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Determination of the Consistency in the Geometric Layout of a Mountainous Topography Road Based on the Determination of the Vehicle Operating Speed Profile Measured Through Radar

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Abstract

The speed of vehicular flow is one of the most important variables to characterize the quality of the service provided to road users, which not only greatly influences the determination of Capacity and Service Levels, but also, that through the knowledge of the operating speeds, the traffic speeds of the different elements that make up the geometric layout (curves and tangents in plan) and the design speed within a particular road section, it is possible to determine the consistency geometric design, which in general terms, expresses the degree of adequacy between the behaviour of the road and the expectations of the driver. . For this work, it is presented, from the determination of the operating speeds, obtained through the use of radar, the consistency in the geometric design along a road section located in the southwest of Colombia and developed in mountainous topography, in which it was possible to evidence the existence of inconsistency in the geometric design in a significant number of elements of the way, which can generate unsafe conditions for road users

Keywords: Operating speed profile, consistency, geometric design

I. INTRODUCTION

Speed corresponds to one of the main indicators to measure the quality of the operation of a transport system, because it involves aspects such as safety, comfort, time and economy during the journey [1], [2]. An efficient transport system can be measured by the quality of the road system and the time used to make the journey along it, with which speed takes on a high degree of importance, which is why it needs to be determined, analyzed, regulated and controlled, in order to create a balance between the user, the vehicle and the road infrastructure [2].

Speed is so important that it is usually the reference parameter used to measure the level of service of a road, offering the driver safety, comfort and speed when transporting [3]. Therefore, it is very important to know the characteristic operating speed of a road corridor, which corresponds to the maximum average speed at which a driver can circulate on a given section of road, under favorable weather conditions, prevailing traffic conditions and without exceeding the safe speed at any time, circulating under free flow conditions [4]; since through this, a relationship could be established with the geometric characteristics of the road, in order to evaluate the consistency of a certain section, which is highly correlated with road safety [5], [6].

Consistency in the geometric design of a road can be defined as the degree of adequacy between the behaviour of the road and the driver's expectations [7]. Within the methods to estimate consistency, the study of operating speed is considered the simplest way to carry it out [8], hence some authors such as Mclean (1981) [9] consider that the main cause of Inconsistency of the designs is related to the difference between the design speed and the operating speed [10]; and Lamm (1986) [7] adopts this postulate and builds its consistency criteria based on successive field studies.

To determine the operating speed within a road element, whether it is shaped in a tangent or a curve, it is necessary to carry out a study of spot speeds, which seeks to measure the quality of traffic movement, through the two components of spot speed, that is, the mean temporal and spatial velocity; and of the travel speed and the walking speed [2].

On-site field speed studies are performed to estimate the speed distribution of vehicles in a vehicle flow and at a specific location on a highway. An on-site field speed study consists of recording the speed of a sample of vehicles at a specific location. The speed characteristics identified will be valid only for the traffic and environmental conditions that exist at the time of study [4].

The main objective of this work has been to determine the operating speed profiles, for the case of cars, buses and two-axle trucks, which correspond to the most representative vehicles of the road corridor under study, in order to evaluate the consistency in the geometric design along a section of highway approximately 6.0 kilometres in length, located between K6 + 886.28 and K13 + 043.05 of the Pasto - Mojarras Highway, towards the southwest of Colombian country.

II. MATERIALS AND METHODS

II.I Aspects used for the evaluation of the consistency of the geometric design

To carry out the evaluation of the consistency of the geometric design of the road section under study, some basic aspects established in the Lamm procedure will be used, which is based on three criteria, of which the first two will be used, as they are the most used by most authors and on which there is more experience.

- Criterion I: comparison between design speed and operating speed, which is a good indicator of the inconsistency that may exist in a particular element.
- Criterion II: comparison of operating speeds between consecutive elements of the road layout. This is a good indicator of the inconsistency experienced by drivers traveling from one element to the next.

Table 1. Lamm consistency criteria

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

Table 1 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.

II.II Characteristics of the elements that make up the section under study

For the purposes of this work, 50 continuous elements were taken along the road section between K6 + 886.28 and K13 + 043.05 of the Pasto - Mojarras Highway, located in the southwest of Colombia. It is a typical layout of mountainous topography, with abundant CURVEture in plan and strong longitudinal slopes.

From the field work carried out, the basic information related to the elements of the layout in plan and profile was obtained, such as the type of element in plan evaluated (tangent or curve), the deflection of the curves, the radius, the maximum cant in the horizontal curves, the length of the elements, their location within the abscissa of the road and the characteristic longitudinal slope of each element evaluated.

Table 2 shows the characteristics of the elements of the road section under study.

II.III Determination of the operating speeds in each element evaluated

For the purposes of this work, the vehicles with the highest incidence in the global component of traffic along the road section under study were taken as a reference, which, according to the vehicle traffic volumes determined by the Instituto Nacional de Vías (INVIAS) of Colombia, correspond to cars, buses and two-axle trucks (small and large).

To determine the minimum size of the spot speed sample, for each class of vehicle considered, the following expression was used [2]:

$$N = \left(\frac{K * S}{E}\right)^2 \qquad (1)$$

Where:

N: is the minimum number of spot speed data to record in each element.

K: constant that corresponds to a certain desired level of confidence, which takes the value of 2.00, for a confidence level of 95.5%.

E: allowed error in estimating the main speed of all traffic, which can be taken at 2.00 km / h.

S: average standard deviation of 8 km / h, as an empirical value for spot speeds on any type of road and traffic.

To determine the spot speed for each class of vehicle considered, the automatic method was used through the implementation of the Bushnell radar gun, whose receiver is designed to read the Doppler frequency, within the range of frequencies between 360 Hz and 43 KHz, capable of taking readings in 0.25 seconds [11]. It should be noted that this field work was carried out in each element and for each direction of circulation independently, respecting in each case the minimum size of the sample, which according to equation (1), turned out to be 64 readings of speed.

III. RESULTS AND DISCUSSIONS

III.I Obtaining the traffic speed for each element

For the determination of the specific velocities in each horizontal curve, these were found as a function of the radius and the maximum cant, which were obtained from planes and direct measurements made in the field.

For the case of the horizontal tangents, the traffic velocity was assigned the highest of the specific velocities of the curves adjacent to it.

In Table 3, the result obtained for the assignment of the traffic speed of each element is presented.

III.II Obtaining the design speed of the section

According to the *Manual de Diseño Geometrico* (INVIAS 2008), with regard to the design speed of a homogeneous section, it is defined according to the category of the road and its topographic characteristics [12], according to what is indicated in Table 4.

Notwithstanding the foregoing, taking into account that the road under study was designed and built long before Table 4 came into force, the characteristics of the road corridor, as it is developed in mountainous terrain, has very poor specifications, which is why for the purposes of this work, will be taken as the project speed, the minimum traffic speed found in the allocation of speeds along the section under study, that is, 40 km/h.

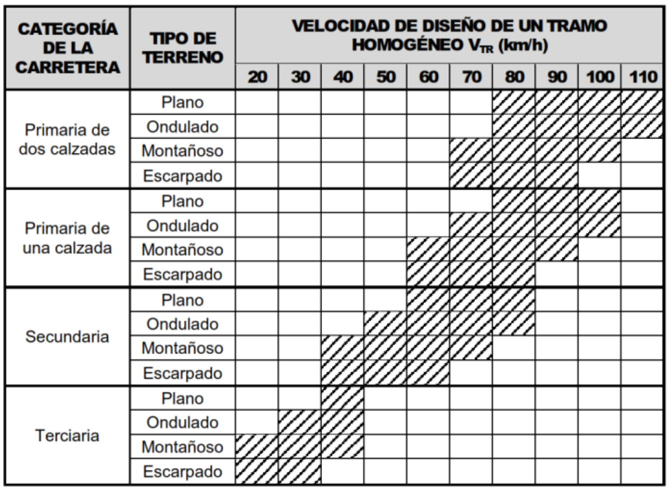
Table 2. Characteristics of the elements of the road section

ELEMENT NUMBER	TYPE OF ELEMENT	SENTIDO	DEFLECTION	RADIUS	CANT (%)	ELEMENT LENGTH	INITIAL ABSCISA	FINAL ABSCISA	SLOPE (%)
1	TANGENT					285.605	KM 6+886,282	KM 7+171,887	6.148
2	CURVE	Right	40^{0} 19'51"	116.698	7.28%	82.145	KM 7+171,887	KM 7+254,032	6.148
3	TANGENT					103.768	KM 7+254,032	KM 7+357,800	6.148
4	CURVE	Left	48^{0} 55'02"	101.552	5.53%	86.702	KM 7+357,800	KM 7+444,502	6.148
5	TANGENT					225.907	KM 7+444,502	KM 7+670,409	6.148
6	CURVE	Right	100^{0} 10'21	65.633	8.46%	114.749	KM 7+670,409	KM 7+785,158	6.148
7	TANGENT					106.418	KM 7+785,158	KM 7+891,576	6.148
8	CURVE	Left	83^{0} 09'40"	51.471	8.75%	74.707	KM 7+891,576	KM 7+966,283	6.148
9	TANGENT					54.74	KM 7+966,283	KM 8+021,023	6.148
10	CURVE	Right	66^{0} 38'49"	60.728	10.22%	70.64	KM 8+021,023	KM 8+091,663	6.148
11	TANGENT					31.751	KM 8+091,663	KM 8+123,414	6.148
12	CURVE	Left	56^{0} 55'45"	118.828	7.58%	118.068	KM 8+123,414	KM 8+241,482	6.148
13	TANGENT					103.895	KM 8+241,482	KM 8+345,377	6.148
14	CURVE	Left	15^{0} 44'31"	193.188	4.07%	53.078	KM 8+345,377	KM 8+398,455	6.148
15	TANGENT					85.341	KM 8+398,455	KM 8+483,796	6.148
16	CURVE	Right	65^{0} 36'00"	85.934	5.53%	98.389	KM 8+483,796	KM 8+582,185	6.148
17	TANGENT					40.512	KM 8+582,185	KM 8+622,697	6.148
18	CURVE	Right	34^{0} 52'25"	155.015	6.12%	94.351	KM 8+622,697	KM 8+717,048	6.148
19	TANGENT					423.775	KM 8+717,048	KM 9+140,823	6.148
20	CURVE	Left	61^{0} 44'09"	87.229	8.16%	93.989	KM 9+140,823	KM 9+234,812	6.148
21	TANGENT					40.704	KM 9+234,812	KM 9+275,516	6.148
22	CURVE	Right	44^{0} 18'30"	111.161	8.16%	85.964	KM 9+275,516	KM 9+361,480	6.148
23	TANGENT					141.439	KM 9+361,480	KM 9+502,919	6.148
24	CURVE	Right	43^{0} 12'49"	138.133	5.24%	104.183	KM 9+502,919	KM 9+607,102	5.027
25	TANGENT					69.472	KM 9+607,102	KM 9+676,574	5.027
26	CURVE	Left	52^{0} 22'35"	102.193	8.16%	93.419	KM 9+676,574	KM 9+769,993	5.027
27	TANGENT					166.655	KM 9+769,993	KM 9+936,648	5.027
28	CURVE	Left	22^{0} 40'19"	177.031	5.53%	70.051	KM 9+936,648	KM 10+006,699	5.027
29	TANGENT					99.511	KM 10+006,699	KM 10+106,210	5.027
30	CURVE	Right	68^{0} 59'15"	101.448	8.46%	122.149	KM 10+106,210	KM 10+228,359	5.027
31	TANGENT					80.981	KM 10+228,359	KM 10+309,340	5.027
32	CURVE	Left	41^{0} 34'52"	146.644	4.37%	106.424	KM 10+309,340	KM 10+415,764	5.027
33	TANGENT					843.146	KM 10+415,764	KM 11+258,910	-6.851
34	CURVE	Right	75^{0} 58'28"	68.316	8.16%	90.587	KM 11+258,910	KM 11+349,497	-6.851
35	TANGENT					75.163	KM 11+349,497	KM 11+424,660	-6.851
36	CURVE	Left	59^{0} 15'35"	87.625	5.24%	90.628	KM 11+424,660	KM 11+515,288	-6.851
37	TANGENT					32.472	KM 11+515,288	KM 11+547,760	-6.851
38	CURVE	Right	46^{0} 35'05"	96.115	7.58%	78.147	KM 11+547,760	KM 11+625,907	-6.851
39	TANGENT					33.323	KM 11+625,907	KM 11+659,230	-6.851
40	CURVE	Right	48^{0} 20'02"	91.364	6.99%	77.073	KM 11+659,230	KM 11+736,303	-6.851
41	TANGENT					79.977	KM 11+736,303	KM 11+816,280	-6.851
42	CURVE	Left	157^{0} 22'02	101.272	8.75%	278.151	KM 11+816,280	KM 12+094,431	-6.851
43	TANGENT					136.689	KM 12+094,431	KM 12+231,120	-6.851
44	CURVE	Left	40^{0} 55'48"	149.548	6.12%	106.831	KM 12+231,120	KM 12+337,951	-6.851
45	TANGENT					54.779	KM 12+337,951	KM 12+392,730	-6.851
46	CURVE	Right	69^{0} 22'18"	100.939	7.87%	122.213	KM 12+392,730	KM 12+514,943	-6.851
47	TANGENT					171.987	KM 12+514,943	KM 12+686,930	-6.851
48	CURVE	Right	103^{0} 28'39	59.336	6.70%	107.162	KM 12+686,930	KM 12+794,092	-6.851
49	TANGENT					37.938	KM 12+794,092	KM 12+832,030	-6.851
50	CURVE	Left	133^{0} 31'54	90.546	6.41%	211.023	KM 12+832,030	KM 13+043,053	-6.851

Table 3. Traffic speed for each element

ELEMENT NUMBER	TYPE OF ELEMENT	RADIUS	CANT (%)	TRAFFIC SPEED	ELEMENT NUMBER	TYPE OF ELEMENT	RADIUS	CANT (%)	TRAFFIC SPEED
1	TANGENT			60	26	CURVE	102.193	8.16%	60
2	CURVE	116.698	7.28%	50	27	TANGENT			60
3	TANGENT			50	28	CURVE	177.031	5.53%	45
4	CURVE	101.552	5.53%	40	29	TANGENT			60
5	TANGENT			45	30	CURVE	101.448	8.46%	60
6	CURVE	65.633	8.46%	45	31	TANGENT			60
7	TANGENT			45	32	CURVE	146.644	4.37%	40
8	CURVE	51.471	8.75%	45	33	TANGENT			50
9	TANGENT			45	34	CURVE	68.316	8.16%	50
10	CURVE	60.728	10.22%	45	35	TANGENT			50
11	TANGENT			55	36	CURVE	87.625	5.24%	40
12	CURVE	118.828	7.58%	55	37	TANGENT			50
13	TANGENT			55	38	CURVE	96.115	7.58%	50
14	CURVE	193.188	4.07%	40	39	TANGENT			50
15	TANGENT			40	40	CURVE	91.364	6.99%	45
16	CURVE	85.934	5.53%	40	41	TANGENT			60
17	TANGENT			45	42	CURVE	101.272	8.75%	60
18	CURVE	155.015	6.12%	45	43	TANGENT			60
19	TANGENT			55	44	CURVE	149.548	6.12%	50
20	CURVE	87.229	8.16%	55	45	TANGENT			55
21	TANGENT			60	46	CURVE	100.939	7.87%	55
22	CURVE	111.161	8.16%	60	47	TANGENT			55
23	TANGENT			60	48	CURVE	59.336	6.70%	40
24	CURVE	138.133	5.24%	40	49	TANGENT			40
25	TANGENT			60	50	CURVE	90.546	6.41%	40

Table 4. Design Speed Values



CATEGORÍA DE LA CARRETERA	TIPO DE TERRENO	VELOCIDAD DE DISEÑO DE UN TRAMO HOMOGÉNEO V_{TR} (km/h)									
		20	30	40	50	60	70	80	90	100	110
Primaria de dos calzadas	Plano							▨	▨	▨	▨
	Ondulado							▨	▨	▨	▨
	Montañoso						▨	▨	▨	▨	
	Escarpado						▨	▨	▨		
Primaria de una calzada	Plano							▨	▨	▨	
	Ondulado						▨	▨	▨	▨	
	Montañoso					▨	▨	▨	▨		
	Escarpado					▨	▨	▨			
Secundaria	Plano					▨	▨	▨			
	Ondulado				▨	▨	▨	▨			
	Montañoso			▨	▨	▨	▨				
	Escarpado			▨	▨	▨					
Terciaria	Plano			▨							
	Ondulado		▨	▨							
	Montañoso	▨	▨	▨							
	Escarpado	▨	▨								

Source: Manual de Diseño Geometrico de Carreteras (INVIAS)

III.III Obtaining the operating speed for each element

With the collected field information, related to the recording of spot speeds for each category of traffic considered, and measured in the two directions of circulation independently, the statistical analysis was carried out, grouping the measured speeds in intervals of class, where the relative and accumulated frequencies could be established, in order to obtain the 85th percentile, which corresponds to the operating speed for each class of vehicle.

Based on the previous procedure, Table 4 was obtained, in which the operating speeds in the north-south and south-north directions are presented, for each element of the way section and discriminated in the different categories of traffic considered.

III.IV Analysis of the consistency of the section through design and operating speeds

For the evaluation of the consistency of the geometric layout of the road, speed profiles will be used, through which sites that present difficulties in the layout can be identified, which can be evidenced from the differences between the operating, traffic and design speeds.

The speed profiles allow to graphically and continuously demarcate along the abscissa, the speed of the section, the traffic speed and the operating speed for the cars, buses and trucks considered.

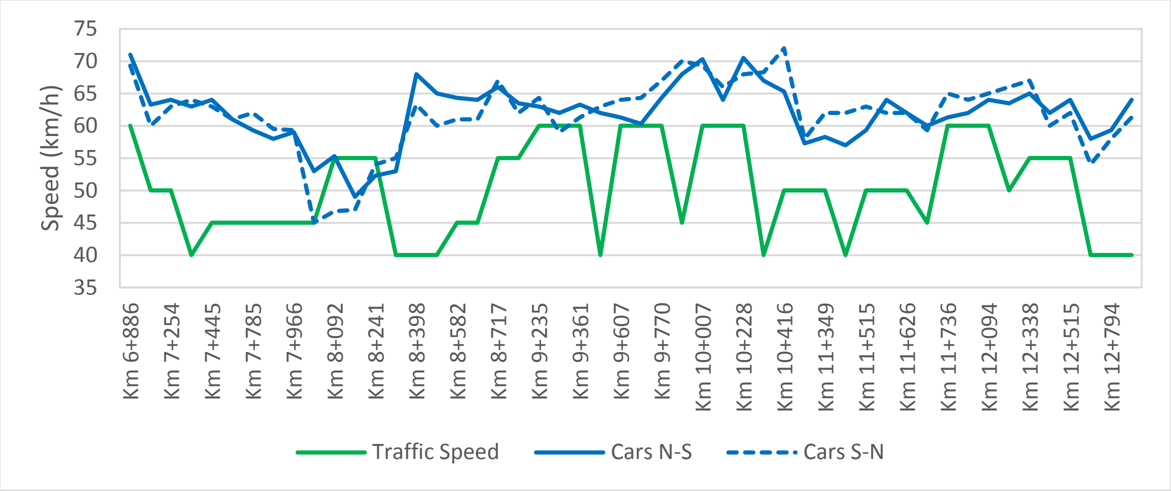


Fig. 1. Profile of operating speeds for automobiles and specific and design speeds for the K6 + 886.28 / K13 + 043.05 sector of the Pasto - Mojarras Highway

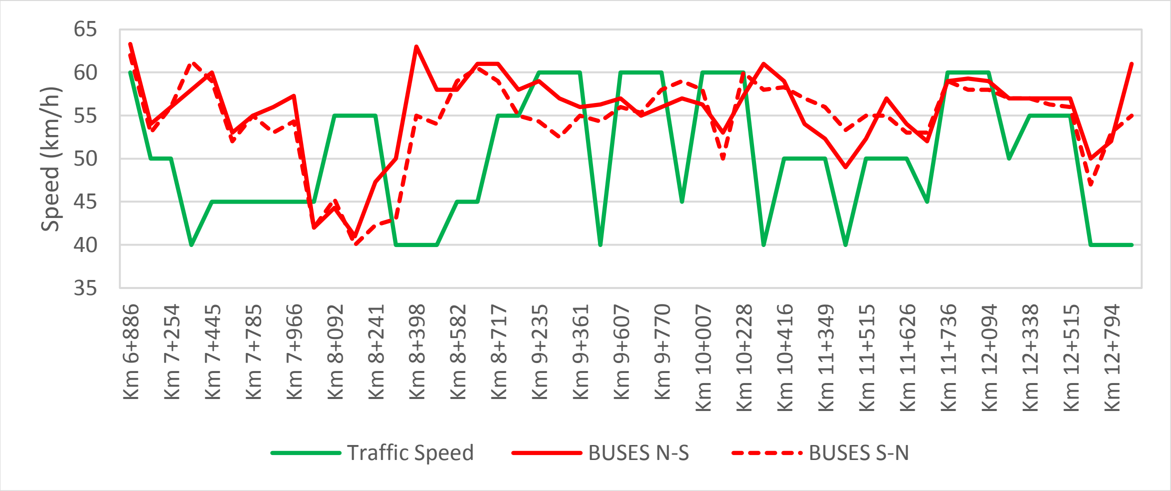


Fig. 2. Profile of operating speeds for buses and specific and design speeds for the K6 + 886.28 / K13 + 043.05 sector of the Pasto - Mojarras Highway

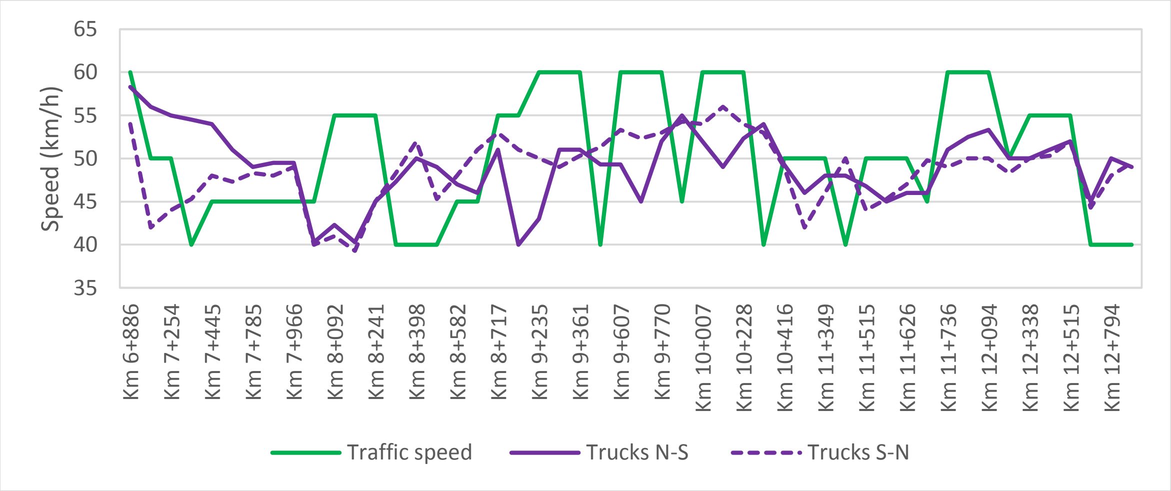


Fig. 3. Profile of operating speeds for two-axle trucks and specific and design speeds for the K6 + 886.28 / K13 + 043.05 sector of the Pasto - Mojarras Highway

In Figures 1, 2 and 3, the operating speed profiles discriminated for each class of vehicle are presented, considering the two directions of movement. Similarly, in each of the graphs, the traffic speed profiles and design speed are also presented.

According to Figure 1, except for elements 11, 12 and 13, located between the abscissa Km 8 + 091,663 and Km 8 + 241,482, in the case of automobiles, these present for the rest of the elements, in general, operating speeds, significantly higher than the specific speeds obtained along the route, which in some of these, especially in the tightest curves, could generate unsafe driving conditions and lead to the occurrence of accidents, attributable to excess speed.

According to Figure 2, in the case of buses, although less evident than in the case of automobiles, it can be observed that in more than 50% of elements along the route, the operating speeds recorded exceed at the traffic speeds and at the design speed, which is considered critical, since these vehicles normally carry a significant number of passengers, and speeding could cause accidents that can affect many people.

In Figure 3, it can be observed for the case of two-axle trucks that the operating speeds recorded are generally lower than those observed in cars and buses, with a large part of these being below the specific speeds. However, in practically all cases, the operating speeds recorded exceed the design speed of the section.

To complement the analysis, in tables 5 and 6, the elements with the lowest consistency are presented in the South – North and North – South directions, respectively. As can be seen, in 9 of the 50 elements, there are “poor” consistency conditions, especially in the case of cars and to a lesser extent for buses, especially in relation to Lamm's I criterion. This means that in a significant number of the elements of the route along the section under study, operating speeds are excessively higher than those of the design, which can generate adverse conditions for road safety.

Table 5. Summary of inconsistency elements - South-North direction

ELEMENTO	TIPO	PRIMER CRITERIO DE LAMM			SEGUNDO CRITERIO DE LAMM		
		CONSISTENCIA VELOCIDAD DE OPERACIÓN VS VELOCIDAD DE DISEÑO			CONSISTENCIA VELOCIDAD DE OPERACIÓN ENTRE ELEMENTOS CONSECUTIVOS		
		AUTOS	BUSES	CAMIONES	AUTOS	BUSES	CAMIONES
4	CURVE	POOR	POOR	GOOD	GOOD	GOOD	GOOD
15	TANGENT	POOR	ACEPTABLE	ACCEPTABLE	GOOD	GOOD	GOOD
24	CURVE	POOR	ACEPTABLE	ACCEPTABLE	GOOD	GOOD	GOOD
28	CURVE	POOR	ACEPTABLE	BUENA	GOOD	GOOD	GOOD
32	CURVE	POOR	ACEPTABLE	ACCEPTABLE	GOOD	GOOD	GOOD
33	TANGENT	POOR	GOOD	GOOD	ACCEPTABLE	GOOD	GOOD
36	CURVE	POOR	ACEPTABLE	GOOD	GOOD	GOOD	GOOD
50	CURVE	POOR	ACEPTABLE	GOOD	GOOD	GOOD	GOOD

Table 6. Summary of inconsistency elements - North-South direction

ELEMENTO	TIPO	PRIMER CRITERIO DE LAMM			SEGUNDO CRITERIO DE LAMM		
		CONSISTENCIA VELOCIDAD DE OPERACIÓN VS VELOCIDAD DE DISEÑO			CONSISTENCIA VELOCIDAD DE OPERACIÓN ENTRE ELEMENTOS CONSECUTIVOS		
		AUTOS	BUSES	CAMIONES	AUTOS	BUSES	CAMIONES
50	CURVE	POOR	POOR	BUENA	GOOD	GOOD	GOOD
32	CURVE	POOR	POOR	ACCEPTABLE	GOOD	GOOD	GOOD
28	CURVE	POOR	ACCEPTABLE	GOOD	GOOD	GOOD	GOOD
24	CURVE	POOR	ACCEPTABLE	GOOD	GOOD	GOOD	GOOD
16	CURVE	POOR	ACCEPTABLE	GOOD	GOOD	GOOD	GOOD
15	TANGENT	POOR	POOR	GOOD	ACCEPTABLE	ACCEPTABLE	GOOD
4	CURVE	POOR	ACCEPTABLE	ACCEPTABLE	GOOD	GOOD	GOOD

On the other hand, in Figures 5, 6, 7 and 8, a summary of the consistency is presented according to each criterion considered, for each direction of circulation. In these graphs, it can be seen that the vehicles with the greatest inconsistencies are, in their order, from highest to lowest: cars, buses and trucks; and that Lamm's Criterion I is the most critical, therefore, unfavorable conditions are to be expected in order to guarantee good road safety conditions, and that therefore, the road section under study may present a high potential for accidents.

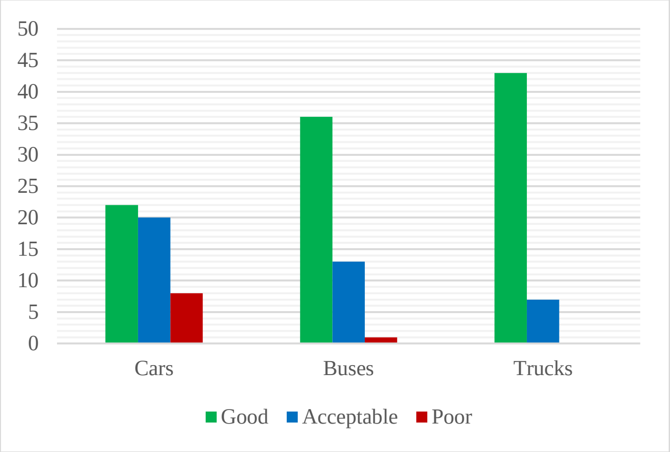


Fig. 4. Summary of consistency - Criterion I - South-North direction

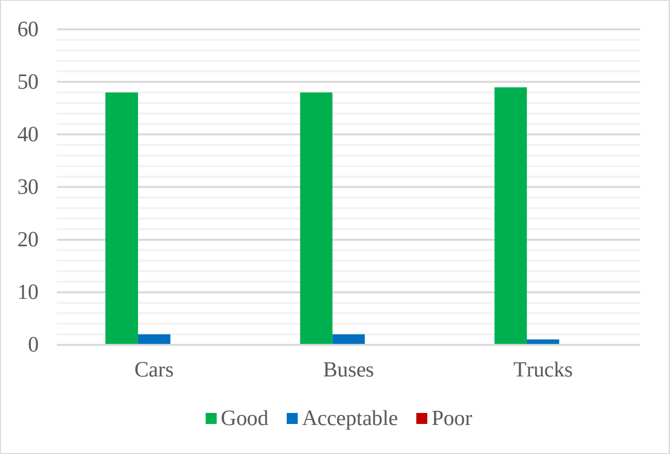


Fig. 5. Summary of consistency - Criterion II - South-North direction

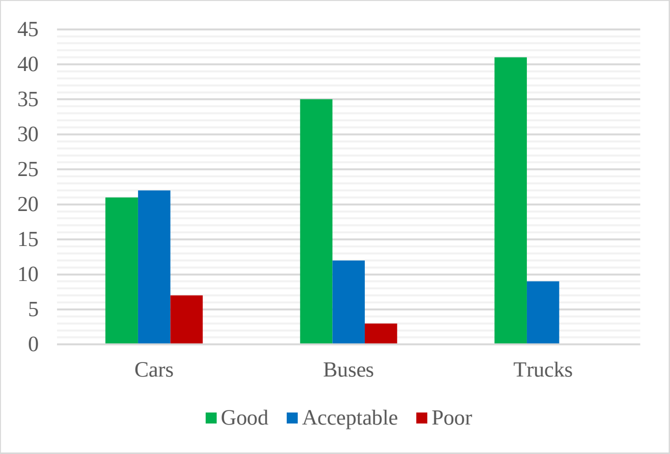


Fig. 6. Summary of consistency - Criterion I - North-South direction

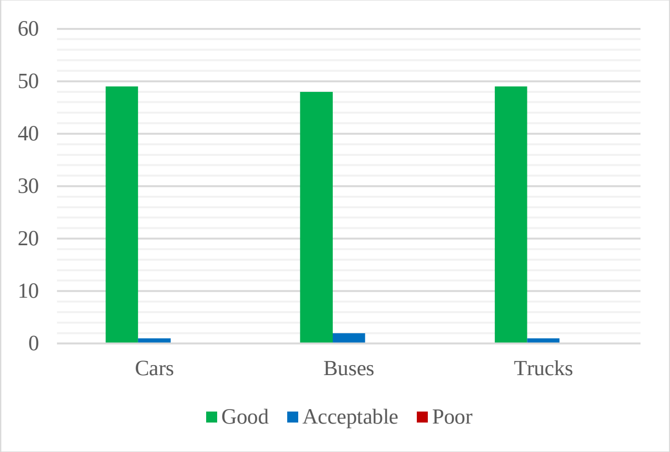


Fig. 7. Summary of consistency - Criterion II - North-South direction

IV. CONCLUSION

In accordance with the results obtained in the studied road section, which is representative of the characteristic geometric layout of a large part of the topography throughout the Colombian territory, which is developed largely in mountainous terrain, it was determined that the geometric layout presents a significant number of elements with poor consistency, which can generate a high potential for the occurrence of accidents, leading to serious injuries and loss of life, taking into account that these roads, made up of a single carriageway, with a Only one lane enabled for each direction of traffic, a significant number of cargo and passenger vehicles travel simultaneously. That is why the authorities in charge are required to implement the necessary actions to improve the geometric characteristics of these road corridors, to make them more comfortable and safer.

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