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Traffic Parameters Through Microscopic Planning Applied In Intermediate Cities

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The study addresses the problems related to vehicular traffic on roads with high congestion in cities with populations of less than one million inhabitants, which characterizes them as intermediate cities, approaching the particular situation in the capital of the Northeastern part of Colombia, in one of its main arteries. The research reflects a diagnosis of the situation, in an area of high vehicular mobility, especially related to private motorized transport, and/or collective and private public transport, which shows the deterioration generated in the infrastructure, as well as conflicts in the planning and organization of urban mobility. An analysis of the current condition is made, measuring traffic engineering parameters by collecting information directly in the field, such as traffic speeds, phases in electronic devices, traffic lights, queue length, waiting times; and then apply the Vissim software, which allows to propose strategies in the short, medium and long term, through a multimodal simulation and 3D visualizations, proposing low cost solutions and positive impact, both in the road network, road operation, control systems and traffic management. These factors make this digital tool very attractive, as it allows and calibrates the parameters, adapting them to the local context according to the particular characteristics of the area.

Keywords: VISSIM software; digital simulation; traffic engineering; traffic congestion; urban mobility.

1. Introduction

Citizen mobility is a right and has become a source of social cohesion. In fact, it is considered the fourth condition of social integration, after housing, health, and education (Vega-Pindado, 2017).

One of the factors for urban mobility to develop effectively is to have road infrastructure built according to permitted design parameters, among other aspects. A road is a transportation infrastructure specially conditioned within an entire strip of land called right-of-way, with the purpose of allowing the circulation of vehicles in a continuous manner in space and time, with adequate levels of safety and comfort (Cardenas-Grisales, 2013). However, the disproportionate increase in the rate of vehicular traffic means that over time, the existing works are insufficient because they exceed the capacity of the roads.

Most Colombian cities were developed without taking into account the rapid demographic and therefore vehicular growth, and without adequate urban planning. The departmental capital, has been no exception and this is evidenced by the vehicular congestion on many of its main roads, added to the fact that it still does not have an Integrated Mass Transportation System, making the situation even more critical.

This municipality is located in the northeast of the country, on the Eastern Cordillera of the Andes, near the border with Venezuela. It is the political, economic, industrial, artistic, cultural, sports and tourist epicenter of the department. It has a population of approximately 750 thousand inhabitants, with a length of 10 km from north to south and 11 km from east to west. According to the Land Management Plan POT, it is made up of 10 communes. The study area is located in commune 2 and is made up of neighborhoods such as Zulima, Santa Lucía, Quinta Oriental and Guaimaral; where hospitals, clinics, commercial premises, residential areas and alternate roads that communicate with sports venues and school and university institutions converge.

According to the PO) (Corporación Concejo Municipal San José de Cúcuta, 2011) for the municipality, in its Article 78 regarding the Classification of the road subsystem, Guaimaral Avenue is an intermediate scale road, with a profile corresponding to a VT3 section with a width between 16 and 30 meters, including mixed lanes, separator and sidewalks; and whose purpose is to interconnect various sectors that make up a mixed land use.

For this reason, the project seeks to offer alternatives to significantly improve the mobility of one of the most congested avenues in the city, with high vehicular and pedestrian flow, which connects the north with the east of the municipality, by analyzing the traffic parameters using a computational tool and modeling the current and future situation to create viable solutions in the short, medium and long term.

Simulation models emerged in the 50's, whose precursor was the Transport Road Research Laboratory in the United Kingdom (TRRL) (CASTAÑO, 2007). The United States, on the other hand, began with the publication of the speech "Simulation of Highway Traffic for the Purpose of Discrete Variables", by Dr. Gerlough, at the University of California around 1955.

By the 1970's the NETSIM, INTEGRATION and AIMSUN2 models allowed to analyze intersections individually (CASTAÑO, 2007).

For two-lane roads, the VTI (Sweden), TRARR (Australia) and TWOPAS (United States) models were developed. These models analyzed cases at the micro-zone level, so later more complex programs were developed to handle a greater number of data, and simulation models were created at the macro and meso levels (Timana, 2014).

In the 60's and early 70's, programs for macroscopic models such as TRANSYT, FREQ and FREFLO were developed. For mesoscopic model analysis, CONTRAM was created for intersections with and without traffic lights (CASTAÑO, 2007). Parallel to the work done with TRANSYT-7F (Valencia Alaix, 1988), they applied the NETSIM5 model to the same network and simulated the initial and future situation with the traffic light plan recommended by TRANSYT-7F and found that significant improvements were achieved in the traffic flow of the analyzed network.

For the analysis of traffic parameters on the avenue under study, it was necessary to use concepts such as Land Use Plan, Mobility Master Plan, traffic simulation models, traffic studies (speeds, queues, and volumes), traffic control devices, capacity and levels of service at intersections with traffic lights.

PTV VISSIM is a world-leading software developed by PTV- Planung Transport Verkehr AG in Karlsruhe, Germany. The acronym derives from the German "Verkehr In Städten - SIMulation" (in English, "Traffic Simulation in Cities") (Ortega-Donaire, 2016; Ptgroupa, 2022; Ptvgroupb, 2022). This tool analyzes the operation of public and private transportation under different parameters such as lane configuration, vehicle composition, traffic lights, stops, among others, with a variety of configurations for the evaluation of alternatives based on traffic engineering and planning performance indicators.

Analogous academic studies have been carried out in Colombia, in sections of cities such as Bucaramanga and Cartagena (Fontalvo Arrieta & Guárdela Vasquez, 2013; García Lora & Monterroza García, 2022; López Mendoza & Mesa Pabón, 2015; Merchán García & Palencia Hernández, 2021; Ruano-Daza & Cobos, 2016); which serves as a basis for doing the same with Guaimaral Avenue, in the city of Cúcuta, whose mobility has been negatively affected in recent years, and without having intervened so far with Traffic Engineering to provide a concrete solution to this problem. Hence the application of the method in this research with its own parameters.

The software is useful for transportation planning, traffic engineering and microscopic simulation of parameters that include vehicle tracking and lane change logics, merges with multiple interfaces for traffic control systems; it also allows the visualization of vehicles and/or pedestrians in 2D and 3D modes to perform animations in different scenarios created from three key elements: the road network, control elements and vehicle demand. All editing of the network must be performed in 2D graphic mode, to visualize aggregate values by segments of colored sections instead of showing each vehicle separately and adjusting the parameters that the user needs to modify (Sanz, n. d.).

After processing and analyzing the field information, data such as queue length, average vehicle speed, vehicle delay time, traffic light programming and service levels are obtained (Sanz, n. d.).

The level of service (Alcaldía Mayor de Santa Fé de Bogotá & Cal y Mayor y Asociados CIA, 1998) is used to evaluate the quality of flow. It is a qualitative measure that uncovers the operating conditions of a flow of vehicles and/or people, and their perception by drivers or passengers. These conditions are described in terms of factors such as speed, travel time, freedom to maneuver, traffic interruptions, comfort, convenience and road safety.

2. Method

The research is applied, descriptive and quantitative; with the reference of academic studies previously conducted in the cities of Bucaramanga and Cartagena, based on field studies and software application. For the case study of the project, an approach to the problem of road congestion with respect to current mobility is offered through the diagnosis of the situation, based on primary and secondary information. The primary information is obtained by carrying out vehicle volume, speed and delays, pedestrian traffic, and passenger boarding and alighting in public transportation buses. With secondary information, traffic accidents are analyzed to identify critical points and a bibliographic review is made on modeling with the software.

The recording, analysis and interpretation of data allow determining the influential factors that generate such mobility deficiency in the road network of Guaimaral Avenue, starting from the intersection of La Gran Colombia Avenue and ending at the intersection with the Bogota Canal, with an approximate distance of 2.25 km.

The study was carried out specifically between the surrounding zonal road and the sections that constitute the accesses and exits to it, which represent a total of 31 intersections, 5 of them with traffic lights. The road network of the avenue under study is characterized, indicating the type of road (single or dual carriageway), respective width, number of lanes, vehicular and pedestrian traffic signals, vertical signals, location, type of pavement and pavement condition. Eight mobility hotspots are identified (Figure 1), due to factors such as accidents and congestion.

Figure 1. Study area and critical points

Speed sampling at intersections is obtained by the floating vehicle method, by having the vehicle circulate at a speed that represents average traffic conditions, allowing the vehicle to "float" among the others. A gauging device is needed to record the times of passage through checkpoints or intersections, taking distances traveled from the beginning of the section, speeds indicated by the vehicle's speedometer, measuring the time taken for each delay experienced by the vehicle and associating each delay to the exact place where it was experienced.

For the estimation of traffic light times, the study is carried out by determining the time cycles, sequences and movements allowed at intersections with this type of devices.

For the gauging of vehicle volumes, counts were performed manually, in directional movements for all intersections and accesses, direction of travel, lane use and obedience to control signals, during two typical days and one atypical day, classifying them according to the type of vehicle, for a minimum period of twelve hours per day, including peak demand hours. More than one gauging device was required at intersections with high vehicular flow. To ensure the veracity of the information collected, 30 gaugers were trained, who could understand the importance of the research. They were instructed on the differentiation of vehicle classification and traffic access flows. Pedestrian gauging was carried out at traffic-light intersections, also by manual counting, during the same hours as the vehicle gauging.

Regarding the modeling, there are 3 options: satellite images, AutoCAD drawings or projections directly from the program, with a schematic on the Internet. For the simulation we decided to work with satellite images, making the location in the desired road segment.

The program allows previewing the road mesh model in 2D and 3D (Figure 2). Once the road mesh of the avenue under study is created, the volume of vehicles is included. Then the vehicle composition is performed. PTV VISSIM offers a series of vehicle models such as: car, truck, bus, streetcar, pedestrian and bicycle. However, it was necessary to create new vehicles that were not in the initial list, such as motorcycle, cab, bus, heavy trucks with two or more axles and six or more wheels. The road section to include the information is indicated and the point of entry of the vehicles is established. The name of the road section and the vehicle volume are then recorded. Once the vehicle volumes for each section have been entered, the vehicle composition is made. After entering the vehicles in each of the road sections, the relative speed at which they will move, obtained in the study, is assigned.

Figure 2. 3D street grid of Guaimaral Avenue

For the pedestrian access, which is independent of the vehicular flow, the road segment, access and exit directions, width and length are determined.

The routes to be taken by vehicles on each road segment are then determined. On the entrances and exits of each vehicular route, the relative flows of each route are entered as a percentage. At each point of conflict, road priorities are established to the design, allowing to assign who has the priority and who must wait. For the creation of a traffic light control, the intersection is identified, the phases are created with the time and sequence study data for each traffic light phase, and the colored phase options are displayed. Once the phases are established, the model is run and the road network is verified with turns and movements before placing the traffic lights.

For public transportation stop zones, distance and location are entered, and for parking zones, the number of parking spaces is entered.

Once the previous steps have been completed, nodes are drawn at the points of interest, generally intersections, and through these nodes the evaluation of the indicators to be analyzed is carried out. The most commonly used indicators in traffic evaluation are: number of vehicles passing through the node (mixed vehicles), queue length at the node in meters, delays in seconds and service levels.

For the creation of the 3D simulation video, the duration of the image and the views to be included in the video are entered.

In the modelling using the PTV VISSIM software, the results of the data are analyzed and evaluated in order to propose alternative solutions to the problem evidenced in the diagnosis.

3. Results

This project is an original research, which has not yet been carried out for any road in the capital city of Cucuta. Regarding the results obtained in the studies for the cities of Bucaramanga and Cartagena, as they have Integrated Mass Transportation Systems, they show elements in mobility with parameters that make them more competitive, with greater urban development. For this reason, it is necessary to take action measures almost immediately, that is, in the short term, and this type of solutions can be provided by this study, which makes it a project that can represent a great social impact to the extent that it will improve the living conditions of the people who will transit through this area and its surroundings.

3.1. Surrounding velocity

For the calculation of the speed of circulation of vehicles traveling in the area under study (Table 1), the method used was to travel several times along the road, with the driver floating within the flow of vehicles, so that the number of cars passing was analogous to the number of cars passing the floating vehicle. During the circulation, the time it takes the vehicle to move along a given length of road is measured.

Table 1. Traffic speeds

VEHICLES	SPEED KM/SG
BUSES	30-40
CARS	30-50
MOTORCYCLES	20-40
TAXIS	30-45
TRUCK	30

3.2. Evaluation of the current traffic situation in the area of influence

The problem that generates traffic congestion at peak hours is related to the lack of road culture, disrespect for traffic signals, use of road space as a parking area, and the absence of passenger loading and unloading bays.

Traffic signalized intersections allow some left turns, increasing the traffic light cycle time. Non-signalized roads allow all left turns, which increases the risk of accidents and hinders traffic flow at these points.

The most critical points are the intersections of Avenida Guaimaral with La Gran Colombia, the Bogotá Canal and the intersection of the Erasmo Meoz Hospital, which are the points of greatest traffic congestion.

Private vehicles and cabs use the road as a parking lot, especially in commercial areas, reducing road capacity and impeding fluid mobility.

Along the entire length of the avenue there is only one bay for passenger boarding and alighting, but it is not used by the public transport service but by cabs and private cars.

3.3. Modeling of the road network in the area of influence for the current situation (Year 0)

For the analysis of the problem, the 16 most relevant intersections of the network were evaluated. Table 2 shows the average indicators per intersection simulating the current traffic conditions of the road corridor.

The column "Total Vehicles in Network" refers to the number of mixed vehicles that traveled in the different directions within the evaluated node. The "Queue Length" column corresponds to the distance measured in meters of vehicles stopped one behind the other within a node; the "Delays" column is the time in seconds that a vehicle takes to enter and exit the node; and the "Level of Service" column is the qualitative indicators for each movement within the node.

Table 2. Average indicators per intersection

Node	Name	Total vehicles in network	Total vehicles in network	Vehicle delay (seg)	Service level
1	Gran Colombia	2.717	34	60.7	E
2	Street 3	1.551	0.4	2.7	A
3	Street 2	1.670	0.5	2	A
4	Street 1A	2.059	9.4	19.1	B
5	Street 0 North	1.795	0.3	1.7	A
6	Street 0A North	1.908	0.6	2.2	A

7	Street 1 North	1.902	0.4	2.1	A
8	Street 2 North	2.376	16	27.1	C
9	Street 4,5 and 5A North	2.547	31.1	55.2	E
10	Street 6B North	1.936	5.8	7.4	A
11	Street 8 North	2.094	0.1	1.5	A
12	Street 8C North	1.960	0.1	1.1	A
13	Street 9B North	1.983	0.3	2.7	A
14	Street 13 North	1.972	3.6	7.1	A
15	Street 15 North	1.949	3.3	4.9	A
16	Canal Bogota	2.008	15.0	39.6	D

Levels of service A (excellent), B (good) and C (acceptable) can be considered appropriate for vehicular mobility. Thirteen of the 16 intersections evaluated show good mobility performance, with low queue lengths and minimal delays. Three intersections show problems due to the levels of service shown, which should be intervened to prevent queues from extending to nearby intersections. These points are: Gran Colombia, Hospital Erasmo Meoz (Streets 4N, 5N and 5AN) and Canal Bogotá. The particular analysis is made for these intersections, which are precisely traffic-light intersections. By reviewing the traffic light cycle times with the software, changes in the phases and cycle times can be proposed to improve this situation.

3.4. Modeling of the road network in the area of influence in the current situation projected for 5, 10 and 15 years

For the projection of future vehicular traffic, the percentage growth of the National GDP (Table 3) used in the traffic and demand study carried out by the Consorcio Estructuración Vial for the Corridor 4 project in Norte de Santander is used.

Table 3. Growth rate of GDP Colombia

Year or Period	Growth Rate (%)
2017 – 2020	4.5
2021 – 2025	4.2
2026 – 2030	3.2
2030 – 2040	3.0

The results presented in the indicator evaluation tables show that the road network is significantly affected as of year 5. A large part of the vehicular movements that take place in the network, become the worst level of service, F; queue lengths increase between 40 and 50 meters, thus affecting nearby intersections and generating greater congestion than the current one. This trend is maintained for the year 10 and 15 projections, and reflects that practically the entire network reaches level of service F, which evidences a total collapse in the mobility of the roadway.

Table 4, shows a summary of average indicators by intersection, showing the need to propose interventions aimed at improving flow conditions and avoiding a major problem in a few years.

Table 4. Average mobility indicators per intersection

Nodo	Volúmenes Vehiculares				Longitud de cola (m)				Demoras de Vehículos (seg)				Nivel de Servicio			
	AÑO 0	AÑO 5	AÑO 10	AÑO 15	AÑO 0	AÑO 5	AÑO 10	AÑO 15	AÑO 0	AÑO 5	AÑO 10	AÑO 15	AÑO 0	AÑO 5	AÑO 10	AÑO 15
1: Gran Colombia	2,717	3,148	2,932	2,426	34,0	87,9	132,6	154,6	60,7	101,4	132,0	171,5	E	F	F	F
2: Calle 3	1,550	1,667	1,590	1,453	0,4	53,9	115,8	132,4	2,7	81,7	160,1	197,3	A	F	F	F
3: Calle 2	1,670	1,741	1,679	1,537	0,5	52,1	77,6	88,4	2,0	72,4	112,2	143,7	A	F	F	F
4: Calle 1A	2,059	2,274	2,353	2,313	9,4	27,1	37,1	46,6	19,1	40,9	53,1	68,7	B	D	D	E
5: Calle 0 Norte	1,795	1,879	1,834	1,700	0,3	41,0	69,6	76,2	1,7	59,6	104,4	126,3	A	F	F	F
6: Calle 0A Norte	1,908	2,018	1,977	1,878	0,6	56,3	89,3	93,8	2,2	67,8	103,7	117,1	A	F	F	F
7: Calle 1 Norte	1,902	2,042	2,029	1,934	0,4	48,1	55,8	65,6	2,1	60,0	66,0	82,5	A	F	F	F
8: Calle 2 Norte	2,376	2,661	2,832	2,738	16,0	52,5	74,1	112,8	27,1	69,4	85,4	119,2	C	E	F	F
9: Calle 4, 5 Y 5A Norte	2,547	2,876	3,012	2,912	31,1	84,5	104,7	120,6	55,2	81,3	100,9	123,3	E	F	F	F
10: Calle 6B Norte	1,936	2,026	1,979	1,873	5,8	67,8	91,3	92,9	7,4	77,0	94,5	103,4	A	F	F	F
11: Calle 8 Norte	2,094	2,450	2,473	2,532	0,1	6,0	47,4	56,7	1,5	8,6	50,2	59,3	A	A	F	F
12: Calle 8C Norte	1,960	2,299	2,330	2,227	0,1	2,2	43,3	76,4	1,1	4,8	52,3	88,5	A	A	F	F
13: Calle 9B Norte	1,983	2,353	2,450	2,360	0,3	2,0	57,0	141,7	2,7	5,3	31,3	76,6	A	A	D	F
14: Calle 13 Norte	1,972	2,311	2,325	2,125	3,6	25,1	48,3	103,4	7,1	27,3	49,1	84,3	A	D	E	F
15: Calle 15 Norte	1,949	2,302	2,232	2,034	3,3	42,6	65,7	91,3	4,9	35,8	71,8	105,8	A	E	F	F
16: Canal Bogotá	2,008	2,436	2,664	2,380	15,0	22,5	46,8	78,3	39,6	45,0	69,0	100,2	D	D	E	F

3.5. Speed and travel time analysis

To obtain this indicator, the entire length of the road section, 2.25 km, is taken and the average time taken by vehicles to travel it is calculated with the software. With the time and distance data, the average speed at which vehicles travel during the hour of maximum demand is determined.

It is important to note that although the speed allowed along the road is 40 km/h, the congestion present at some critical points prevents this value from being maintained. When the analysis of travel time in the current situation and the average travel speed along the road is made, the data in Table 5 is obtained, which shows that for year 5 the speed is reduced to half the value of year 0 and the travel time increases twice as much, worsening the parameters for the other future projections.

Table 5. Speed and travel times

Guimaral Avenue	Unimproved situation			
	Year 0	Year 5	Year 10	Year 15
Average speed (Km/h)	18.96	8.8	6.5	5.3
Travel times (min)	7.1	15.4	20.7	25.3
Corridor length (Km)	2.25			

3.6. Evaluation of the road network with proposed solutions to improve mobility

Low-cost, high-impact proposals. It consists of analyzing the intersections with the highest vehicular flow, eliminating the left turns currently allowed, which reduces the traffic light cycle time and the number of phases, and diverting the flow towards a "block ear turn" type movement (Figure 3), which, although it increases the length of the route, reduces travel times. It is also proposed to install traffic lights at 3 intersections (Calle 3ª, Calle 0ANorte, Calle 15Norte), increasing the number of existing traffic lights from 5 to 8. Finally, the construction of a traffic circle at the intersection of the Erasmo Meoz hospital is recommended. On the other hand, parking should be prohibited on all of Guaimaral Avenue. This proposal considerably improves mobility conditions up to year 5 of the projection. For the year 10 projection onwards, other measures requiring greater investment should be presented.

Proposals for modification of existing road infrastructure. The construction of 4 additional traffic circles in addition to the Hospital roundabout (La Gran Colombia, Calle 1ª, Calle 8C Norte, Calle 13 Norte) is contemplated. This alternative solution is required since some of the traffic signalized intersections are no longer functional for the year 10 projection. Left turns should be prohibited at all traffic signalized intersections, thus reducing the traffic signal cycle time and the number of phases. Stop signs would be maintained on the Avenue at those intersections that are not signalized. Required turns could be made at block edges or through the traffic circles that would become important turn-arounds for the area of influence.

Evaluation of the low-cost, high-impact proposal. Taking into account that this only works correctly up to year 5, the evaluations are presented with the current and projected vehicular flow in 10 and 15 years, since the latter year is where the total collapse of the mobility of the road is evidenced if this first proposal is maintained as the only mitigation measure for the vehicular congestion in this avenue.

As an example, Table 6 shows the indicators for the intersection of Guaimaral Avenue with La Gran Colombia Avenue for conditions without improvements, and Table 7 shows the same indicators but with the low-cost solution proposal, showing positive changes in the levels of service.

Table 6. Indicators for Gran Colombia conditions

Nodo	Movimiento	Volúmenes Vehiculares				Longitud de cola (m)				Demoras de Vehículos (seg)				Nivel de Servicio			
		AÑO 0	AÑO 5	AÑO 10	AÑO 15	AÑO 0	AÑO 5	AÑO 10	AÑO 15	AÑO 0	AÑO 5	AÑO 10	AÑO 15	AÑO 0	AÑO 5	AÑO 10	AÑO 15
Gran Colombia	SW -SE	118	147	105	47	37,8	129,5	194,3	222,6	24,8	51,1	75,2	138,1	C	D	E	F
	SW - N	254	308	264	174	37,8	129,5	194,3	222,6	46,6	80,4	137,8	233,9	D	F	F	F
	SW - NE	513	623	454	209	37,8	129,5	194,3	222,6	28,7	56,9	79,3	127,8	C	E	E	F
	SE - N	244	286	334	365	10,0	13,8	19,0	59,9	39,0	42,7	50,0	121,7	D	D	D	F
	SE - NE	57	87	119	133	10,0	13,8	19,0	59,9	39,8	42,7	49,8	114,5	D	D	D	F
	N - SE	331	313	335	319	92,2	200,6	205,2	207,1	155,1	350,3	389,5	389,6	F	F	F	F
	N - NE	134	135	133	126	92,2	200,6	205,2	207,1	81,5	123,3	124,0	131,9	F	F	F	F
	N - SW	311	317	314	293	92,2	200,6	205,2	207,1	94,7	138,5	136,4	144,1	F	F	F	F
	SE - SW	30	40	51	59	4,0	6,9	11,9	52,7	39,8	43,4	41,7	104,4	D	D	D	F
	NE - SW	564	710	668	566	31,6	73,3	151,1	157,6	47,0	73,3	114,3	127,3	D	E	F	F
	E- N	150	181	156	130	24,3	61,9	152,2	159,6	33,3	62,7	113,3	167,3	C	E	F	F
	TOTAL	2,717	3,148	2,932	2,426	34,0	87,9	132,6	154,6	60,7	101,4	132,4	171,5	E	F	F	F

Table 7. Indicators for Gran Colombia with low-cost solution proposal

Nodo	Movimiento	Volúmenes Vehiculares		Longitud de cola (m)		Demoras de Vehículos (seg)		Nivel de Servicio	
		AÑO 0	AÑO 5	AÑO 0	AÑO 5	AÑO 0	AÑO 5	AÑO 0	AÑO 5
Gran Colombia	SW -SE	180	175	37,5	198,2	27,9	46,8	C	D
	SW - NE	986	1074	37,5	198,2	24,8	43,2	C	D
	SE - N	811	867	4,6	39,6	7,1	8,5	A	A
	SE - NE	68	78	4,6	39,6	11,4	12,8	B	B
	N - SE	498	588	12,9	18,3	14,4	16,5	B	B
	N - SW	324	358	12,9	18,3	14,9	17,0	B	B
	NE - SW	631	720	13,9	38,6	19,1	21,0	B	C
	E- N	146	153	10,8	35,1	15,1	16,4	B	B
	TOTAL	3644	4013	13,3	55,0	17,1	24,1	B	C

Evaluation of the proposal with changes in road infrastructure. As an example, Table 8 illustrates the indicators for Gran Colombia Avenue with the proposed construction of a traffic circle, showing good performance of the network until year 20 when evaluating the levels of service. Similarly, there are favourable situations with the construction of the other traffic circles.

Table 8. Gran Colombia indicators with proposed traffic circle construction

Nodo	Movimiento	Volúmenes Vehiculares			Longitud de cola (m)			Demoras de Vehículos (seg)			Nivel de Servicio		
		AÑO 10	AÑO 15	AÑO 20	AÑO 10	AÑO 15	AÑO 20	AÑO 10	AÑO 15	AÑO 20	AÑO 10	AÑO 15	AÑO 20
Gran Colombia	W-SW	0	0	0	0,0	0,0	180,4	0,0	0,0	0,0	A	A	A
	W-SE	196	22	21	0,0	0,0	180,4	0,4	0,6	1,6	A	A	A
	W-NE	794	949	68	0,0	0,0	180,4	0,7	1,2	2,3	A	A	A
	W-NW	367	412	29	0,0	0,0	180,4	0,8	1,3	3,5	A	A	A
	S-SW	50	62	5	0,0	0,0	94,5	0,8	1,8	2,5	A	A	A
	S-SE	0	0	0	0,0	0,0	94,5	0,0	0,0	0,0	A	A	A
	S-NE	116	142	11	0,0	0,0	94,5	0,3	0,4	0,9	A	A	A
	S-NW	348	417	25	0,0	0,0	94,5	0,7	1,1	1,7	A	A	A
	E-SW	862	992	75	0,0	0,0	187,4	0,7	1,1	3,3	A	A	A
	E-SE	0	0	0	0,0	0,0	187,4	0,0	0,0	0,0	A	A	A
	E-NE	0	0	0	0,0	0,0	187,4	0,0	0,0	0,0	A	A	A
	E-NW	217	247	14	0,0	0,0	187,4	0,4	0,7	1,4	A	A	A
	N-SW	483	569	26	0,9	1,6	228,5	1,4	1,7	2,7	A	A	A
	N-SE	483	563	36	0,9	1,6	228,5	2,3	2,9	5,9	A	A	A
	N-NE	218	252	12	0,9	1,6	228,5	1,9	3,1	5,1	A	A	A
	N-NW	142	165	14	0,9	1,6	228,5	2,1	3,2	5,5	A	A	A
	TOTAL	4277	4991	336	0,2	0,4	172,7	1,1	1,5	3,1	A	A	A

It is important to clarify that the software does not corroborate the operation of geometric designs, therefore, a traffic circle of approximately 30 meters radius is proposed for this specific intersection, to be evaluated by means of its respective geometric design, verifying the compliance of the intersections and thus establishing the correct measurements of these elements. Speed and travel time analysis with the proposed solutions (Table 9).

Table 9. Speed and travel times resulting from the proposed solutions.

Guimaral Avenue	Unimproved situation			
	Year 0	Year 5	Year 10	Year 15
Average speed (Km/h)	27.5	23.2	28.95	25.3
Travel times (min)	5.1	6.01	4.9	5.5
Corridor length (Km)	2.25			

It is possible to observe the improvement of the values when compared to Table V. For a total length of 2.25 km of track, it is traveled in an average time of 5.5 minutes, maintaining average speeds above 20 km/h, during the next 15 years.

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4. Conclusions

The study of vehicular traffic parameters of a road, through the PTV VISSIM software, allows to determine the behavior of the traffic system by defining characteristics of vehicular volumes, queue length, vehicle delays, average speed, travel times and service levels, taking its operation as such based on the software simulation, knowing its direct area of influence to propose solutions that guarantee the proper functioning of the existing and projected road system, without inconveniencing the user or making any type of investment in infrastructure, considering the importance of the different modes of transportation, urban morphology and land uses assigned to the different sectors of the municipality to facilitate the mobility of users and accessibility to the surrounding areas that border the rest of the road network.

The problem of vehicular mobility on Guaimaral Avenue is a situation that must be addressed promptly, as the area tends to become increasingly congested, making it necessary to intervene in traffic engineering to prevent deterioration of current and future conditions in this important area of influence.

It is essential to start with interventions that require low investments, such as those proposed in the low-cost, high-impact alternative for the first 5 years of projection. These are proposals that consider changes in traffic signal timing, implementation of new electronic control devices at other intersections, and the establishment of signs that indicate to drivers the prohibition of some movements such as left turns and allow others, such as block turns. These solutions should be complemented with road education programs for the community, such as respect for parking areas, proper use of public transportation stops, respect for traffic signals, and respect for electronic control devices, among others. This proposed solution implies a significant improvement in the levels of service that will be achieved by year 5 of the projection if compared to the levels of service for the current situation.

Mobility improvement proposals that include modifications to the road infrastructure, since they require greater investments, should be considered to be operational as of year 10 of the projection at the latest. These solutions have to do directly with the construction of traffic circles, under geometric designs appropriate to the road conditions. This alternative substantially improves traffic conditions for the current situation and even improves the service levels projected with the low-cost solutions applied up to year 5 of the projection.

If none of the proposed solutions were implemented, traveling the 2.25 km length of this avenue would drastically decrease the quality of life of users, going from an average vehicle speed of 18.96 km/h in year 0 to 5.3 km/h in year 15 of projection; while the travel time for the same route would increase from 7.1 to 25.3 minutes in the same period of years, which would cause a total collapse in relation to the levels of service at all intersections of this road corridor. On the contrary, applying the solution alternatives, a speed of 27.5 km/h is projected for year 0 and approximately in year 15, it would be 25.3 km/h, which indicates that the travel speed value would remain constant during the next 15 years without detriment. Regarding travel time, an average travel time of 5.5 minutes would be maintained over the same period.

The software used in the study is a highly functional tool that ensures success in traffic management, since it provides solutions based on predictive traffic models throughout the network and in real time.

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