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Diagnosis of road capacity and service level using the highway capacity manual

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Diagnosis of road capacity and service level using the highway capacity manual

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Abstract. Vehicle congestion is a phenomenon that affects the world due to the potential increase in its population. Consequently, the capacity and level of service of Norte de Santander, Colombia, main avenue was analyzed, being the epicenter of the problem. This article was carried out using the highway capacity manual 2000, in addition to collecting information by means of vehicle gauges, conceptualizing the causes and critical points of the sector to diagnose the vehicle situation, proceeding to classify and process according to the highway capacity manual 2000. It is concluded that currently the system is with a level of service D and E, being these unstable, with tolerable speeds in some specific hours, but an incident on the road would cause little mobility, long queues and high waiting times for its narrow road space.

1. Introduction

Traffic congestion is a considerable problem faced by large cities and has undesirable consequences such as uncomfortable road use, car accidents, worsening performance of road networks, air pollution and economic issues [1], This has been increasing in recent decades due to the increase of private cars which in turn has been a result of population increase and economic growth [2], for example, a bus is a system of delaying when it stops for passengers, waiting for them to get on and off, and a system of losing full occupancy [3]; some of the effects of traffic congestion are the level of service (represented by the delay), air pollution and psychological effects [4]. One of the parameters that evaluate the effectiveness of traffic organization is the level of traffic service, which is the relationship between the average speed of vehicles and the speed of vehicles in free traffic conditions [5]. It is empirically recognized that there are two types of traffic flows: flows with slow or stopped cars (stuck or congested flows) and smooth flows [6], in addition to the decision to cross the road made by pedestrians, deciding mainly by the distance of the vehicle in the opposite direction and not its speed [7], invading road space and limiting the movement of vehicles (in addition to endangering the safety of pedestrians and drivers).

In many Latin American cities, urban public transport is often run by many small private companies, which have a certain number of routes and buses available, therefore, planning, provision and control of urban public transport tends to focus mainly on economic objectives to ensure the financial sustainability of the system [8]; In the case of Colombia, its capital Bogotá is one of the most congested cities in the world, being the third most congested country, because drivers spend 48 hours a year in the midst of maximum congestion [9], caused by the low capacity of the main roads for movements at specific times: entry and exit of school students and workers. Cities smaller than the capital have been affected over time, as is the case of the city of San José de Cúcuta, Colombia, where the increase of foreigners to the country and mainly in the city (from Venezuela), street vendors and the culture of pedestrians, occupying road space, prevent the effective mobilization of vehicles and putting the lives of both parties at risk by crossing the street recklessly; Although the Mayor's Office has established norms that govern and organize traffic, there is still a need for greater compliance and regulation of mobility with respect to Venezuelan vehicles, due to the border status [10].

The capacity and level of service of the main commercial avenue of San José de Cúcuta, Colombia, is determined by means of the highway capacity manual 2000 (HCM 2000), determining through the analysis and application of formulas the causes and critical points that will serve as a study with the objective of improving vehicle congestion and eliminating waiting times; being its main manifestation in the progressive reduction of traffic speeds with respect to a traffic flow free of congestion caused by the high vehicle demand of San José de Cúcuta, Colombia, where these measures solve the congestion with low cost, reducing travel times, fuel consumption, operating costs and air pollution.

2. Methodology

The sample was carried out in the main commercial avenue of San José de Cúcuta, Colombia, diagnosing the current situation with respect to mobilization, vehicle speed, percentage of road capacity, average speed and type of vehicles, to specify the level of service provided. Information was collected through vehicle capacity and counts in hours of the day with greater and lesser incidence [11], and then analyzed and classified through 6 equations of the methodology HCM 2000 [12], serving as a practical guide for the analysis of the level of service of the highway facilities, where it includes methods to perform the analysis of basic undersaturated segments, intersections and facilities of highways [13] and urban streets in part, applies a segment travel time equation to estimate the travel time of vehicles, where the segment operating time equation includes a component that takes into account the delays due to sources along the segment [14]; the six equations corresponding to the methods are: Equation (1), for calculating the adjustment factor for heavy vehicles.

$$(\mathrm{Fhw}) = \frac{1}{1+\mathrm{Pt}(\mathrm{Et}-1)+\mathrm{Pr}(\mathrm{Er}-1)}, \tag{1}$$

where Pt is defined as the proportion of heavy vehicles in traffic, expressed in decimal, Pr would be the proportion of recreational vehicles in traffic, Et is the equivalence of vehicles by heavy vehicles and Er is the equivalence of vehicles by recreational vehicles.

The equivalent light vehicle flow rate is calculated with Equation (2), identifying V as the volume demand for a full peak hour (speed/hour), PHG as the peak hour factor (PHF), and Fc as the slope adjustment factor.

$$(\mathrm{Vp}) = \frac{\mathrm{V}}{\mathrm{PHF}*\mathrm{Fc}*\mathrm{Fhw}}. \tag{2}$$

The estimated free flow speed (FFS) is based on base free flow speed (BFFS), fLS is the adjustment for lane width and berm width, and fA is the adjustment factor for access points, developed by the following Equation (3).

$$(\mathrm{FFS}) = \mathrm{BFFS} - \mathrm{fLS} - \mathrm{fA}. \tag{3}$$

Using Equation (3), the average travel speed (ATS) is calculated using the Equation (4), taking into account that Fnp is the percentage of adjustment for non-overtaking zones.

$$(\mathrm{ATS}) = \mathrm{FFS} - 0.1225\mathrm{Vp} - \mathrm{fnp}. \tag{4}$$

Finally, the percentage of time delay is calculated by determining base PTSE (BPTSE) for both lanes of combined travel and knowing the adjustment for the combined effect of traffic lane distribution and the percentage of no-passing zones over PTSE (Fd/ns), through Equation (5) and Equation (6).

$$(\mathrm{BPTSE}) = 100(1 - e^{-0.00879\mathrm{vp}}). \quad (5)$$

$$(\mathrm{PTSF}) = \mathrm{BPTSE} + \frac{\mathrm{Fd}}{\mathrm{np}}. \quad (6)$$

3. Results

3.1. Vehicle seating capacity

Traffic data are an important contribution to traffic analysis for the planning and design of a transport system, forecasting and impact assessment of urban development projects [15]. Table 1 illustrates the information collected from vehicle capacity, finding a considerable fluctuation between the number of vehicles that transit from one sector of the avenue to another, due to the increase in street vendors or pedestrians that circulate in the streets, Saturday decreases the number of vehicles that transit, consequently, is the day of greater road invasion, but due to the decrease in vehicle traffic, reduce congestion on this day. The average of the total number of vehicles traveling during the week is 32424, while the daily average is 5404 vehicles per day.

Table 1. Working weekdays.

Avenue with	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Street 5	6502	5978	6588	6447	6324	4510
Street 6	7048	7313	6378	5456	6837	4443
Street 7	5814	5394	5324	5081	5691	4277
Street 8	4362	5981	5476	5053	5410	4149
Street 9	5517	5192	4889	5311	4703	4053
Street 10	5651	4400	4973	4761	5217	4041

The highest percentage of traffic moving in this area is 81.05% light vehicles, 17.75% buses and 1.20% heavy vehicles, this distribution being illustrated in Table 2. Since it is a commercial sector, the vast majority of vehicles are automobiles for the movement of pedestrians to shopping areas; buses were considered as heavy vehicles. The development of the construction industry sector also increased the demand for freeways, one of which can be seen in the increase in the number of heavy vehicles transporting logistics projects, triggering a number of serious problems on the highways, including traffic congestion.

Table 2. Traffic composition by day.

Day	%Light vehicles	%Buses	%Heavy vehicles	Total, heavy vehicles
Monday	82.27	17.02	0.71	17.73
Tuesday	81.81	16.41	1.77	18.18
Wednesday	81.61	17.18	1.21	18.39
Thursday	84.55	14.47	0.98	15.45
Friday	81.31	17.51	1.19	18.70
Saturday	79.05	19.64	1.31	20.95

3.2. Adjustment for heavy vehicles

Table 3 shows the Er and Et values for Equation (1) (buses have been included as heavy vehicles), obtaining the result of the daily heavy vehicle adjustment factor (See Table 4), with Thursday being the day with the highest factor as it has the lowest number of vehicles in transit compared to Saturday with the lowest factor.

Table 3. Equivalence of heavy vehicles and recreation to determine tracking times [14].

Type of vehicle	Horuly intensity (vehicles/hour)	Type of terrain	
		Plane	Mountainous
Trucks, Et	0-600	1.1	1.8
	> 600-1200	1.1	1.5
	> 1200	1.0	1.0
Recreational vehicles, Er	< 1200 >	1.0	1.0

Table 4. Equivalence factor for heavy vehicles.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Factor	0.9826	0.9821	0.9820	0.9848	0.9816	0.9794

3.3. Demand for flow rate

The lowest flow rates obtained by the gauges were between 12:00 and 12:15 p.m.; using this information the flow rate demand was calculated by means of Equation (2), assuming the value of Fc=1 according to Table 5.

Table 5. Slope adjustment factor in tracking time.

Hourly intensity (vehicles/hour)	Plan	Type of land mountainous
0-600	1	0.77
> 600-1200	1	0.94
> 1200	1	1

Table 6 shows the amount of vehicle flow in an hour with lower traffic speeds, where Thursday traffic is greater than Saturday due to the number of heavy vehicles concentrated on that day. The average number of vehicles that travel daily in an hour is 382 vehicles/hour. The maximum capacity for the life of two lanes is 1700 vehicles/hour for each lane [12], this being 3400 vehicles/hour, since Vp is less than the capacity of the road, we calculate the level of service based on the percentage of time delay.

Table 6. Flow rate demand.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Vehicles/hour	377	390	385	429	400	312

3.4. Free flow speed

FFS is the average speed of vehicles in a given installation, measured in low volume conditions, when drivers tend to drive at the desired speed and are not limited by the control delay [16]. The free flow base speed was concluded to be 60 km/h, being the maximum urban speed allowed by the Colombian traffic code, replacing this value in Equation (3), and using Table 7 and Table 8 to assume the values of fLs - fA.

Table 7. Adjustment due to track width and berm width (fLS) [14].

Lane width (m)	Reduction of FFS (Km/h)/ Berm width			
	> 0 < 0.6	> 0.6 < 1.2	> 1.2 < 1.8	> 1.8
2.7 < 3	10.3	7.7	5.6	3.5
> 3 < 3.3	8.5	5.9	3.8	1.7
> 3.3 < 3.6	7.5	4.9	2.8	0.7
> 3.6	6.8	4.2	2.1	0

Table 8. Adjustment due to number of access points (fA) [14].

Access points (km)	Reduction of FFS (Km/h)
0	0
6	4
12	8
18	12
> 24	16

FFS = (60 Km/h – 7.5 Km/h - 8 Km/h) → 44.5 Km/h

3.4.1. Average theoretical travel speed. Speed is an important factor in road safety that affects both the occurrence and severity of accidents, associated with a higher probability of being involved in an accident [17]. Equation (4) is used to calculate the average theoretical trip speed, being at 12 noon due to the highest low speed record; Fnp is 4.3 because it has an hourly intensity of 300 vehicles/hour, 40% no passing zone. According to Table 9, the average theoretical weekly travel speed is 35.42 km/h, with the highest indicator on Wednesdays and the lowest on Thursdays.

Table 9. ATS.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Km/h	35.50	35.32	35.38	34.84	35.20	36.30

3.5. Percentage of time following another vehicle

The level of service of a roadway is defined by the percentage of time used in following a vehicle and the average speed of travel, the former being the average percentage of travel time that a vehicle must travel in a line behind a vehicle at slow speed due to not being able to pass it, causing vehicle congestion across the width of the roadway. By means of Equation (5) and Equation (6), the percentage of time delay is calculated, illustrated in Table 10; where having an intensity of 400 vehicles/hour with a traffic distribution of 50/50 per lane and 40% of non-overtaking zone, the numerical value of fd/np corresponds to 19%, being these the values of time delay.

Table 10. BPTSE and PTSF.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
BPTSE	87.81%	80.95%	71.29%	68.59%	70.31%	76.00%
PTSE	90.81%	89.95%	90.29%	87.59%	89.31%	95.00%

3.6. Level of service

According to the percentage of delay between 87% and 95%, the service level E is classified (Table 11) for midday and Saturdays at any time; that is, there is a flow operating by force, low speeds with volumes lower than the capacity of the road due to high waiting times due to road congestion; in some cases, the speed and volume can have a zero value in urban areas.

Table 11. Criteria for determining the level of vehicle service [14].

Service standards	Percentage of follow-up time
A	< 40
B	> 40 -55
C	> 55 -70
D	> 70 -85
E	> 85

3.6.1. Service level 1. The level of service for each business day was calculated for the period of 8:00 a.m. to 9:00 a.m., because that is generally the time when the highest traffic volumes are encountered. The procedure is the same as the previous service level calculation, using the values of the corresponding time period. The results of the procedure are shown in Table 12. With the percentage of time delay obtained and through Table 8, it is concluded that the level of service for weekdays is D, while for Saturday the level of service is E.

Table 12. Service level 8:00 - 9:00 a.m.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
PTSE	71.52%	71.88%	72.78%	76.17%	71.88%	85.11%

3.6.2. Service level 2. The highest volume of vehicles in the afternoon hours was recorded between 4:00 p.m. and 5:00 p.m., due to the end of working hours. Table 13 shows that the weekday service level included in these hours is the same as in the morning hours with a D and E service for Saturdays.

Table 13. Service level 4:00 - 5:00 p.m.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
PTSE	75.72%	77.94%	79.95%	77.61%	77.28%	88.95%

According to the results obtained, the FHP value is between 0.75 and 0.95, which indicates that there is not a great variation in vehicle flow within each hour, that is, the mobility problem is not due to the variation in vehicle traffic. Likewise, the percentage of heavy vehicles is quite low, only 1.2%, and that of public service buses is 17.75%, so the composition of traffic would not be the cause of the mobility problem either.

The problem found on 7th Avenue, as already mentioned, is peculiar, because it would be expected that with higher volumes of traffic the speed of service would decrease, and on the other hand, that with lower volumes of traffic there would be higher speeds, however, it can be explained by the presence of street vendors who invade the width of the road and reduce the useful width of it, since a street vendor occupies on average 1 m per 1.2 m of public space, although there are cases in which the space can reach 4 m by 1.2 m and even 5 m by 3 m when they take out chairs and even refrigerators, so it is not surprising that the presence of informal vendors on Avenue 7 with Street 5 to 10 has such an impact. Therefore, in order to quantify the impact caused by these informal vendors and other factors, average speeds obtained on site are compared to theoretical average speeds. Next, in Table 14, the comparison between the speeds for 12 noon (critical speed) is made.

Tabla 14. Comparación de velocidades.

Day	Theoric mean speed	Average speed measured on site at 12 am
Weekdays	31.28	6.63
saturday	32.79	6.25

The tables above clearly show a huge difference between the measured speeds and the calculated speeds. This difference in speeds is worrying, since the circulation speeds are reduced by about 80%, that is, in concrete numbers, a reduction of more than 24 Km/h. Thus, this road infrastructure would be underutilized due to the absence of citizen culture of the different actors involved.

4. Conclusions

The capacity of the road was built to operate with 3400 vehicles/hour, being used only 12% of it, that is to say that the delay times are in 89% to 95% for Saturdays, being really notorious with the theoretical speeds that are developed between 34 km/h and 35 km/h for light and heavy vehicles. The average speeds obtained by the gauges ranged from 13 to 14 km/hour during the week, on Saturdays from 10.1 km/h, with critical speeds between 11:00 a.m. and 13:00 p.m. from 5 km/h to 8 km/h. Currently, the level of service of the avenue is level E for weekdays at noon and level D for the hours before and after this time, but due to the population growth (perpendicular to the vehicle) of the region will increase the flow of vehicles and tend to move to levels of service E and F.

Given that it was concluded that the problem of mobility in the sector derives from illegal occupation of public spaces, it is proposed to seek the maximum use of the existing conditions, with the minimum investment in work, using the functional regulation of traffic to the maximum, which includes legislation and regulations adapted to the needs of traffic, as well as activities that encourage discipline and education on the part of the user, in addition to the installation of public transport stops, so that this will generate a decrease in the number of times that these vehicles stop to board or leave passengers, and thus, not obstruct the passage of other vehicles. Also, within this category is the promotion of public transport, because when more people travel through the city using the bus instead of their vehicle, there will be less traffic congestion, and also the user will be able to travel faster, cheaper and more relaxing.

The factor would be improved by optimizing the public transportation system (17.75% of vehicle traffic), regulating bus stops, increasing parking lots and prohibiting parking, using alternate routes for heavy vehicles (1.20% of vehicle traffic), prohibiting road invasion by pedestrians and street vendors, especially on Saturdays with the highest commercial sales. Cities must be projected taking into account the population increase, being the good design of public transport and the displacement by means of transport that contributes with the environment as the bicycle, ecological alternatives to give solution to the problems of mobility of the cities.

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