the streets have one lane per direction reduces the risk of a fatal accident when riding a bicycle.
4. More accidents than expected were found in Main street-main street intersections and roads with three or more lanes with a speed limit of 80 km/h.. Thus, the above tells us that intersections type Main street-main street and the intersections where at least one road has three o more lanes are more dangerous at a speed limit of 80 k/h.
5. The high incidence of 3 and 4 entrances and exits could explain drivers do not reduce their speed at intersections with few points of conflict, an event that, on the contrary, occur in roundabouts. Therefore, although roundabouts have a high number of conflict points, they have little presence of fatal cyclist-car accidents.

5 Concluding Remarks and Future Work

The descriptive statistics analysis shows that the type of intersection with the highest risk of a fatal accident is formed by one main street and a street. Public transport is the kind of vehicle most involved in fatal accidents with cyclists.

Also, the following patterns could be found: in the intersection main street-street non-orthogonal where a road has three or more lanes per direction the private vehicle is the main one causing fatal accidents with cyclists; public transportation shows to be a vehicle hazardous for cyclists who circulate at street-street orthogonal intersections with one and two lanes per direction; the presence of traffic lights at intersections where the streets have one lane per direction reduces the risk of a fatal accident when riding a bicycle; roads with a higher speed limit increase the risk of a cyclist-car fatal accident at intersection type main street-main street and the intersections where at least one road has three o more lanes.

In future work, the analysis will be extended to include variables such as the traffic index and the flow of cyclists and include new techniques such as the market basket analysis. In addition, it will seek to classify the intersections of a polygon in the GMA based on the risk of suffering a fatal cyclist-car accident.

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