Application of the HSM predictive method at four-leg signalized intersections. Case study: Lima, Peru.

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Abstract-The Highway Safety Manual (HSM) recommends the predictive method to characterize intersections quantitatively in terms of the number of accidents that may occur. The time period, geometric design, type of traffic control and traffic volumes are used as variables. Considering that the predictive model was originally developed with information from the United States road network, a local calibration factor is needed to adjust the results to the reality of each country. In Peru, road traffic accidents are one of the most critical problems affecting society. More than 80,000 traffic accidents have been registered every year since 2010. Of these events, 70% occur in the Metropolitan area of Lima and 34.9% of these are reported at intersections. This considerable proportion is logical because this type of infrastructure generates the highest number of conflict points between vehicles and pedestrians. Hence, this article proposes the predictive method as a tool to improve road safety management and to make the best decisions in order to reduce the frequency and severity of traffic accidents. For this purpose, the predictive method was applied to 2 four-leg signalized intersections located in one of the main roads of Lima; both of them presents a high traffic volume of vehicles, passengers and pedestrians. Once applied the predictive method, a calibration factor of 0.841 was obtained. The result shows a dispersion of 15.89% compared to the accidents observed at the intersections within the study area. The calibration factor allowed us to adjust the HSM predictive method to a Peruvian reality. With this information, road safety strategies can be formulated to reduce the traffic accident rate at signalized intersections.

I. Introduction

According to the World Health Organization (WHO), each year, road traffic crashes cause approximately 1.3 million fatalities worldwide. It is also stated that 93% of road traffic deaths occur in low- and middle-income countries [1]. In Peru, more than 80,000 accidents have been reported every year since 2010 [2]. In addition to this, Provias Nacional, a Peruvian entity from the ministry of transport and communications, affirms that the fatality rate in Peru is 27 deaths per 10,000 vehicles. This value is currently 15 times higher than the statistics reported by more developed countries. Clearly, these indicators show that road traffic crashes cost Peru around US$ 350 million each year [3].

The public authorities in charge of managing road infrastructure in Peru: The Ministry of Transport and Communications, Regional Governments and Local Governments do not have a standard method to facilitate the management of road safety in the different stages of road infrastructure projects. The lack of monetary funds and technical knowledge from governmental entities turns the construction and evaluation of road safety models really difficult to be developed in the entire country, but possible in specific areas since it requires a lot of information, time for data processing and the use of specialized statistical tools [4].

The HSM 2010 provides a series of steps to improve road safety management. Through this methodology, it is possible to: identify locations with high accident rates, analyze current road safety and simulate a series of countermeasures in order to reduce the number and severity of accidents. It is also possible to perform a cost-benefit analysis that helps in the making decision process. It is essential for this methodology to have an exhaustive and quality database for a specific period of time. This database should incorporate vehicular and pedestrian volumes, road geometry, traffic control devices, number of accidents and other relevant information related to the study area [5]. For this reason, the present article aims to apply the HSM predictive method to a case of study in order to obtain the Calibration Factor for a Peruvian road Network in further analysis.

The study area of this research is located in one of the most important and extensive roads of Lima Metropolitan area: Javier Prado Avenue, which has an extension of approximately 20 km (12.43 mi). This avenue has an Annual Average Daily Traffic (AADT) of 58,498 vehicles per day (veh/day), a heavy traffic of both pedestrians and passengers of the public transportation system, and problems of vehicular congestion [6]. The importance of the study area is due to the fact that 70% of crashes in Peru occur in Metropolitan Lima area and 34.5% of these are reported at intersections [7]. This is due to the numerous conflict points generated in this type of infrastructure, caused by the trajectories performed by vehicles, pedestrian and cyclists within the intersection.

II. State Of The Art

Since the publication of the HSM in 2010, the predictive method has been investigated in the United States and worldwide. In the article "Calibration of Highway Safety Manual Predictive Methods for 4-Leg Signalized Intersections at Urban and Suburban Areas in Kansas" [8], the HSM predictive method was applied considering a total of 198 intersections and accident information from 2013 to 2015. Based on the previous information, a calibration factor of 1.174 was estimated, which means that the method underestimates the number of accidents occurring in that locality.

Furthermore, the article " Missouri-Specific Crash Prediction Model for Signalized Intersections"[9] used the crash

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prediction methodology by calibrating 2 statistical models: the first one applied the Safety Performance Functions (SPFs) provided by the HSM and the second one developed specific applicable SPFs for the Missouri locality. For this purpose, data was collected from 601 four-leg signalized intersections. The calibration factor of the HSM model was 3.98, indicating a disproportionate difference between the observed crashes at the intersections and the crash frequency calculated using the HSM models. The authors considered for research the development of models specific to the state of Missouri. The local model considered variables such as AADT, speed limit, type of traffic control, exclusive left-turn lanes, exclusive right-turn lanes, right turns on red, number of bus stops, number of schools and alcohol outlets located within a 300-meter radius from the center of the intersection. Finally, the results demonstrated the accuracy of the model developed for Missouri.

In the article "Methodology for the application of predictive method for road safety analysis in urban areas. The case study of Brescia" [10] the predictive method was applied in European cities. A four-leg signalized intersection and two road segments were used as a case study. The parameters of the HSM predictive method were minimally modified according to the specific conditions and data availability. However, in this research, no specific SPFs were developed for the Brescia locality, but those recommended by the HSM were used. The results demonstrated a minor deviation between the data of accidents occurred and the number of accidents estimated by the predictive method. Despite this, the authors recognized that this methodology is an extremely powerful and beneficial tool for the prevention of traffic accidents. Indeed, they consider it is more convenient for road authorities to perform calibrations of the original model and its coefficients than to develop new statistical models for the local condition.

In the article "Development of an accident prediction model for Italian freeways" [11], specific SPFs were developed to estimate the frequency of accidents on freeway segments belonging to the Italian road network. The SPFs were based on AADT and segment length. These models were adjusted by Accident Modification Factors (AMFs), which adapted the specific conditions of each segment to the same conditions used to develop the SPFs. The variables of the AMFs were road segment length, radius and horizontal curve length, lane width, vehicle volumes, among others. Then, the model adjustment was performed through the calibration factor Ci. This factor was obtained by dividing the observed accidents by the number of accidents calculated through the predictive method. The calculation of this factor was important because it allowed to observe the variability that exists in the frequency of accidents at different locations. These variations may depend on climate, driver population, trip purpose, geometric design, driver behavior, vehicle characteristics, number of accidents that are not reported, and accident reporting procedures. The authors concluded that the prediction models represent a solid and reliable tool for professionals to estimate accidents along the Italian freeway network.

III. METHODOLOGY

The procedure for applying the predictive method and calculating the calibration factor for four-leg signalized intersections is described in Figure 1.

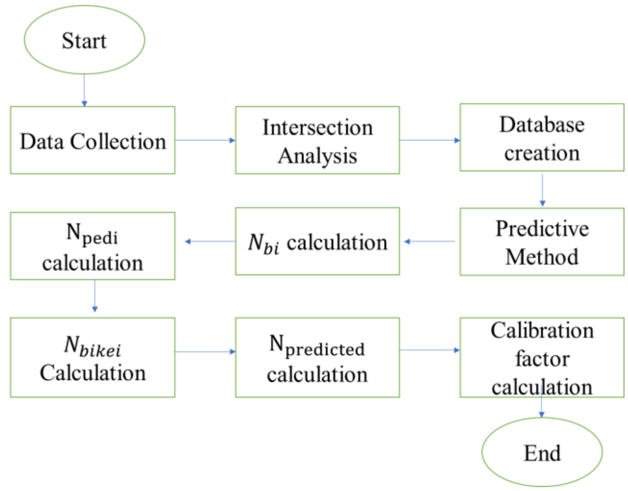

Fig.1 Methodology Flow Chart.

A. Data Collection

Firstly, it is necessary to collect specific information about the intersections in study within a minimum period of 3 years. Two four-leg signalized intersections were studied. The first is the intersection between Javier Prado Avenue and Palmeras Street. The second one is the intersection between Javier Prado Avenue and Arenales Avenue. Table I details the input information needed to apply the predictive method.

TABLE I
INPUT INFORMATION NEEDED TO APPLY THE PREDICTIVE METHOD

Required information
AADT major road (veh/day)
AADT minor road (veh/day)
Number of approaches with left-turn lanes
Number of approaches with right-turn lanes
Number of approaches with left-turn signal phasing
Number of approaches with right-turn-on-red prohibited
Intersection red light cameras
Sum of all pedestrian crossing volumes
Maximum number of lanes crossed by a pedestrian
Number of bus stops within 1000 ft (300 m)
Schools within 1000 ft (300 m)
Number of alcohol sales establishments within 1000 ft (300 m)

The data was collected with the support of different institutions. One of them is the Transportation Department of Lima, which provided information about the vehicle and pedestrian traffic volumes. The National Police Department of Peru (PNP), institution that reports traffic accidents, provided data on the accidents that occurred at the intersections under analysis. It was also required the number of bus stops, schools and liquor stores . This information was gathered during the field visit in August 2020. A radius of action of 1000 ft (300 m) around each intersection in the study area was considered for the analysis.

On the other hand, during the site visit the operational characteristic of each intersection was evaluated. Right turns, left turns, phases allowed in the traffic light, and right turns on red were observed.

B. Intersection Analysis

This section considered the geometric characteristics of the intersections, the current physical conditions, and the presence of roadway elements such as traffic sign and the presence of bus stops, schools, and liquor stores. Based on this, permitted intersection movements, intersection conflict points and possible causes of traffic accidents were identified. Figure 3 shows the permitted movements of intersection 1.

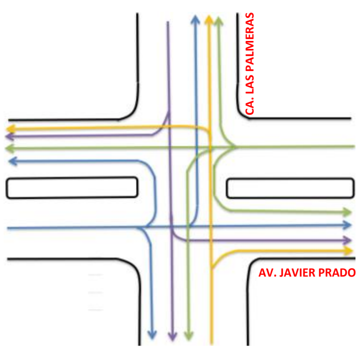

Fig. 3 Permitted movements of intersection 1.

In order to understand the distribution and severity of accidents at intersections, statistical graphics were made of the occurrence of accidents and were classified into subtypes such as: crashes, run-over accidents, rollovers, run-offs, passengers falling down from bus, and special accidents. Special accidents are those events that are atypical and are not included in the classification. Passengers falling down from bus refers to the case when passengers get in or off the bus but got injured because the bus starts to move while it occurs.

C. Database creation

With all the information collected, an Excel database was created in order to depurate possible erroneous information. The required information was filtered from the accident data and duplicate data was eliminated considering the number that identifies each report.

D. Predictive Method

Equation 1 shows the general formula of the predictive method. The predicted number of accidents $N_{predicted}$ consists of the sum of Safety Performance Functions, which are equations developed by the HSM. These equations are related to the type of collision: vehicle-vehicle N_{bi} , vehicle-pedestrian N_{pedi} and vehicle-cyclist N_{bikei}. In addition, each function considers specific Accident Modification Factors (AMFs) to each type of accident, whose values are obtained from equations or tables of the HSM. The AMFs adjust the calculation of the average accident frequency by increasing or decreasing the final result according to the particularities of each intersection. Finally, the method presents a Calibration Factor (Ci) that adjusts the results to the real behavior of each intersection. For the estimation of the Ci, only the traffic accidents formally reported were considered.

$$N_{previsto} = (N_{bi} + N_{pedi} + N_{bikei}) \times C_i \tag{1}$$

$$N_{bi} = N_{SPF} \times (FMA_1 \times FMA_2 \times FMA_3 \times FMA_4 \times FMA_5 \times FMA_6) \tag{2}$$

E. N_{bi} calculation

The N_{bi} indicates the average frequency of traffic accidents that do not include pedestrian or cyclists. As shown in equation 2, it is composed by seven terms. The first one refers to the accident prediction determined by theN_{SPF} and the remaining 6 to the AMFs that reflect the specific conditions of each study intersection.

The N_{SPF} for four-leg signalized intersections is calculated by an equation using the AADT of the main roadway and the secondary roadway of the intersection. It considers single and multi-vehicle crashes. There are 6 AMFs that adjust the N_{bi}:

- *AMF1-Intersection Left-Turn Lanes*

It considers the number of approaches with left turn lanes. Table II shows the values proposed by the HSM for signalized intersections depending on the number of approaches with left turn lanes. Here we can observe that the more accesses have left turns, the lower the coefficient value is consider.

TABLE II
INSTALLATION OF LEFT-TURN LANES ON INTERSECTION APPROACHES

Intersection type	Intersection traffic control	Number of approaches with left-turns			
		1	2	3	4
Four-leg intersections	Traffic signal	0.90	0.81	0.73	0.66

In intersection 1 there are 4 left turn lanes, while in intersection 2 there is only 1. The values obtained are 0.66 and 0.90 for intersections 1 and 2 respectively.

- *AMF 2- Intersection Left-Turn Signal Phasing*

This factor considers the types of left-turn signal phasing. For permissive left-turns, the AMF is 1.00. For protected left-turns the AMF is 0.94 and for protected/permissive and permissive/protected left-turns the AMF is 0.99. For a protected left turn, the FMA value is lower, since there are no vehicles traveling in the opposite direction that could generate any type of conflict.

- *AMF 3- Intersection Right-Turn Lanes*

The number of approaches with right turn lanes determines the AMF values. When no approach has no right turn lanes, the AMF=1.00. The HSM establishes that for 1 approach the value is 0.96, for 2 approaches the coefficient is 0.92, for 3 approaches the value is 0.96 and for 4 approaches the coefficient is 0.85. In the investigation the intersections have 4 and 3 approaches with right turns.

- *AMF 4- Right Turn on Red*

The presence of right turn on red at intersection approaches is a base condition of the HSM methodology that generates an AMF=1.00. If the intersection has no such right-turn approaches during the red interval, the AMF can be calculated from Equation 3.

$$\mathrm{AMF}_4 = (0.98)^{n\ prohib} \tag{3}$$

For the intersections analyzed, there is no right turn allowed during the red interval at any of the four approaches. Considering this condition, the factor values were 0.922 for both intersections.

- *AMF 5- Lighting*

This factor addresses the absence of lighting at an intersection in evaluating road safety. For a base condition with no lighting, an FMA = 1.00 is considered. For intersections with lighting, equation 4 is used.

$$AMF = 1 - 0.38 \times p_{ni} \tag{4}$$

Where the value of p_{ni} is the proportion of accidents occurring during the night. This value was found in Table III. For both signalized intersections a value of 0.9107 is obtained.

TABLE III
NIGHTTIME CRASH PROPORTIONS FOR UNLIGHTED INTERSECTIONS

Intersection type	Proportion of crashes that occur at night p_{ni}
3SG and 4SG	0.235

- *FMA 6-Red Light Cameras*

This factor includes the presence of cameras that automatically detect vehicles that do not respect the red interval of the traffic light. In the study area there is no such traffic control device at any of the intersections. Thus, it is considered an AMF=1.

Finally, the number of accidents generated by the $\mathrm{N_{SPF}}$ is multiplied by each of the AMFs. From this calculation, a value of 8.76 accidents was obtained for intersection 1 and 12.49 accidents for intersection 2.

F. N_{pedi} calculation

The $\mathrm{N_{pedi}}$ relates the accidents that can occur in the vehicle-pedestrian interaction. It is possible to calculate its values, using equation 5. The $\mathrm{N_{pedbase}}$ is calculated through formulas established by negative binomial regressions of the HSM according to the IMDA of the intersection, the pedestrian volume and the number of lanes crossed by pedestrians.

$$\mathrm{N_{pedi}} = \mathrm{N_{pedbase}} \times \mathrm{FMA_1} \times \mathrm{FMA_2} \times \mathrm{FMA_3} \tag{5}$$

The AMFs involving the $\mathrm{N_{pedbase}}$ are related to the type of facilities next to the intersection. These can be classified into:

- *Bus Stops*

This factor considers the number of public transportation stops located within 300 meters of the center of the intersection. The base condition is AMF=1.00 when there are no stops. Since both intersections have 2 bus stops, it is recommended to use the AMF from Table IV. Thus, the AMF for both intersections is 2.78.

TABLE IV
ACCIDENT MODIFICATION FACTOR (AMF1P) FOR THE PRESENCE OF BUS STOPS NEAR THE INTERSECTION

Number of bus stops within 1,000 ft of the intersection	AMF
1 a 2	2.78

- *Schools*

It is important to evaluate the presence of schools within 1000 ft (300 meters) of the intersection. For the base condition the HSM considers an FMA=1.00 when there are no schools near the study area. However, the HSM establishes a value of 1.35 when there are schools nearby at intersections.

- *Alcohol Sales Establishments*

This evaluates the presence of establishments such as liquor stores, bars, restaurants, grocery stores, etc. The base condition is the absence of alcohol sales establishments near the intersection within a radius of 300 meters, that is, AMF=1.00. The available values are expressed in Table V.

TABLE V
ACCIDENT MODIFICATION FACTOR FOR THE NUMBER OF ALCOHOL SALES ESTABLISHMENTS NEAR THE INTERSECTION

Number of alcohol sales establishments within 1,000-ft of the intersection	AMF
1 a 8	1.12

Since there are 4 and 6 alcohol sales centers for intersections 1 and 2 respectively, the value of 1.12 proposed by the Manual is considered. Finally, an average frequency of vehicle-pedestrian accidents of 2.02 and 3.46 is obtained for intersections 1 and 2, respectively.

G. N_{bikei} Calculation

The number of collisions occurred in the vehicle-cyclist interaction can be estimated through equation 6. It is composed of the $\mathrm{N_{bi}}$ and an adjustment factor for bicycle accidents $\mathrm{f_{bikei}}$. The value recommended by the HSM is 0.015. Applying equation 6, the values of 0.14 and 0.20 are obtained for intersections 1 and 2 respectively.

$$\mathrm{N_{bike}} = \mathrm{N_{bi}} \times \mathrm{f_{bikei}} \tag{6}$$

G. $N_{predicted}$ calculation

The $\mathrm{N_{predicted}}$ is the result of the predictive method after applying the general formula for signalized intersections. For the first simulation a calibration factor Ci=1.00 is considered. Subsequently, it is recalculated using the observed traffic accident data.

I. Calibration factor calculation

Once the average frequency of traffic accidents has been calculated for the intersections over a 3-year period, the calibration factor is calculated. Therefore, the number of traffic accidents reported by the police stations is divided by the number of accidents estimated by the predictive method. This process is detailed in equation 7.

$$\mathrm{C_i} = \left(\frac{\sum_{\mathrm{total}} \mathrm{N_{observed}}}{\sum_{\mathrm{total}} \mathrm{N_{predicted}}}\right) \tag{7}$$

IV. RESULTS

The present study covers a three-year analysis period (2017-2019). Table VI details the frequency of accident subtypes reported at both intersections. It is evident that the most reported accidents at both intersections 1 and 2 are crashes with 43.75% and 76.92% respectively.

TABLE VI
FREQUENCY OF ACCIDENT SUBTYPES REPORTED ON STUDY INTERSECTIONS

Accident Subtypes	Intersection 1		Intersection 2	
		%	Conteo	%
Run Over	4	25.00%	2	3.85%
Crashes	7	43.75%	40	76.92%
Run-Offs	2	12.50%	3	5.77%
Specials	1	6.25%	2	3.85%
Roll-Over	1	6.25%	1	1.92%
Passenger fall from bus	1	6.25%	4	7.69%
Total	16	100%	52	100%

The combined $\mathrm{N_{bi}}$ is the multiplication of the 6 MFAs involving vehicle-to-vehicle crashes. The combined AMF from $\mathrm{N_{pedi}}$ is obtained from the multiplication of the AMFs for vehicle-pedestrian interaction crashes. Table VII summarizes the Accident Modification Factors used at the two intersections.

TABLA VII
ACCIDENT MODIFICATION FACTORS USED IN THE PREDICTIVE METHOD

Accident Modification Factors	Variable	Intersections	
		1	2
Intersection Left-Turn Lanes	FMA_{1i}	0.66	0.90
Intersection Left-Turn Signal Phasing	FMA_{2i}	1.00	1.00
Intersection Right-Turn Lanes	FMA_{3i}	0.85	0.92
Right Turn on Red	FMA_{4i}	0.92	0.92
Lighting	FMA_{5i}	0.91	0.91
Red Light Cameras	FMA_{6i}	1.00	1.00
AMF combined $\mathrm{N_{bi}}$	$FMA_{\mathrm{combb}i}$	0.471	0.695
Bus Stops	FMA_{1p}	2.78	2.78
Schools	FMA_{2p}	1.35	1.35
Alcohol Sales Establishments (Liquor Stores)	FMA_{3p}	1.12	1.12
AMF combined $\mathrm{N_{pedi}}$	FMA_{combpedi}	4.203	4.203

The HSM method contemplates certain characteristics of the study intersections, but there are other factors that are not considered in this methodology that can contribute to the generation of accidents. For example, the U-turns at intersection 1 generate a greater number of conflict points between pedestrians and vehicles. In total, it was possible to estimate the occurrence of 10.82 accidents for intersection 1 and 16.13 accidents for intersection 2 during 2019 as shown in Table VIII.

TABLA VIII
SUMMARY OF THE PREDICTIVE METHOD APPLIED IN 2019

Intersection	N bi	N pedi	N bike	Total
1	8.67	2.02	0.13	10.82
2	12.49	3.46	0.19	16.13

It was also possible to estimate the number of accidents that occurred in 2017 and 2018 using 2019 vehicle volumes. The HSM recommends performing this type of calculation when there is insufficient data to perform the analysis. The results obtained are detailed in Table IX.

TABLE IX
PREDICTIVE METHOD RESULTS FOR THE YEARS 2017-2019

Intersection	$N_{observed}$	$N_{predicted}$	Ci
1	16	32.46	0.493
2	52	48.39	1.075
Total	68	80.85	0.841

After applying Equation 7, a ratio of observed accidents over the expected number of accidents is calculated. With this ratio, the calibration factor is obtained for the 2017-2019 period for four signalized intersections. A Ci value of 0.493 was calculated for intersection 1 and 1.075 for intersection 2. This difference evidences the possible traffic accidents that have not been reported in a proper manner, the behavior of the road users, the characteristics of the vehicle population, among others. From the total number of accidents, a Ci value of 0.784 was calculated for both signalized intersections, which can be used for future local research.

V. CONCLUSIONS

The values of the combined AMFs with the N_{bi} at intersections 1 and 2 are 0.471 and 0.695 respectively. This result indicates that intersection 1 and 2 reduced respectively 52.90% and 30.50% the expected vehicle-vehicle accidents considering the same conditions. Therefore, to better adjust the model it is necessary to consider other characteristics that may increase conflicts at intersections, such as U-turns, which are not considered in the HSM.

The Ci obtained at intersection 1 and 2 is 0.493 and 1.075. This variability in the results is due to human and environmental factors that generate traffic accidents such as road user behavior, travel purposes, among others. For the four-leg signalized intersections in the study area, the Ci is 0.841. This result validates that the number of accidents estimated by the predictive method is higher than the observed accidents by 15.89%.

The Ci calculation allows estimating the number of accidents that occur at signalized intersections. This research represents an initiative to implement the HSM methodology in a new jurisdiction. To achieve significant results, not only should more intersections begin to be analyzed and the Calibration Factor obtained, but also the effectiveness of countermeasures that would reduce the accident rate in the long term should be measured. In this way, a data base will be obtained that will allow future road safety analyses of the Peruvian reality.

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