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Effectiveness of the advanced stop line for motorcycles in Bucaramanga validated by means of a logistic regression model.

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***Abstract*—** Road traffic accidents are a significant public health concern worldwide, and it is essential that individual countries adopt distinct safety measures to safeguard vulnerable road users. The objective is to analyze traffic accidents occurring at Motorcycle Advanced Stop Lines by applying a Logistic Regression model. When a traffic accident occurs, a motorcycle is involved and is 15 times more likely to be of high severity compared to accidents with other road users. The implementation of this initiative requires political will. Furthermore, technical studies should support to regulate horizontal and vertical signage, which can be included in Colombia's road signage manual in the future.

Keywords: transport safety, traffic, health policy, accident prevention.

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I. INTRODUCTION

The estimated global circulation of 313 million motorcycles, of which 77% are in Asia, 5% in Latin America, and 16% in North America and Europe [1]. The World Health Organization (WHO) expresses concern over these figures, given that traffic accidents resulted in the deaths of 1.35 million people and injuries to 50 million others in 2018. Of these data, 54% of the deceased corresponded to vulnerable users (Pedestrian and bike users - 26% and motorcyclists - 28%) [2]. By 2021 the figure remained unchanged as more than one million people were killed in road crashes around the world, mainly children and young people aged 5 to 29 [3].

In Colombia, the National Development Plan (PND) 2014-2018 established Road Safety as a state policy, which was further reinforced by Law 1702 of 2013, enabling the creation of the National Road Safety Agency (ANSV). Through the adoption of administrative, educational, and operational interventions, the National Road Safety Agency (ANSV) strives to prevent, reduce, and manage road accidents, while raising awareness and promoting a culture of road safety across all strata of society [4]. Aligned with the objectives, the Ministry of Transport enacted Resolution 2410 of 2015, which establishes the Comprehensive Program of Service Standards and Road Safety for motorcycle traffic. This program aims to comprehensively address the major vulnerabilities observed in motorcycle traffic, with the goal of reducing accident rates among motorcyclists and improving their interaction with other road users. Its objective is to minimize the physical, emotional, social, economic, and political costs arising from motorcycle accidents [5].

Road intersections are widely acknowledged as sites that experience a high frequency of collisions and injuries, as they serve as a convergence point for a variety of road users, such as motorcyclists, cyclists, pedestrians, and vehicles [6], [7].

In addition to intersection-related accidents, motorcyclists amplify their risk of experiencing a road accident by neglecting to take evasive measures while operating their vehicles. Two types of conflicts may arise under this assumption: rear-end crashes, in which a vehicle strikes the one ahead from behind; and lateral sliding, which can result from turning maneuvers, particularly on motorcycles, and may lead to side crashes. Furthermore, the behavior of motorcyclists who ride in "dynamic lanes" behind another leading motorcyclist should be considered, as they may need to make evasive maneuvers when overtaking cars [8]. Therefore, encouraging responsible human behavior while driving, particularly on roads where motorcycles are prevalent, is essential. Research conducted in Vietnam has identified several factors that contribute to motorcycle accidents, including lane-keeping infractions, constant acceleration during a trip, failure to maintain a safe distance, changing lanes without signaling, and continuous zigzagging [9].

Signalized intersections in urban areas pose critical points with high accident rates, prompting various initiatives to address them, including the implementation of the Advanced Stop Line (ASL). Initially introduced in the United Kingdom by the Department for Transport for bicycles, ASLs have since been extended to motorcycles [10]-[13]. In the United States, these areas are referred to as Advanced Stop Boxes, and have been installed in Portland [14].

Other northern European countries, such as the Netherlands, Germany, Belgium, and Denmark, have replicated ASLMs. The European Union's ROSA Project proposed to improve intersection design by installing ASLs, which are defined as areas that allow motorcyclists to stop ahead of the main stopping line at traffic light-controlled intersections. The access of motorcycles to ASLs can be achieved through lanes reserved for buses, taxis, or bicycles, thus aiming to reduce the risk of these vehicles circulating between lanes of other vehicles [15]. Despite the potential benefits of this measure, there have been limited studies on its effectiveness, such as the one conducted in Barcelona. A quasi-experimental design was used to evaluate the effectiveness of ASLMs, which involved comparing a period with and without ASLM. During phase, I, 35 ASLMs were installed, while only 16 were installed during phase II. Results from the study showed an increase in the relative risk of collision during phase I, whereas no significant changes in the risk of suffering an accident were found during phase II [16].

ASLMs have been implemented in Asian countries, including Malaysia, specifically in the city of Kuala Lumpur, to address the persistent conflict between motorcyclists and other vehicles due to the high volume of traffic [17]. Research in this country demonstrate that the use of ASLMs by motorcyclists during red traffic light intervals ranges from 5% to 55%. The underutilization of ASLMs is attributed to motorcyclists' non-compliance with traffic light regulations or the encroachment of other types of vehicles. That research also presented technical details related to ASLMs, including intersection geometric data, traffic signal operation information (e.g., red phase time), average daily traffic volume, and traffic behavior (e.g., compliance, non-compliance, misuse, and red-light violations) [18].

In Latin America, several cities such as Santiago de Chile (Chile), Buenos Aires (Argentina), Natal and Rio de Janeiro (Brazil) and Bucaramanga (Colombia) have implemented ASLMs [1], [19]-[21]. Among these countries, only Chile has regulated this measure through Law 21.088, commonly known as the "Ley de Modos." In 2008, Natal (Brazil) introduced the "Faixa de retenção" program to address conflicts arising from the differences in acceleration between motorcycles and cars during the transition to green. To facilitate access to the ASLMs, a dedicated lane was established to enable motorcyclists to proceed to the front of the intersection where the ASLM is positioned, without having to zigzag between the vehicles [19].

In Buenos Aires, Argentina, a pilot test titled "Safe Detention Zone for Motorcycles" was implemented in 2012 at two intersections, and the outcome was favorable. The motorcyclists embraced the initiative, while the drivers of other vehicles accorded them due respect. The success of the pilot test led to the expansion of ASLMs to eight avenues [22].

In Colombia, there are experiences with ASLMs in Bogotá and Bucaramanga. In Bogotá, the city council presented the draft agreement 444 (2015) for the creation of the pilot test of the ASLMs in a route of 1.1 kilometers, which contains four semi-traffic intersections and a pedestrian route on “Avenida Ciudad de Cali” from the street 72 to street 65 bis, in a north-south direction [23]. In Bucaramanga, the Transit Directorate (DTB), by means of Resolution 714 (2016), developed a pilot test to implement the ASLMs on Avenue 27 in a stretch of 1.8 kilometers and the adaptation of an exclusive lane for motorcycles, which were later installed in other semi-traffic intersections [24].

This study aimed to evaluate the effectiveness of the Advanced Stop Lines for Motorcycles (ASLMs) implemented as a pilot test at selected traffic light intersections in Bucaramanga, Colombia. To achieve this, a Logistic Regression model was employed, which facilitated the identification of the underlying factors contributing to accidents and their severity.

II. ADVANCED STOP LINES FOR MOTORCYCLES - ASLMS

ASLMs at intersections featuring traffic lights offer motorcyclists a designated area ahead of the pedestrian crossing, while the traffic light is red. This strategic positioning allows for greater visibility and improved exit positioning for motorcyclists. Notably, motorcyclists are insulated from being obscured in vehicular traffic, thus conferring priority for movement when the traffic light changes to green. Consequently, this approach optimizes the weight-to-power ratio of motorcycles.

ASLMs deployed at intersections equipped with traffic lights aim to segregate motorcyclist movements during the red phase, thereby avoiding conflicts with other vehicles upon transition to the green phase. Consequently, the ASLMs minimize the interaction between motorcycles and other vehicular traffic [17]. Furthermore, the ASLMs help maintain pedestrian safety by dissuading motorcyclists from using pedestrian crossings [6].

In Colombia, the DTB implemented the ASLMs in response to the prevalence of reckless conduct on the road by motorcyclists. This behavior, which includes zigzagging, inadequate spacing between vehicles, using sidewalks, and failure to adhere to traffic rules, has been identified as the primary cause of road accidents. Consequently, the DTB commissioned a technical evaluation in June 2016, leading to the initiation of a pilot test of ASLMs to minimize the risk of accidents at traffic light intersections within the city [20].

DTB conducted a series of studies to establish the viability of deploying horizontal road signs to facilitate the use of ASLMs. The technical guidelines for these signs were outlined in document 202 of the DTB, which included detailed technical specifications and illustrations of 34 types of intersections throughout the city. (See Figure 1).

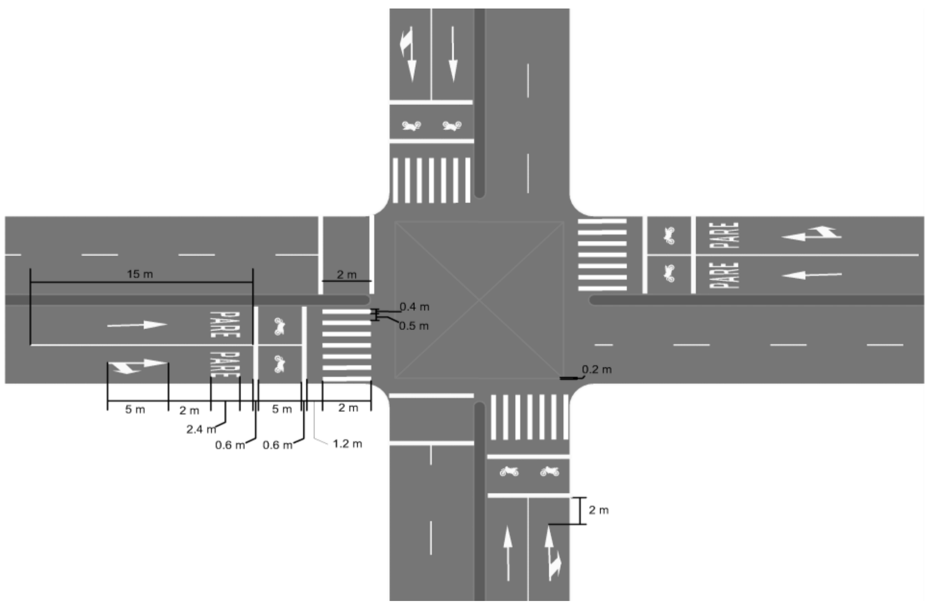

Figure 1: Advanced Stop Line for Motorcycles signage. Details of the distances covered by the ASLMs established in Bucaramanga – Colombia. Source: Bucaramanga Transit Directorate (DTB) publication in 2016.

III. METHODOLOGY

In Bucaramanga, the pilot test for ASLMs was initially conducted for a period of six months. Based on its outcome analysis, the measure was subsequently extended to cover 168 traffic light intersections [24]. In addition to the implementation of road signs at traffic lights intersections, the DTB's road culture and control groups were consistently deployed to ensure adherence to traffic regulations and guarantee the enforcement of the measures implemented. The groups responsible for road culture conducted socialization campaigns and citizen education programs to rapidly establish a harmonious relationship between the ASLMs, motorcyclists, cyclists, pedestrians, and other vehicle drivers. Figure 2 shows the socialization of the ASLMs at one of the city's intersections.

Figure 2: Socialization campaign of the ASLMs in Bucaramanga - Colombia.
Source: DTB (2016).

a. Estimation of Statistical Models

According to the National Land Traffic Code of Colombia, an accident refers to an event that typically occurs involuntarily, triggered by a moving vehicle, and results in damage to both individuals and property involved in the incident. Additionally, such an event can have an adverse impact on the regular flow of vehicular traffic on the roads encompassing the location or in the vicinity of the occurrence [25].

To estimate accidents based on available data, diverse statistical techniques have been utilized to develop models that can anticipate traffic accidents at intersections, roads, and roundabouts [26]-[28]. These models rely on a range of variables such as (i) the road (urban or rural, pavement conditions, etc.), (ii) the vehicle (displacement, capacity, etc.), (iii) environmental conditions (climate, wet soil, etc.), and (iv) and (iv) and human behavior (type of road actor, distraction when driving, alcohol consumption, zigzagging, traffic control, time of the event, speeding) [29].

To investigate the factors that impact road accidents and their associated probabilities, a logistic regression technique was implemented. The dependent variable was defined as the "severity of the accident," which was comprised of two distinct categories: high (injured and fatalities) and low (only damages).

b. Multinomial Logistic Regression

The logistic model establishes a correlation between the probability of an event occurring as a function of certain variables that are deemed to be influential based on theory (or prior experience). Consequently, Logistic Regression (LR) involves the development of a logistic function of the independent variables that permits the classification of individuals into one of two subpopulations or groups delineated by the two values of the dependent variable (1 and 2). The most general case, involving explanatory p-variables, $X' = (1, X_{1,} X_{2,\dots,} X_p)$

$$P(Y=1) = \frac{1}{1+exp[-(\beta_o+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_p X_p]} \quad (1)$$

$$P(Y=1) = \frac{1}{1+e^{-X'\beta}} \quad (2)$$

Where $\beta = (\beta_o, \beta_{1,} \beta_2, \dots, \beta_p)'$ are the parameters of the model; exp(.) refers to the exponential function [30], [31]. The estimation of parameters is accomplished by utilizing the maximum likelihood method, which ensures that the coefficients estimated are plausible [32]. To evaluate the model's overall goodness of fit, various indices, such as the Hosmer-Lemeshow goodness-of-fit index, deviation statistic, and Hosmer-Lemeshow goodness-of-fit contrast, are employed. Additionally, the verification of the model diagnosis is undertaken comprehensively by evaluating the goodness of fit on a case-by-case basis through the analysis of the residuals of the model and their influence on estimating the parameter vector of the model with leverage [33].

c. Data collection

DTB provided the total accident rate database of the municipality of Bucaramanga, which consisted of 31,000 claims that occurred between January 2012 and December 2019. After subjecting it to a thorough cleaning process, researchers selected only 4,901 (15.8%) accidents that took place at intersections with traffic lights where ASLMs were implemented. To enable comparative management of data, researchers identified two distinct periods: the first period, from 2014 to 2016, did not have access to ASLM (control group), while the second period, from 2017 to 2019, had ASLM implemented (intervention group). The statistical analysis was conducted using RStudio [34] (RStudio Team, 2015).

IV. RESULTS

The sites marked with ASLMs had 2,528 accidents from 2014 to 2016 and 2,373 accidents from 2017 to 2019, resulting in a reduction of 155 accidents (6.13%) between the two periods. After the pilot test, researchers implemented ASLMs in 24 sections of the city. In the following sections: T1_Cra27, T23_Cra15, T3_Cra33, and T22_Cra21 where there was a reduction in the percentage of fatalities of 25, 50, 60, and 100, respectively.

A bivariate analysis was conducted to compare periods with and without ASLM. The results indicate a significant reduction of 33.33% in accident fatalities and only a 14.15% reduction in property damage, while there was a 6.35% increase in the number of injured individuals. The analysis reveals that the highest number of fatalities occurred during daylight hours, involving motorbikes, and on secondary roads. The severity of accidents, which served as the dependent variable, was significantly associated (p< .05) with the predictor variables (Table 1).

Table 1: Variables associated with accidents before and after the ASLM implementation.

Var.[a]	Cat.[b]	Severity of accidents		Chi.[c]	*p*
		Low	High		
Per.[d]	ASLM (off).[e]	1455	1073	11.98	.001
	ASLM (on).[f]	1249	1124		
Sch.[g]	Day	1982	1395	54.36	.000
	Night	722	802		
Mot.[h]	Yes	642	1809	1664.80	.000
	No	2062	388		
Road	Primary	57	127	45.24	.000
	Secundary	2647	2070		

Sourse: Own elaboration.

[a] Variable. [b] Category. [c] Chi-square. [d] Period. [e] ASLM (off): period sin Advanced Stop Line Motorcycles [f] ASLM (on): period with Advanced Stop Line Motorcycles. [g] Schedule. [h] Motorcycle.

The proposed logistic regression analysis determines whether the set of study variables (road type, ASL, schedule, motorcycle, the number of vehicles involved, day of the week, and month) determine if they have any kind of relationship with the severity of the road accident, a dependent variable that was dichotomized as follows: (High severity [Injured and fatalities=1], Low severity [damage only=0]). The initial model was (3):

$$P[Y=1]=\frac{1}{1+e^{-(\beta_o+\beta_1*ASL(off)+\beta_2*Moto(Yes)+}\beta\_3*Schedule(Night)+\beta\_4*Road(Primary)+\beta\_(5*)\,No\_Veh\_Inv} \quad (3)$$

Concerning the adequacy assessment of the model, it is evident from Table 2 that the Hosmer and Lemeshow test with a Chi-square of 2.59 (p = .858) indicates that the estimated model fits the data appropriately.

The variables included are significant at a level of 5%. The coefficient of determination, Nagelkerke's R2 indicates that it explains 42.7% of the variance of the severity of the road accident.

The procedure of estimation of the logistic regression model is performed through the method of maximum likelihood.

This model generates a correct classification of cases of 79%, finding that it correctly classified road accidents with high severity in 82% while the classification for low severity was 76%.

In this sense, if the road accident occurs on a primary road, it is 3.5 times more likely to have high severity compared to a secondary road. Regarding the night schedule, it is 1.7 times more likely to be a serious accident than at night. Being a motorcycle involved in a road accident has 15 times more chances that it is of high severity compared to being involved in other types of other road users. In the case of ASL (on), it is 1.2 times more chance of being a high-severity accident compared to ASL (off). The final estimated model turned out to be (4):

$$P[Y=1]=\frac{1}{1+e^{-(-2.004+0.19*ASL(on)+2,74*Moto(Yes)+0.54*Schedule(Night)+1.26*Road\ (Primary)}} \quad (4)$$

Table 2: Logistic regression results of the severity of road crashes in Bucaramanga for 2014-2020.

Dependent variable: Severity of the accident. Low[a] (0), High (1)	β	Error standard	Wald	df	Sig.	Exp (β)	95% C.I.[b] Exp (B)	
Road (Primary)	1.26	0.19	40.67	1	.00	3.52	2.39	5.20
Schedule (Night)	0.54	0.07	49.33	1	.00	1.72	1.48	2.00
Motorcycle (Yes)	2.74	0.07	1389.46	1	.00	15.49	13.41	17.89
ASL (on)	0.19	0.07	7.74	1	.00	1.22	1.06	1.40
Constant	-2.00	0.07	744.92	1	.00	0.13		

Sourse: Own elaboration.

[a] Reference category. [b]95% C.I.: confidence interval for Exp (β).

The implementation of ASLMs in numerous cities worldwide underscores the necessity for countries to enact measures regulating vehicular interactions, particularly those that arise from the proliferation of motorcycles. The vertical signaling of the ASLMs allows for the reduction of traffic conflicts and an increase in vehicular flow as shown in technical studies [35], [36]. A case in point is a study conducted in the city of Bandung (Indonesia) between September and December 2012, which revealed that the ASLM referred to as the "Red Box" at the Ahmad Yani-Laswi intersection led to a 13% surge in vehicular flow while concurrently reducing traffic accidents by 39% [35], [36].

This type of measures requires the endorsement of traffic regulators, and thus many cities have conducted pilot tests that are marked by horizontal signage. This involves the deployment of road markings that define the exclusive waiting zone for motorcycles, as observed in cities such as São Paulo, San Vicente, and Belo Horizonte (Brazil), as well as Bucaramanga (Colombia).

In 2014, when ASLMs were first implemented in São Paulo (Brazil), 1,249 individuals had already perished on the roads, of whom 1,042 were vulnerable users [37]. Preceding the introduction of ASLMs, the impact of this measure was observed to be positive, culminating in a 21% decrease in fatalities, particularly among vulnerable users. Similarly, in the case of Bucaramanga, the accident rate involving fatalities decreased by 33.33%.

According to a study conducted in Malaysia, the rate of usage of ASLMs by motorcyclists was 56.2% at four intersections in the city of Kuala Lumpur. The implementation of ASLMs resulted in a reduction of traffic conflicts by 71.2% when compared to signaled intersections without ASLMs [17]. However, the utilization rate of ASLMs in Bucaramanga was not evaluated.

In 2016, Bucaramanga installed 168 ASLMs across 24 road sections. In a study conducted in Barcelona (Spain) in two phases, 35 ASLMs were installed in phase I in 2009 and 16 in phase II in 2010 [16], [28]. In Barcelona, it was found that at an intersection in phase I, the relative risk of collision, of being injured, and a motorcycle was involved was increased, different from that reported for another intersection in phase II where there were no significant changes in the risk of suffering an accident [28]. In São Paulo (Brazil) the number of ASLM implemented was 397 between 2013 and 217; but to date, no results have been published on the impact of the measure [29], [37].

V. CONCLUSIONS

168 ASLMs were implemented in the pilot test in Bucaramanga, resulting in a reduction of mortality in specific sites within the city. Global validation of the ASLMs' effectiveness was conducted using multinomial logistic regression, which showed that in the ASLM (off) period it was 1.8 times more likely to have a fatality than to be injured for the ASLM (on) period. For the damages-only category, it was observed that if the accident occurred in the ASLM period (off) it was 1.24 times more likely that they were only damages than that it was injured for the period with ASLM (on).

The permanent implementation of ASLMs requires political will based on technical studies to promote the regulation of horizontal and vertical signage, and subsequent inclusion in the road signs manual of Colombia. Chile's incorporation of ASLMs in the National Transit Code, known as "Ley de Modos," provides a relevant example in Latin America. Complementary measures, such as road education processes, monitoring, and control of standards for motorcyclists and vehicles, and improvements in the city's road infrastructure, are also necessary.

It is necessary to carry out "in situ" studies like the one developed in Indonesia in the ASLM [36] to establish the behavior of motorcyclists when using it and how this affects traffic conflicts and vehicular flow or through computer simulations [38].

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VII. DATA AVAILABILITY STATEMENT

Certain data, models, or code generated or used during the study may be proprietary or confidential and are subject to restrictions on their disclosure. The DTB provided the database used in the study. It should be noted that traffic accident records are presented as an anomaly.

VIII. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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