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Influence of the inconsistency of the geometric layout on the road accident rate in a stretch of road with mountainous topography in southern Colombia

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Abstract

Road accidents are one of the factors that most adversely affect today's society, both due to the high number of victims it involves and the material losses it generates, year after year. In the case of Colombia, there is a high risk for the occurrence of traffic accidents on highways, because a large part of the road sectors that make up the country's road network are developed in mountainous topography, where due to the low budgets invested in road solutions by the authorities in charge, there are deficient geometric layouts, which generate a poor level of consistency. In this manuscript, the inventory of accidents that occurred during the period 2009 to 2014 is presented, along the Pasto - Chachagui road sector, located in the south of the country. By contrasting the location of the reported accidents, with the geometric characteristics of the route, it was possible to show that there is a close relationship between the inconsistency of the geometric route and the occurrence of traffic accidents, and it can be noted that most of the accidents occurred in those sections in which there is a poor geometric layout.

Keywords: road accident rate, mountainous topography, consistency, geometric design.

I. INTRODUCTION

Accident rate is one of the aspects that has the greatest negative impact on society, due to the high number of victims it charges every year around the world, including deaths and injured, in addition to the great material losses that it entails [1], [2]. The occurrence of traffic accidents occurs due to the concordance of various factors, which depend on human nature, the road infrastructure, the vehicle and the physical or climatic environment in which the vehicle operates [3], being related with infrastructure, one of the most relevant for traffic engineering. Therefore, it is very important to achieve a comprehensive design of the road, in such a way that it contains the necessary elements for proper operation and that the geometric characteristics of the route allow users to provide homogeneity, safety and comfort, in such a way that the risks of the occurrence of adverse events, such as accidents, are minimized [3], [1].

A notable point to highlight is related to the importance of topography in the geometric design of a road [4], which in Colombia constitutes one of the variables with the greatest impact on the execution of a road project, since a large part of the country's geography is developed in mountainous terrain. This circumstance, added to the scarce resources available to the state for investment in infrastructure, have a great impact on the deficient specifications, which both in plan and in profile, are usually present in the geometric layouts of many of the country's highways.

In view of the above, it is important to take into consideration the importance of the consistency of the geometric design in road safety, taking into account that it allows establishing the degree of adaptation between the behaviour of the road and the expectations of the driver [5], which in the case of mountainous topography, tends to present unfavourable conditions in developing countries such as Colombia.

To measure the magnitude of the problem associated with the accident rate, Traffic Engineering has implemented a series of indices, through which indicators are established that allow making comparisons of interest related to the severity of the problem in a place and in a given time. For this purpose, the details related to the accidents are contrasted with other variables such as the population census, the number of motor vehicles and traffic [2]. It is worth noting that in order to obtain reliable accident rates, all the information related to the details of the accidents must be based on data collected by the authorities in charge of the regulation and control of vehicular traffic [6].

The objective of this work focuses on establishing possible correlations between the occurrence of traffic accidents and the consistency of the geometric design for the case of road corridors developed in mountainous topography. For this purpose, an analysis is made of the traffic accidents that occurred along the San Juan de Pasto - Chachagui road sector during the 2019-2014 period, where the possible causes of these events are identified, emphasizing the conditions of service offered by the road, with respect to those expected by drivers, with regard to its geometric layout.

II. MATERIALS AND METHODS

The data on accident rates used in this study were obtained from the reports provided by the Secretary of Traffic and Transportation of the municipality of San Juan de Pasto and by the Highway Police, attached to the department of Nariño. These reports contain information related to the location of the event's occurrence site, type of accident, determination of the number of injured and/or deaths, date and time of occurrence and hypotheses about the possible causes of the accident.

Table 1 presents a summary of the main characteristics related to the accidents that occurred along the road corridor under study, during the years 2009 to 2014.

Table 1. Summary of accident characteristics - Period 2009 - 2014

Road Section	Number of Accidents	Injured	Deaths	Type of Accident
5+700	1	1	0	Vehicle collision
5+800	1	1	1	Vehicle collision
6+200	1	2	0	Vehicle collision
6+700	1	2	0	Vehicle collision
6+800 6+850	2	2	0	Pedestrian run over
6+900 7+000	3	3	1	Vehicle collision
7+600	1	1	0	Vehicle collision
7+800	1	2	0	Vehicle collision
8+300	1	5	2	Rollover
9+500	1	1	0	Vehicle collision
10+400	1	1	0	Pedestrian run over
10+600 10+650 10+760 10+800	4	6	0	Vehicle collision Pedestrian run over Vehicle collision Vehicle collision
11+800	1	3	0	Vehicle collision
12+550	1	0	1	Vehicle collision
12+900 13+000	3	4	0	Rollover Vehicle collision Vehicle collision
13+100 13+200	2	1	1	Fall of car occupant Vehicle collision
13+500	1	0	1	Vehicle collision
14+700	1	2	0	Vehicle collision
14+900	1	2	0	Vehicle collision
15+000	1	0	1	Vehicle collision
15+900	1	2	0	Vehicle collision
17+450	1	2	0	Vehicle collision
17+900	1	1	0	Vehicle collision
19+200	1	2	1	Vehicle collision
19+600	1	4	0	Vehicle collision
21+000	1	2	0	Vehicle collision
22+000	2	7	0	Rollover Vehicle collision
22+900	1	1	0	Fall of car occupant
24+000	1	1	0	Pedestrian run over
25+800	1	0	1	Vehicle collision
25+900	1	1	0	Vehicle collision
26+500	1	1	0	Vehicle collision
26+950	1	1	1	Vehicle collision
27+000	1	1	0	Pedestrian run over
27+600	1	0	1	Pedestrian run over
27+700	1	1	0	Vehicle collision
27+957 28+070	2	1	1	Vehicle collision Pedestrian run over

For the processing and analysis of accident information, the following was done:

1. Organization of accident reports: the information in the accident record was reviewed and they were broken down by abscissa and by date of occurrence of the event.

2. Accident inventory: the information of all accidents was processed and some graphs of the statistics that represent it were generated.

3. Determination of the Annual Average Daily Traffic: the AADT information for the years 2009, 2010, 2011, 2012, 2013 and 2014 was obtained from the annual records issued by the Instituto Nacional de Vías. This information is required to determine some of the accident rates.

4. Calculation of basic accident rate indicators: the basic accident rate was calculated; Danger Index (Ip) and Severity Index (Is), by sections of one kilometer in length and for each year of analysis.

In equation (1), the expression to calculate the Danger Index (Ip) is presented.

$$Ip = \frac{Nat * 10^6}{AADT * 365 * L} \qquad (1)$$

Where Nat is the number of total accidents recorded in a year, AADT is the average daily traffic and L is the length of the section. It is expressed in veh / km.

On the other hand, the Severity Index (Is) is calculated by means of equation (2).

$$Is = \frac{(M * 18 + H * 2 + S * 1) * 10^6}{AADT * 365 * L} \qquad (2)$$

Where M is the number of accidents with fatalities, H the number of accidents with injuries, S the number of accidents with property damage, AADT the average daily traffic and L the length of the section.

On the other hand, the Morbidity Index (Imorb) and Mortality Index (Imort), for each section of one kilometer, are calculated according to equations (3) and (4), respectively.

$$Imorb = \frac{Nah}{L} \qquad (3)$$

Where Nah is the number of accidents involving injuries in each year and L is the length of the section.

$$Imort = \frac{Nam}{L} \qquad (4)$$

Where Nam is the number of accidents that register deaths in each year and L is the longitude.

Once the proposed accident rates had been calculated, the determination of the critical points in terms of road safety continued. For this purpose, those sections in which at least one of the accident rate indicators were greater than or equal to the sum of the mean, plus the standard deviation, were taken as critical.

On the other hand, to take into account the characteristics of the geometric layout, an assessment of the consistency of the layout was taken, in accordance with the two criteria proposed by Lamm, related to the operating speed and the design speed [7], [8]. Table 2 shows the three levels of consistency considered to measure the quality of the service provided to users, based on the results obtained when applying the two Lamm criteria: criterion I, based on the comparison of the speeds of operation and design elements of the route, and criterion II, based on the comparison of operating speeds between consecutive elements of the route [9].

Table 2. Consistency criteria according to Lamm

Consistency rating	**Criterion I (km/h)**	**Criterion II (km/h)**
Good	$\lvert V_{85} - V_d \rvert \leq 10$	$\lvert V_{85\,i} - V_{85\,i+1} \rvert \leq 10$
Fair	$10 \leq \lvert V_{85} - V_d \rvert \leq 20$	$10 \leq \lvert V_{85\,i} - V_{85\,i+1} \rvert \leq 20$
Poor	$\lvert V_{85} - V_d \rvert > 20$	$\lvert V_{85\,i} - V_{85\,i+1} \rvert > 20$

III. RESULTS AND DISCUSSIONS

The road inventory carried out along the road under study yielded the following results: along the 23 km that make up the section, there are berms smaller than 1.5 m; no curves feature over width; there are 139 horizontal curves, which yields an approximate average of 6 curves per kilometer, that is, a horizontal curve every 150 m, most with relatively small radius; 139 between tangents, of which 81 (58.28%) are less than 50 m in length, and only 15 (10.8%) have a length greater than 150 m; Throughout the entire stretch, there is no good lighting at night, nor reflective horizontal signage; there are no adequate sections for parking vehicles in case of incidents; Almost all the vertical signs are in good condition, but some of them are beginning to be in poor condition, and there is also a deficit of signs indicating “speeding” in pedestrian areas; there are no efficient structures for pedestrians, and there is no adequate complementary infrastructure for the transit of motorcyclists, cyclists or pedestrians; the condition of the pavement is good; there are fixed objects on the road, very close to the edge of the road, such as retaining walls and culvert heads, which do not have adequate signage; the ditches are inadequate throughout the section, generating potential risks in the occurrence of an accident; there is little visibility distance between horizontal curves; there are no clear side zones for braking and stopping vehicles in the event of loss of control; 100% of the side barriers present inadequate termination that generate high risk to users [10].

Table 3 shows the accident rates, broken down into one kilometer sections. In the aforementioned Table, the accident rates that exceed the sum of the mean plus the standard deviation are highlighted, in order to determine the critical accident sites. In accordance with the indications, four critical sections are obtained: PR8 – PR9, PR10 – PR11, PR13 – PR14 and PR27 – PR28.

Table 3. Accident rates for the Pasto - Chachagui section

PR	**Indices**			
	Ip	**Is**	**Imorb**	**Imort**
5– 6	0.53	2.78	1	1
6– 7	0.68	1.17	2.75	-
7– 8	0.65	3.14	2	1
8– 9	0.48	8.66	5	2
9– 10	0.48	0.96	1	-
10– 11	0.9	1.32	2	-
11– 12	0.48	0.96	3	-
12– 13	0.55	4.61	1	1
13 – 14	0.82	5.1	1.33	1
14 – 15	0.56	1.12	2	-
15 – 16	0.53	2.78	2	1
16 – 17	-	-	-	-
17 – 18	0.49	0.99	1.5	-
18– 19	-	-	-	-
19 – 20	0.5	2.72	3	1
20 – 21	-	-	-	-
21 – 22	0.51	1.01	2	-
22 – 23	0.73	1.08	3	-
23 – 24	-	-	-	-
24 – 25	0.49	0.25	1	-
25 – 26	0.55	4.94	-	1
26 – 27	0.49	2.7	1	1
27 – 28	0.99	5.81	1	1
Mean	0.6	2.79	2.03	1.1
σ	0.15	2.1981	1.1115	0.3
σ+mean	0.75	4.99	3.14	1.4

In Fig. 1, the relative distribution of accidents with respect to the study period is shown. A higher concentration of accidents can be observed during the last three years considered within the study period.

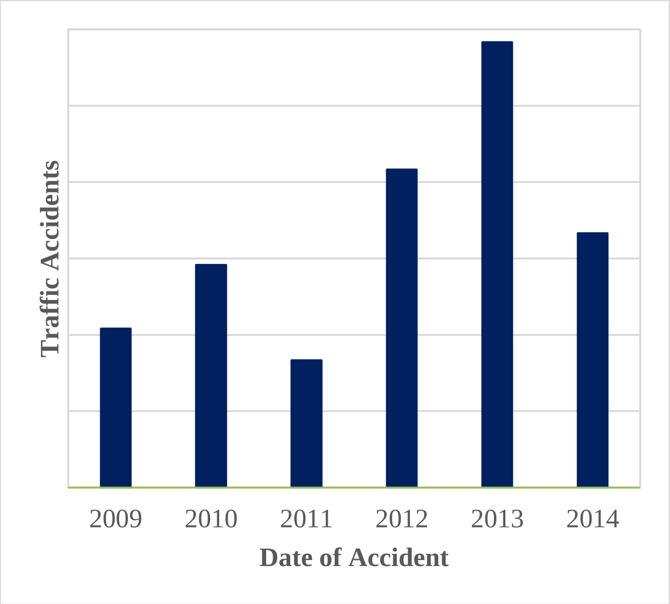

Fig. 1. Distribution of the accident rate during study period

In Table 4, it can see the details about the accidents that occurred in the critical points detected along the road sector under study. As can be seen, the predominant type of accident is the collision between vehicles.

Table 4. Information on accidents at critical points

PR	**Type of Accident**	**Date**	**Injured**	**Deaths**
8+300	Rollover	2/05/2009	5	2
10+650	Pedestrian run over	13/11/2010	2	
10+760	Vehicle collision	21/06/2010	1	
10+600	Vehicle collision	15/11/2012	1	
10+400	Pedestrian run over	3/12/2013	1	
10+800	Vehicle collision	8/08/2013	2	
13+000	Vehicle collision	6/06/2012	1	
13+000	Vehicle collision	16/06/2013	2	
13+500	Vehicle collision	27/01/2013		1
13+100	Fall of car occupant	15/04/2014	1	
13+200	Vehicle collision	7/01/2014		1
27+000	Pedestrian run over	8/07/2012	1	
27+957	Vehicle collision	14/10/2012	1	
27+600	Pedestrian run over	13/02/2014		1
27+700	Vehicle collision	29/03/2014	1	

In Table 5, the results of Lamm's I criterion can be observed, for the four critical accident sectors established above. It should be noted that this Table only shows the sections adjacent to the sites where traffic accidents were recorded.

In Figure 2, the relative distribution of the accidents with respect to the geometric characteristics, in relation to the level of consistency in the layout, is shown, taking into account the two Lamm criteria. It can be seen that about 56% of the accidents that occurred throughout the sector under study occurred in sections with poor consistency in the geometric layout. It is also noted that only 8% of the accidents occurred in sections with good consistency in the geometric layout.

Table 5. Summary of the results of Criterion I of Lamm for the critical accident section

INITIAL PR	FINAL PR	LAMM'S CRITERIA I FOR CONSISTENCY OPERATING SPEED NORTH - SOUTH DIRECTION			LAMM'S CRITERIA I FOR CONSISTENCY OPERATING SPEED SOUTH - NORTH DIRECTION		
		CARS	BUSES	TRUCKS	CARS	BUSES	TRUCKS
Km 8+241,482	Km 8+345,377	Good	Fair	Good	Good	Good	Good
Km 10+309,340	Km 10+415,764	Poor	Fair	Fair	Poor	Poor	Fair
Km 10+415,764	Km 11+258,910	Poor	Good	Good	Fair	Good	Good
Km 12+832,030	Km 13+043,053	Poor	Fair	Good	Poor	Poor	Good
Km 13+043,053	Km 13+427,790	Good	Good	Good	Poor	Fair	Fair
Km 13+427,790	Km 13+566,377	Poor	Fair	Good	Fair	Good	Good
Km 26+879.44	Km 26+981.38	Fair	Fair	Good	Poor	Poor	Fair
Km 26+981.38	Km 27+038.88	Fair	Good	Good	Poor	Fair	Fair
Km 27+038.88	Km 27+131.44	Fair	Good	Good	Poor	Fair	Fair
Km 27+536.43	Km 27+638.52	Good	Good	Good	Good	Good	Good
Km 27+672.97	Km 27+714.57	Fair	Good	Good	Fair	Good	Good
Km 27+893.33	Km 28+201.40	Fair	Good	Good	Fair	Good	Good

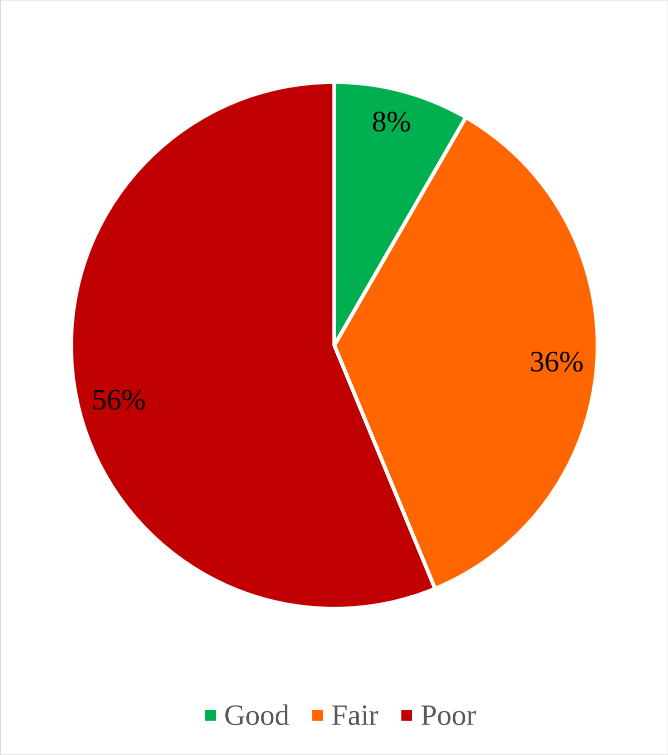

Fig. 2. Location of accidents with respect to the level of consistency of the geometric layout

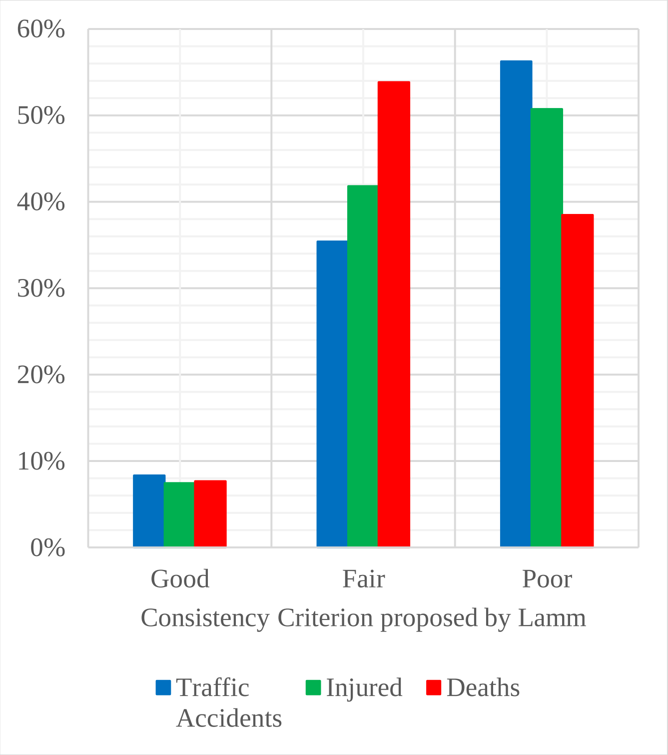

Fig. 3. Distribution of accidents and casualties with respect to the level of consistency

In Fig. 3, another interesting graph is shown, where the distribution of accidents and victims with respect to the level of consistency of the geometric layout is presented. It can be clearly observed that the highest concentration of accidents and victims, counting deaths and injuries, occurs in sections with poor or regular consistency in the route.

In a complementary manner, Fig. 4 shows the distribution of accident types with respect to the level of consistency of the layout. It can be seen that the most predominant type of accident is the collision between vehicles and that these occur mostly, in sections of poor and regular consistency.

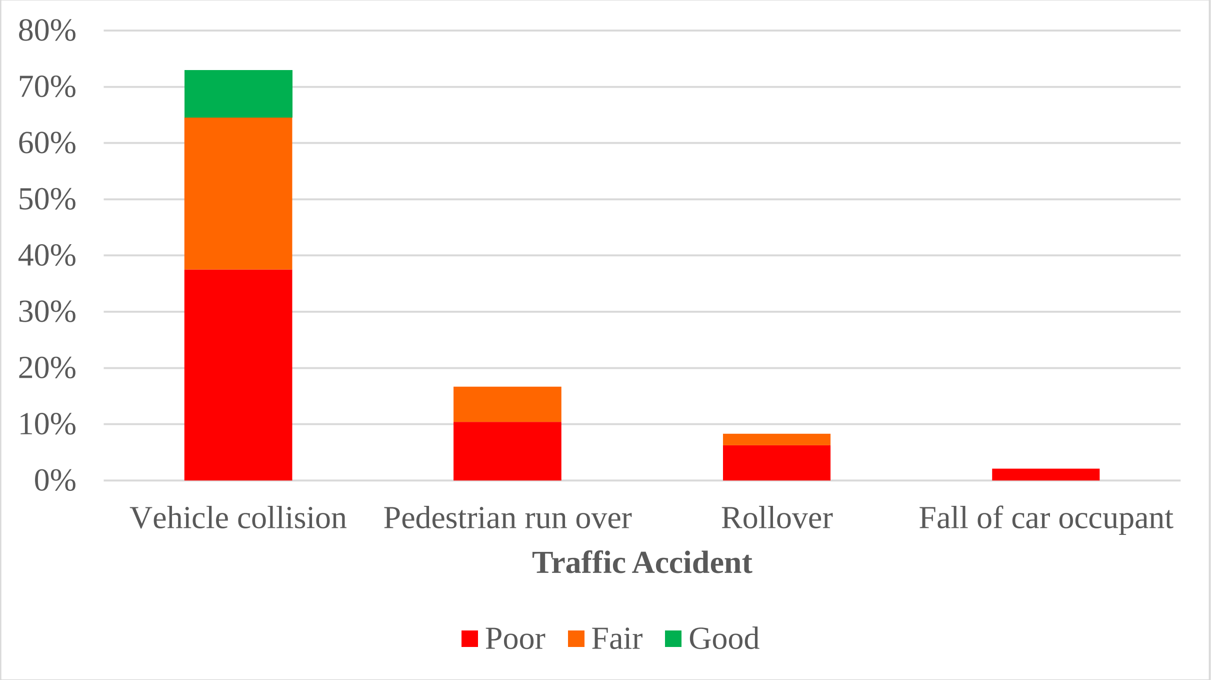

Fig 4. Distribution of accident types with respect to consistency level

According to the details shown in Figures 2, 3 and 4, the direct relationship between the accident rate and the poor specifications of the geometric layout is revealed.

IV. CONCLUSION

According to the results obtained in the present work, it was established that there is a close relationship between the consistency of the geometric design in the layout of a road and the occurrence of traffic accidents. It was observed that most of the accidents, where in addition to the material losses there was a significant concentration of victims, including deaths and injured, occurred in those sections in which there is a poor geometric layout. For this reason, a greater investment is required from the Colombian authorities in improving the country's road network and, above all, in mountainous sectors, which is where road sectors with poor geometric layouts predominate, where they prevail strong longitudinal slopes and horizontal curvatures with relatively small radius, which generate specific speeds lower than the operating speeds with which users circulate.

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