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RISKY BEHAVIOUR AMONG ROAD USERS AT LOCATIONS WITH HIGH PROBABILITY OF CRASH OCCURRENCE

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Abstract: The aim of this research is (1) to identify places with a high probability of crash occurrence (LHPCO) in Villavicencio-Colombia and (2) to carry out road safety audits in each LHPCO to evaluate the behaviour of road users and speed measurements. As a methodological structure, the analysis of crash data is considered, linked to assessments of road safety audits, with which it is obtained that motorcyclists are overrepresented in the statistics of road injuries. In addition, a total of seven LHPCOs were identified. In these locations, pedestrians engaged in a large number of risky behaviours, and speed measurements indicated that car drivers select high speeds near crosswalks. Interventions such as public education or police enforcement are needed to reduce the risky behaviour of pedestrians and motorists near high-risk locations.

Keywords: road safety, risky behaviour, road crash, road users, mobility

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INTRODUCTION

Road crashes result in approximately 1.35 million fatalities every year, being the 8th leading cause of death across all ages and 1st for people aged 5 to 29 years (World Health Organization, 2018). High-income countries have established strategies to reduce traffic fatalities, such as road rules and education, which have resulted in important safety improvements (World Health Organization, 2018). However, this is not the case for low- and middle-income countries (LMICs) such as Colombia (Ahmed et al., 2023), where fatality rates have been increasing during the last decade (Jacobs and Sayer, 1983; Heydari et al., 2019; Sperling and Deluchi, 1989). In Colombia, road traffic crashes are the 2nd leading cause of mortality after homicides. It is estimated that 28% of all fatalities in Colombia are associated with road trauma (Instituto Nacional de Medicina Legal y Ciencias Forense, 2020), with vulnerable road users such as pedestrians and motorcyclists being the most affected (World Health Organization, 2018; Republica de Colombia, 2008). In 2019, road fatalities were 6826 representing 13.75 road traffic fatalities per 100,000 inhabitants, which results in a fatality rate well above other countries such as Spain (4.1), Australia (5.6) and Sweden (2.8).

To develop evidence-based road safety countermeasures, it is important to understand road user behaviour and its determinants (Acera et al., 2023). Human factors and road user behaviour are considered to be a key determinant of safety together with broader systemic factors such as policies, infrastructure, social culture, etc (Oviedo and Parker, 2017; Escobar et al., 2021; Salmon and Read, 2019; Serter et al., 2018). A number of methodologies have been developed to analyse road user behaviour such as driving simulations (Tapiro et al., 2018; Oviedo et al., 2019), behavioural coding of naturalistic videos (Bastos et al., 2020; Jha et al., 2017), self-report questionnaires (Oviedo and Parker, 2017), qualitative studies (Torres et al., 2019; Oviedo et al., 2019), and direct on-road observations of road user behaviour (Escobar et al., 2021; Iryo and Alhajyaseen, 2017). Of all of these methodologies, on-road observations are considered to be one of the most cost-effective methodologies to investigate road user behaviour with high reliability and validity. Although on-road observations could offer important insights into road user behaviour (drivers and pedestrians), their applications have been limited in Colombia. For example, Cantillo, Arellana and Rolong (Cantillo et al., 2015) used observations of road crossing behaviour and self-reported data to build a model to predict pedestrian route choice behaviour while crossing urban roads. Likewise, Oviedo-Trespalacios and Scott-Parker (Oviedo and Parker, 2017) explored factors influencing pedestrians' decision to cross a main road using a footbridge through observations of pedestrian crossing behaviour and

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the pedestrians' perceptions of risk. Other research conducted in Colombia found that footbridges increase the probability of crashes for all road users, as opposed to at-level intersections that have a positive impact on road safety (Vergel et al., 2019). Research about risky pedestrian behaviour conducted in Manizales by Escobar, Cardona, and Hernández-Pulgarín (Escobar et al., 2021) analysed crash points near to education facilities and measured relation between risky behaviours and age-group among pedestrians. However, large scale studies examining on-road interactions between road users and traffic infrastructure are virtually non-existent in the academic literature.

The Road Safety Audit (RSA) is a methodology used to analyse and study the impact of road infrastructure on road safety (Bulpit, 1996). RSA is a formal evaluation of existing infrastructure considering road safety issues that could cause road crashes among all road users (TDG, 2013). In recent years, Colombia has started to implement RSAs. However, these mostly target infrastructure and motor vehicles, while interactions with pedestrian and other vulnerable road users are generally overlooked (Alcaldía Mayor de Bogotá, 2005; Dallos and Rodrigo, 2015; Londoño et al., 2017). The present study combines RSA and on-road observations to gain an understanding of road safety issues in Colombia. Specifically, this research investigated crash data and locations with a high probability of crash occurrence (LHPCO) in Villavicencio - Colombia, through the analysis of the available historical data and a heat map built with the kernel density method. Additionally, RSA was conducted on LHPCO, studying road infrastructure and incorporating behavioural observations of pedestrians, taking special attention to risky pedestrian behaviours (i.e. offenders of traffic rules).

Figure 1. Geographical location of study zone (Source: authors)

MATERIALS AND METHODS

The research methodology includes two sequential main phases: (1) crash data analysis, and (2) road safety audit and behavioural observations. The project was conducted with the approval of the Universidad Nacional de Colombia (Sede Manizales).

Phase 1. Study zone: Villavicencio is the capital city of the Meta state in Colombia, located south of Bogota, Colombia´s capital city (Figure 1). It has a population of 492,052 inhabitants with 48.98% male and 51.02% female (Departamento Administrativo Nacional de Estadistica – DANE, 2018). According to Road Safety National Agency (Agencia Nacional de Seguridad Vial - ANSV for its acronym in Spanish), they had 76 road crash fatalities, representing 15.44 deaths per 100,000 inhabitants. This rate is higher than the national value of 13.75. The ANSV also identified that 80.26% of fatalities were males, suggesting gender-based differences in traffic behaviour and safety. Few studies related to road safety have been conducted in more regional areas of Colombia (Agencia Nacional de Deguridad Vial, 2023). Most of the published research has been conducted in major cities such as Bogota, Barranquilla and Medellin. In 2017, Lizcano-Gutierrez and Lozano-Romero (Lizcano and Lozano, 2017) analysed historical data about road safety in the Villavicencio city to make an epidemiological profile from a health point of view. However, any study has used RSA and behavioural observations in the city.

Phase 2. Crash data analysis

Road crash dataset: The 2012-2019 crash data was sourced from Road Safety National Observatory (Observatorio Nacional de Seguridad Vial - ONSV for its acronym in Spanish), which is part of the ANSV (Agencia Nacional de

Deguridad Vial, 2023)0. This dataset includes road crashes with geographical coordinates or road directions, date, hour, city, department, type of crash, users and vehicles involved (pedestrian, cyclist, four-wheeler vehicle, motorcycle, truck, etc.), severity level (fatalities, injuries or property damage), among other characteristics. The road crashes in the Villavicencio municipality were plotted in a GIS tool according to their coordinates.

Equivalent crash performance (ECP): Crash data was used to identify Locations with a High Probability of Crash Occurrence (LHPCOs) on the road network in the Villavicencio municipality. To achieve this, the Equivalent Crash Performance (ECP) was calculated at each location. The ECP is a methodology that determines the probability of crashes at different locations while accounting for all crashes with varying levels of severity. The ECP methodology uses Equation (1) (Sugiyanto, 2017), as follows:

$$ECP = PD * (PDC) + NF * (NFC) + F * (FC) \quad (1)$$

Where PD, NF and F are the ECP constants for property damage, non-fatal and fatal crashes, respectively, calibrated for each particular country or region considering the casualty cost of each type of crash (Sugiyanto, 2017); *PDC* is the Property damage crashes in the study area, NFC is non-fatal crashes in the study area and *FC* is the Fatal Crashes in the study area.

In Colombia, ECP constants were measured and established by the ASNV, i.e. 12 (F - fatal crashes), 2 (NF - non-fatal crashes), and 1 (PD - property damage crashes). The equivalence between severity levels of road crashes utilised in this study is consistent with other countries in Latin America: 1-3-9.5 in Costa Rica (Guerrero, 2015) and 1-2-6 in Mexico (Rascón et al., 2015), for example. The ECP was calculated at each point considering a geographical circular buffer of 80 meters. This value is called aggregated ECP.

Heat map: Subsequently, a geostatistical model based on Kernel density was used to identify the LHPCO in Villavicencio municipality. Kernel density (Equation 2) (do Bonfim et al., 2018) is a method that uses a kernel function to search an area circularly over each crash resulting in a continuous and raster surface (do Bonfim et al., 2018; Thakali et al., 2015).

$$f(x,y) = \sum_{i=1}^{n} \frac{1}{ECP * 2 * \pi h^2} * Wi * K(\frac{di}{h}) \qquad (2)$$

In equation 2, the density estimate at each ECP location (x,y) is f(x, y); h is the kernel size; K is the kernel function; di is the distance between each ECP and Wi is the intensity of the point, represented as the aggregated ECP. The heat map is built using ArcMap tools. This method is commonly used in crash analyses worldwide (Cheng et al., 2016; Hashimoto et al., 2016; Achu et al., 2019). Specifically, it allows differentiating through a colour scale the points or areas of the Villavicencio municipality with greater road safety issues.

Phase 3. Road Safety Audits (RSA) and behavioural observations: Once the LHPCOs were identified, RSA and behavioural observations were conducted at each one of the locations. The RSA involved field visits where traffic, infrastructure characteristics and traffic conflicts were collected. Traffic characteristics were investigated, considering both motorised road users and pedestrians. For motor vehicles, the number and type of vehicle were recorded. Additionally, instantaneous speed was estimated using a radar gun for all motorised vehicles.

At signalised intersections, vehicle speeds were only recorded when traffic lights were green. Also, pedestrian counts were conducted considering risky and compliant pedestrian behaviour. Pedestrians risky crossing behaviour was coded based on three main behaviours (Republica de Colombia, 2002): (a) pedestrian crossing on authorized path when traffic light gives pedestrians priority, (b) risky pedestrian crossing on authorized path when traffic lights are giving priority to vehicles, and (c) risky pedestrian crossing a corridor without authorized paths. Figure 3 shows the three pedestrian behaviours observed in this study. The infrastructure characteristics collected for the RSA included: widths of sidewalks and roads, road material, number of lanes, road markings, and traffic lights. Additionally, during the ob servation, conflicts among road users were recorded. The conflicts among road users (Figure 2) were classified as crossroad conflicts (between direct traffic, turning left traffic, and direct traffic and between turning traffic (Figure 2), convergence and divergence conflicts, and pedestrian and traffic conflicts. A descriptive analysis was conducted considering the primary information collected from the ANSV and the RSA and behaviuoral observations.

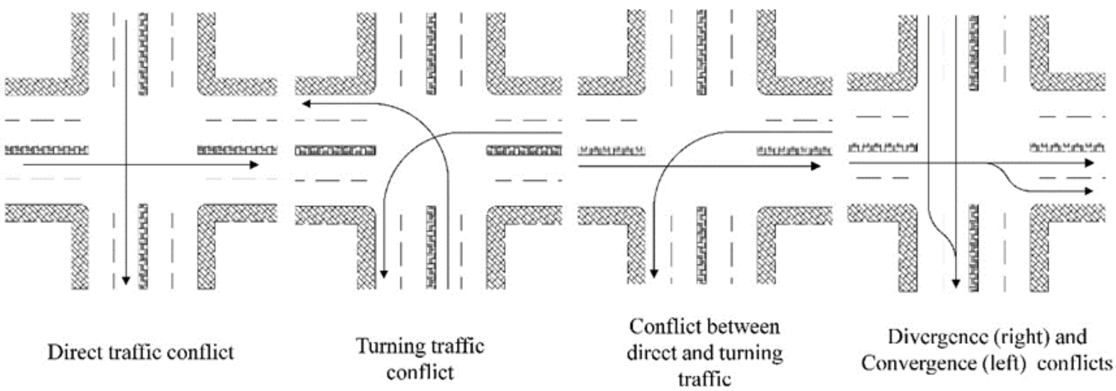

Figure 2. Crossroad, convergence and divergence conflicts (Source: Adapted by authors to Cardona, 2018)

Figure 3. Pedestrian behaviour on LHPCO (Source: authors)

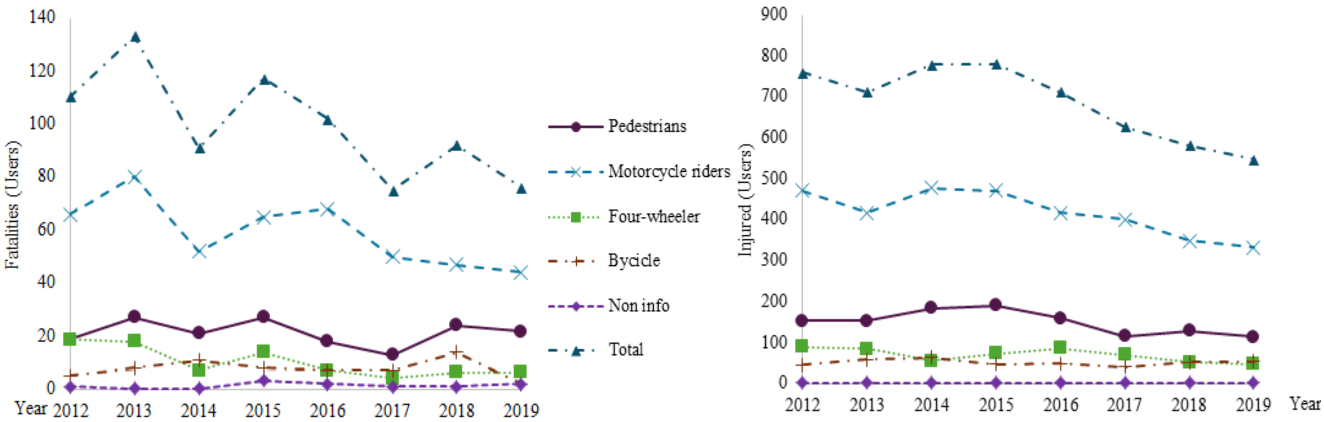

Figure 4. Fatalities (above) and injuries (below) caused by road crashes in Villavicencio (2012-2019) (Source: authors)

RESULTS AND DISCUSSION

Traffic crashes in Villavicencio: Road crashes in Villavicencio were analysed using data collected by the ANSV. An examination of injury trends showed that fatalities have decreased since 2012, with a peak of 133 fatalities in 2013 (Figure 4). The year with the lowest number of registered fatalities was 2017 with 75. From 2012 to 2019 fatalities decreased by 30.91%. Moreover, injury data showed a decrease in 27.80% from 2012 to 2019 with a peak of 781 injuries in 2015 (Figure 4). Bicycle riders were the only group that increased their injuries during the period (12%) while other types of road users had declining injury rates (51.38% four-wheelers, 29.79% motorcycle riders and 20.93% pedestrians). An examination of fatalities by road user type showed that motorcyclists account for the highest proportion of road fatalities. For example, in 2019, motorcyclists accounted for 57.89% of all road fatalities, which is more than double the percentage of pedestrians (20.80%). It is clear that vulnerable road users such as motorcycle riders and pedestrians are overrepresented in fatal road crashes in Villavicencio.

Table 1. Road crashes by day of the week and time of day (Source: authors)

Day	0:00 3:00	3:00 6:00	6:00 9:00	9:00 12:00	12:00 15:00	15:00 18:00	18:00 21:00	21:00 0:00	Day time*	Night time**	Non-info	Total	% of total
Mon	8	13	54	58	91	91	73	22	294	116	3	413	14.43
Tue	4	12	66	46	71	71	65	34	254	115	5	374	13.07
Wed	5	21	71	49	75	69	72	32	264	130	3	397	13.87
Thu	7	5	58	61	83	71	59	35	273	106	3	382	13.35
Fri	6	16	80	55	70	90	78	38	295	138	9	442	15.44
Sat	13	18	52	57	70	82	92	54	261	177	3	441	15.41
Sun	21	20	47	80	75	71	80	45	273	166	6	445	15.55
Wkd	30	67	329	269	390	392	347	161	1380	605	-	1985	69.36
Wknd	34	38	99	137	145	153	172	99	534	343	-	877	30.64
Total	64	105	428	406	535	545	519	260	1914	948	32	2862	100
% of total	2.24	3.67	14.95	14.19	18.69	19.04	18.13	9.08	66.88	33.12	1.12	100	
*Day time: 06:00 and 18:00; **Nigth time: 18:00 - 06:00													

The 2012-2017 data from ANSV allowed disaggregated analyses of traffic crashes considering age, hour, date, type of road crash, among others. Road crashes were organised by day of the week and time of day in Table 1. According to the day and the hour of the incident, two periods with higher crash incidence were identified: Saturday between 18:00 and 21:00, and Monday between 12:00 and 18:00. Additionally, noon was the period with the largest concentration of road crashes during the week. Weekends and night-time concentrated more than one-third of the road crashes. A chi-square test showed a significant relationship between day of the week and time of the day ($\chi2$ (42, n = 2,862) = 85.45, $p < .001$, φc = .071). It needs to be clarified that not all the traffic crash reports had complete data. Underreporting and missing data are common issues in LMICs road safety archives (World Health Organization, 2009). According to this, it is evident that pedestrians are hit more by motorcycles (64%). Additionally, cyclists (62%), motorcycle riders (65%) and four-wheelers (65%) are more likely to be hit by four-wheelers. Overall, four-wheelers are the objects with more crashes (58%).

Table 2. Road crashes by type of user and collision object (Source: authors)

Type of user	Collision Object					Total
	Motorcycle	Four-wheeler	Bicycle	Fixed Object	Non-info	
Pedestrian	466 (43-64%)	260 (13-36%)	1 (4-0%)	0	0	727
Motorcycle rider	491 (45-25%)	1298 (67-65%)	19 (83%-1%)	16 (62-1%)	171 (68-9%)	1995
Car's driver	23 (2 -7%)	209 (11-65%)	2 (9-1%)	10 (38-3%)	77 (31-24%)	321
Bicycle rider	107 (10-37%)	178 (9-62%)	1 (4-0%)	0	2 (1-1%)	288
Total	1087	1945	23	26	250	

Table 3. Severity of road crash percentage by age group (Source: authors)

Age groups	Severity of road crash per age groups				Total road crashes
	Injured	% Injured	Fatality	% Fatality	
(00 - 04)	58	85.29	10	14.71	68
(05 - 09)	80	93.02	6	6.98	86
(10 - 14)	89	87.25	13	12.75	102
(15 - 19)	254	84.95	45	15.05	299
(20 - 24)	500	85.18	87	14.82	587
(25 - 29)	370	84.86	66	15.14	436
(30 - 34)	328	85.64	55	14.36	383
(35 - 39)	268	88.45	35	11.55	303
(40 - 44)	206	83.74	40	16.26	246
(45 - 49)	161	84.29	30	15.71	191
(50 - 54)	152	81.72	34	18.28	186
(55 - 59)	128	84.21	24	15.79	152
(60 - 64)	107	78.68	29	21.32	136
(65 - 69)	89	81.65	20	18.35	109
(70 - 74)	46	69.7	20	30.3	66
(75 - 79)	31	53.45	27	46.55	58
Over 80	27	50	27	50	54
Total	2894	83.59	568	16.41	3462

Road users aged 20-24 years have the greatest number of road crashes (n = 587, 16.96%) while road users over 80 years have the least road crashes (n = 54, 1.56%). However, the highest proportions of fatalities (when compared to injuries per age group) are in the elderly group (60 years and over) ranging from 21.65% and a maximum of 50.00% for people over 80. On the other hand, children between (5 – 9 years) have the lowest fatality rate with 6.98% (Table 3). The association between age and road crash severity was significant ($\chi2$ (16, n = 3,462) = 110.53, $p < .001$, φc = .179). Motorcyclists crash more frequently as adults (ages between 20 and 44 years) while pedestrians are involved more frequently in road crashes as children (0 and 9 years) and older adults (over 60 years) (Figure 5).

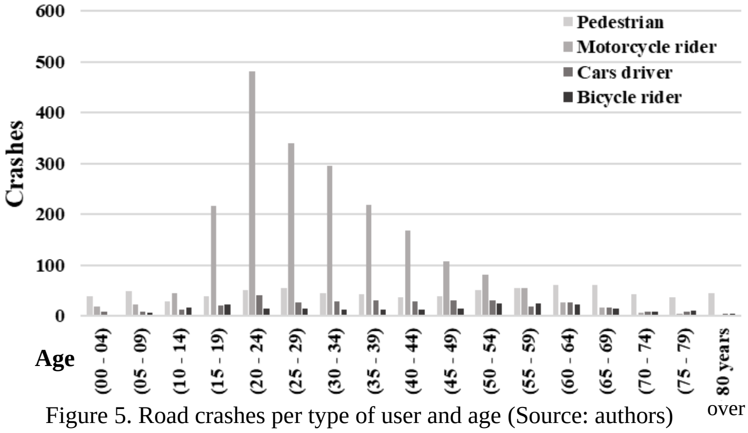

Figure 5. Road crashes per type of user and age (Source: authors)

Locations with high probability of crash occurrence (LHPCO): The ECP analysis was conducted to identify high probability crash locations in Villavicencio. The heat map is presented in Figure 6. LHPCOs were defined with the highest ECP. Those critical points were shared and checked with Villavicencio local government to know about road safety investment made in those points in the last years and the relevance of the points Some LHPCOs in the west of Villavicencio were not included because the local government had initiated road works to improve the safety of these locations. Given that the main objective of this investigation is to analyse high-risk locations, LHPCO #5 was also included as recommended by the local government because of the high number of fatalities caused by road crashes since the most recent upgrade two years ago. Table 4 shows the geographical coordinates and type of road infrastructure of the LHPCOs identified for the road safety audits and behavioural observations. They include three intersections and four corridors (Figure 7).

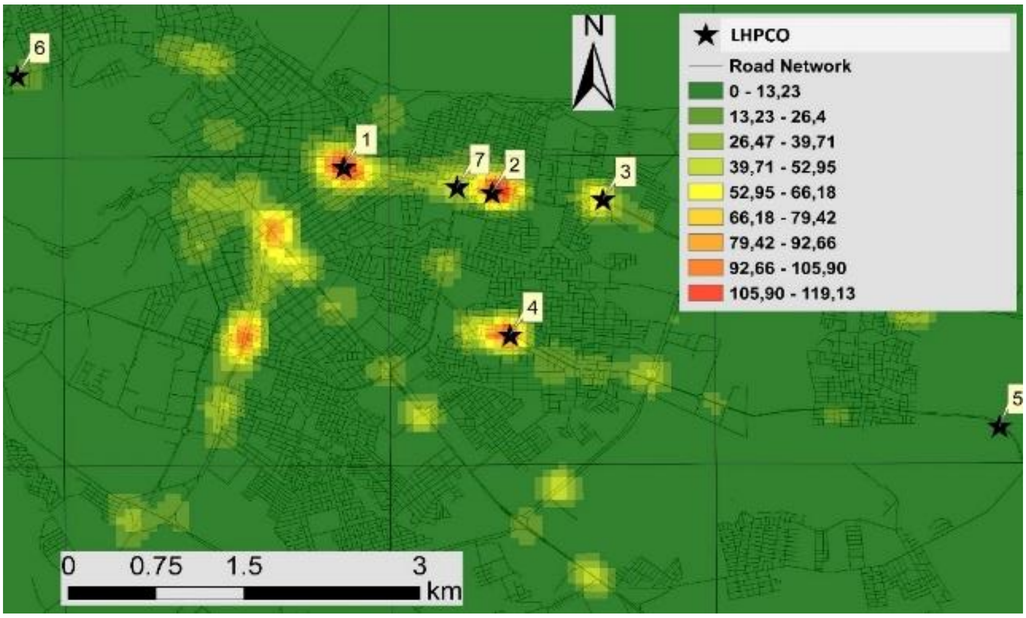

Figure 6. ECP results and locations with high probability of crash occurrence (LHPCOs) (Source: authors)

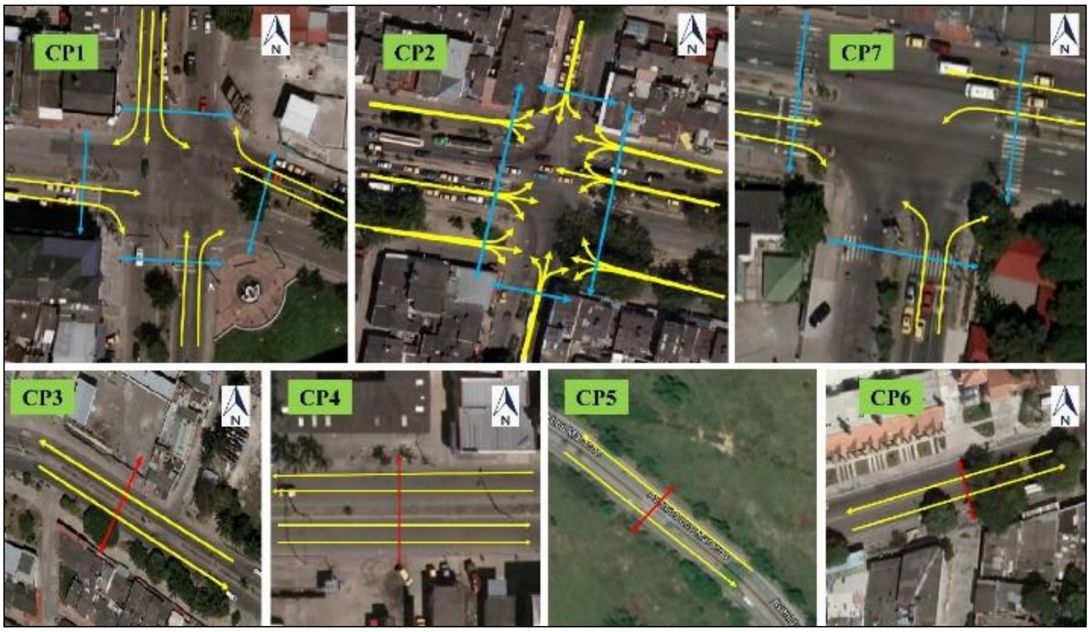

Figure 7. Traffic and pedestrian maneuvers at LHPCO (Source: authors)

Table 4. Geographical coordinates and type of road infrastructure in LHPCOs (Source: authors)

CP	Latitude	Longitude	Type of road infrastructure
1	4.149134	-73.628575	Four-leg intersection
2	4.147032	-73.617216	Four-leg intersection
3	4.146458	-73.608705	Corridor
4	4.1355	-73.615886	Corridor
5	4.127978	-73.57836	Corridor
6	4.156647	-73.653619	Corridor
7	4.147494	-73.619896	“T” intersection

Road safety audits and behavioural observations: Results from the road safety audits (RSA) and behavioural observations are presented in Table 5. Most of the traffic composition was comprised of four-wheeler cars, and conflicts were higher at intersections than on corridors. Conflicts between pedestrians and traffic are indeterminate on corridors because they do not have authorized paths to cross (red arrow in Figure 7), making their behaviour unpredictable and dangerous (Shaaban et al., 2018). In all sites, pedestrians were observed to engage in large numbers of road crossing violations (> 81.66% of the recorded 2,955 events).

Table 5. Traffic and pedestrian flows and conflicts in high probability crash locations (Source: authors)

HPCL	Traffic flow				Pedestrian flow			Conflicts					
	Total	FW	M	B	Total	C	R	PT	DT	TLDT	D	C	TL
1	11722	63.48%	32.32%	4.20%	876	19.18%	80.82%	16	16	4	5	5	0
2	12651	58.65%	39.41%	1.94%	552	12.50%	87.50%	28	40	4	8	12	2
3	10621	45.94%	50.75%	3.31%	216	0%	100.00%	∞	0	4	2	2	1
4	4077	43.46%	49.91%	6.62%	262	0%	100.00%	∞	0	0	0	0	0
5	2311	37.04%	60.93%	2.03%	18	0%	100.00%	∞	0	0	0	0	0
6	3472	66.96%	32.00%	1.04%	188	0%	100.00%	∞	0	2	3	3	1
7	15470	63.12%	34.93%	1.95%	843	36.18%	63.82%	17	0	9	2	3	2
Total	60324	54.09%	42.89%	3.01%	2955	18.34%	81.66%	-	56	23	20	25	6
	FW. Four-Wheeler M. Motorcycle B. Bycicle				R. Risky pedestrian C. Compliant pedestrian			PT. Pedestrian and traffic DT. Direct traffic TLDT. Turning left and direct traffic D. Divergence C. Convergence TL. Turning left					

Table 6 shows the results from the instantaneous speed measurements. A total of 3,628 speed measurements were registered. Totals were organized according to the LHPCO speed limit (30, 40 or 60 kph). For the locations with a 60 kph speed limit, the average speed registered was 47.51 kph (SD = 10.72 kph). For LHPCO #5 and #6 the average speeds (65.63 kph and 42.36 kph) were higher than the speed limits (60 kph and 40 kph). As expected, the average speeds were higher on corridors (48.98 kph) than road intersections (35.57 kph). Additionally, the number of vehicles driving 10 kph above the speed limit was estimated. Generally, 10 kph or more above the speed limit is considered to be an intentional behaviour rather than an error (Fleiter et al., 2010). LHPCO #5 presented the highest percentages of intentional speed limit offenders. A chi-square test confirmed that the proportion of intentional speed limit offenders decreases with higher speed limits ($\chi 2$ (6, n = 3,982) = 365.64, $p < .001$, $\varphi c = .303$).

Table 6. Vehicles' speed behaviour analysis on LHPCO (Source: authors)

LHPCO	Speed Limit (SL)	Speed					Kph over SL		
		# Data	Mean	SD	Max	Min	Under SL	SL (30 kph)	> 30 kph over SL
1	60	839	42.54	10.5	92.2	11.3	789	71 (8.46%)	768 (91.54%)
2	60	729	40.03	10.2	79.6	11.5	697	94 (12.89%)	635 (87.11%)
3	60	250	48.85	12.7	93.2	12.2	208	8 (3.2%)	242 (96.8%)
4	60	294	40.51	10.8	76.9	11	280	47 (15.98%)	247(84.02%)
5	60	262	65.63	10.8	118	16.5	91	6 (2.29%)	256(97.71%)
6	40	282	42.36	12.6	91.7	5.7	121	41 (14.54%)	241(85.46%)
7	30	972	24.96	14.4	93	10	749	749 (77.05%)	223(22.95%)
Total (sites with 30kph SL)		972	24.96	14.4	118	10	749	749 (77.05%)	223(22.95%)
Total (sites with 40kph SL)		282	42.36	12.6	93	5.7	121	41 (14.54%)	241(85.46%)
Total (sites with 60kph SL)		2374	47.51	10.7	91.7	11	2065	226 (9.52%)	2148(90.48%)

DISCUSSION

The present investigation analysed road user behaviour at locations with a high probability of crash occurrence in a Colombian city. The crash data analysis showed that motorcycle riders are overrepresented in road fatalities in Villavicencio (57.89%) (Agencia Nacional de Seguridad Vial, 2023). The proportion of fatalities that involved motorcyclists in this study is larger than those reported in South-East Asia (49.90%) and high-income countries (10.9%). This result highlights the importance of targeting this at-risk group of road users with interventions such as education and intensive police enforcement of the road rules. Alternatively, governments should also seek to disincentivise this transport mode in LMICs by providing access to safe and sustainable public transportation (Haworth, 2012). All age groups had similar rates of pedestrian fatalities. However, older adults presented the highest proportion of fatalities when involved in a crash. Injured elderly pedestrians have been reported to be at higher risk of severe injuries compared to other age groups in previous research (Charters et al., 2018; Kim, 2019). This finding is very concerning because Colombia has an ageing population. In the last census (2018) (Departamenta Administrativo Nacional de Estadistica – DANE, 2018), results showed that people aged 65 years and older accounted for 9.1% of the population, an increase of 2.8% from the previous census in 2005. The results of this study highlight the need to consider older pedestrians in developing road safety interventions and the design of road infrastructure. Furthermore, it is important to support this highly vulnerable group of road users to meet their mobility needs in a way that promotes their health and well-being (Luiu and Tight, 2021), which is usually overlooked in transport policies in LMICs.

Behavioural observations showed that pedestrians frequently engage in risky behaviours such as crossing roads when traffic signals are giving priority to vehicles. A potential explanation for this is that the Colombian authorities are prioritising motorised traffic over pedestrians and other forms of active travel by creating excessive delays or not timing the pedestrian walking speeds correctly (Hasan et al., 2020). Previous studies have shown the importance of accurately selecting cycle length and green/red times at signalised intersections to provide optimal waiting and crossing times for pedestrians (Almodfer et al., 2016). A potential solution for this is to prioritise the flow of pedestrians and similar road users through mid-block pedestrian crossings or shared zones (Shaaban et al., 2018).

The most relevant conflicts found in the study are related to pedestrians and motorised traffic. Corridors without pedestrian infrastructure registered an increased number of pedestrian-motorised vehicles conflicts. This can be explained by the lower predictability of pedestrian behaviour, which results from pedestrians having more potential affordances or actions that they can take as opposed to motorised vehicles. Generally, in urban environments, drivers of motorised vehicles must follow a designated path. On-road intersections with authorised pedestrian crossings that prioritise pedestrians are a good alternative to reduce this uncertainty (Shaaban et al., 2018). It is important to give pedestrians more significant priority while sharing the road by minimising walking distances and avoiding the use of infrastructure such as footbridges, which have low accessibility and acceptance (Oviedo and Parker, 2017; Cantillo et al., 2015). Pedestrian-centred policies will increase the safety, sustainability, and accessibility of the transport system.

Speed limits and driving speeds at the LHPCOs identified in the present study were found to be a threat for pedestrians. Given the numbers of pedestrians observed crossing the road at these locations, some of the speed limits are relatively high, i.e., 30 kph, 40 kph and 60 kph. This is an important risk factor because research has shown that a 30 kph speed limit is not sufficient to guarantee safe transit in zones with a high number of pedestrians, recommending 25 kph as a speed limit (Kröyer, 2015). When considering the actual driving speeds in the present study, nearly 75% of the drivers reached speeds higher than 30 kph independently of the speed limit.

Also, one fifth and one-tenth of the vehicles have speeds higher than 50 and 60 kph respectively. The probability of surviving in a collision for a pedestrian is 50% and 10% when vehicles reach speeds of 50 and 60 kph, respectively (Rosén and Sander, 2009). Considering that Colombia has speed limits in urban areas of 60 kph, there is a need to update the legislation to increase the safety of vulnerable road users (Kumphong et al., 2016; Wali et al., 2018).

When looking at speeding rates, vehicles driving above the speed limit, another important finding is that between 5.65% and 23.4% of all speeding incidents appear to be intentional. Fleiter et al. (Fleiter et al., 2010) explain that driving 10 kph above the speed limit is typically an intentional behaviour rather than an error, suggesting that this is a behaviour strongly linked with the personality, attitudes and beliefs of Colombian drivers. The results of the present study are not surprising since speeding has previously been recognised as a critical road safety issue in Colombia (Oviedo and Parker, 2018; Posada et al., 2000). Speeding is extremely risky for drivers and other road users, particularly in areas with large numbers of pedestrians. Police enforcement and public education are still primarily needed to reduce speeding among Colombian motorists.

CONCLUSION

The results show that motorcyclists and pedestrians face a higher risk compared to those in motorized vehicles. This trend is consistent with research findings from other low- and middle-income countries (LMICs) around the world. There is a significant need to promote more sustainable and healthy modes of transport in developing regions. Notably, younger and elderly road users are overrepresented in crash statistics, indicating a critical need for targeted safety interventions for these groups.

These demographic groups are considered vulnerable road users globally, regardless of a country's level of development. This underscores the necessity of including them in road safety planning in Colombia, where they are currently overlooked. Moving forward, it is imperative to revise the Colombian road safety strategy, as existing legislation and enforcement practices have proven insufficient in mitigating risky behaviours among both pedestrians and motorists. The prevalent issue of speeding among motorized vehicles demands immediate attention, as it poses a significant threat to all road users.

Future infrastructural development must prioritize and promote walking and cycling over other modes of transport. The absence of safe and suitable at-level pedestrian crossings is a widespread problem in Colombia and other LMICs. Addressing this gap is crucial for enhancing pedestrian safety and fostering a more pedestrian-friendly urban environment. Consequently, comprehensive efforts to improve road safety should focus on creating safe and accessible walking pathways, enforcing vehicle speed limits more effectively, and implementing targeted interventions for vulnerable populations, ensuring a safer and more inclusive transportation system for all.

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