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Delay at bus stops of Metrolinea transport system, based on parameters measured "in situ". Case study Bucaramanga-Colombia

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Abstract

The purpose of this research is to determine the theoretical capacity of the Metrolinea transport system according on delay at bus stop predictive model, based on parameters measured “in situ”. The Metrolinea is an integrated mass transportation system (SITM) which was developed in Bucaramanga, Colombia, and is based on the concept of a bus rapid transit (BRT) with fixed stops in exclusive places. It has a design, service and specialized infrastructure. It follows a trunk line structure interconnecting the three neighboring municipalities of Bucaramanga, Floridablanca and Piedecuesta, guaranteeing their use and high passenger demand. The project consists of a delay model at bus stops along the different stops of the trunk corridor that connect these three municipalities, allowing us to predict the most useful parameter. The methodology developed in situ consists of visual observation, executed in the existing trunk, and has an approximate length of 16.8 Km. The distance between each of its stations is variable, ranging from 230m to 2980m. The measuring requires one to board the bus, record the times spent during the journey, calculating the one with the highest demand, recording the flow of passengers, as well as calculating the delay times, interruptions and incidents. The data was collected in the year 2017 on market days. The calculation methodology used is contained in the manual of transit capacity and quality of service (TCQSM), this allowed us to determine the calculations corresponding to the theoretical capacity of the system and delay at the bus stops model.

Keywords: public transport; metrolinea; dwell-time; delay at bus stop; capacity.

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1. Introduction

In Colombia, the implementation of BRT type mass transit systems (Bus Rapid Transit) has generated a series of adjustments at road infrastructure level, as well as changes in urban public passenger transport routes, urban transport routes management, and led to the creation of feeding systems, construction of new infrastructure and development of monitoring centers that allow various emergency situations or system operations to be attended. There are several representative parameters for the characterization of this type of system, but the most useful and indeed most important is the capacity determination (Kittelson et al., 2003), which refers to the number of passengers that can be transported versus the number of passengers that want to get on and off at each stop.

The integrated system of public transport Metrolínea SA was implemented in the city of Bucaramanga and its suburbian area in February 2010. It was conceived to improve vehicular mobility, eliminate typical causes of delay and reduce pollution in the city. Currently the system is composed of an infrastructure that includes a trunk corridor, pre-trunk and feeders, pedestrian bridges, transfer stations and intermediate stations. It has two operating companies who direct the management of the road passenger transport operation that uses the integrated public transport system on a daily basis. The system is based on the concept of fast transit buses, with fixed stops in exclusive places, has a design, service and specialized infrastructure, and a pre-payment smart card system to ensure the operation runs smoothly by avoiding additional delays due to onboard payments or ticket inspections.

This research focuses on the characterization and modeling of the Metrolínea's theoretical capacity using the methodology contained in the Transit Capacity and Quality of Service Manual (TCQSM), which will allow us to determine a delay model at the stops of this type of transportation system. In a previous investigation, the capacity of the Transmilenio (Peña & Moreno, 2014) system was determined, as a consequence of this project it was necessary to analyze similar systems in Colombia to have a broader perspective and in this way understand better the possible variations of its parameters or phenomena present in a same type of system under similar conditions of study and analysis. Using data collected in situ along the trunk, it was possible to demonstrate which stop possessed the highest demand in the system, in turn all the other stops were also analyzed, which allows a variety of data to be included not only at the busiest stop, but also at the others, benefitting the model since it achieves a more accurate gague of transport activity throughout the system. Within the collected data, delay times, interruptions and incidents were all recorded, which allows us to analyze the variation of the average delay times according to the number of passengers when any of these situations occur.

2. Description of the public transportation system in study

Metrolínea is the Integrated Mass Transportation System of Bucaramanga and its metropolitan area, comprised of the municipalities of Floridablanca, Piedecuesta and Girón. In 2006 construction began, and the system became operational in February 2010, beginning with a one-month trial period.

The SITM (Integrated Mass Transit System) is based on the concept of a rapid transit bus, with fixed stops in exclusive stations, connected to feeder bus routes that are responsible for transporting passengers from urban concentration areas to bus stops on the trunk routes. These systems have emerged in response to the public transport problems that occur in different countries, in this case in Colombia and, more specifically the city of Bucaramanga, such a system is developed to give the user a low-cost, swift, secure and efficient journey, that will drastically improve quality of life as well as boost urban development. Currently the infrastructure encompasses: a trunk corridor which is exclusively used for articulated buses, pre-feeder and feeder roads, pedestrian bridges, intermediate and transfer stations and a provisional storage yard.

This system is characterized by having a ticket payment system before getting on the bus, which avoids additional delays and allows the operation to run more smoothly. Payment is done by purchasing or recharging a smart card, when getting on the bus the user makes a single ticket purchase, which can be validated at any stop along the trunk routes or onboard the feeder buses that serve as a connection between the large urban areas and trunk routes, this payment's main benefit is that the user may change routes within the transport system without additional surcharge. The system's infrastructure consists of fixed stops especially designed to pick up and drop off passengers, where there are support staff available. The various routes and maps will be clearly displayed as a means of guidance for the public. The stops are built on elevated platforms, with entry at ground level. Delays due to the "access gap" will be avoided through various mechanisms, for example the use of ramps, as is the case in systems of this type in other cities of the world.

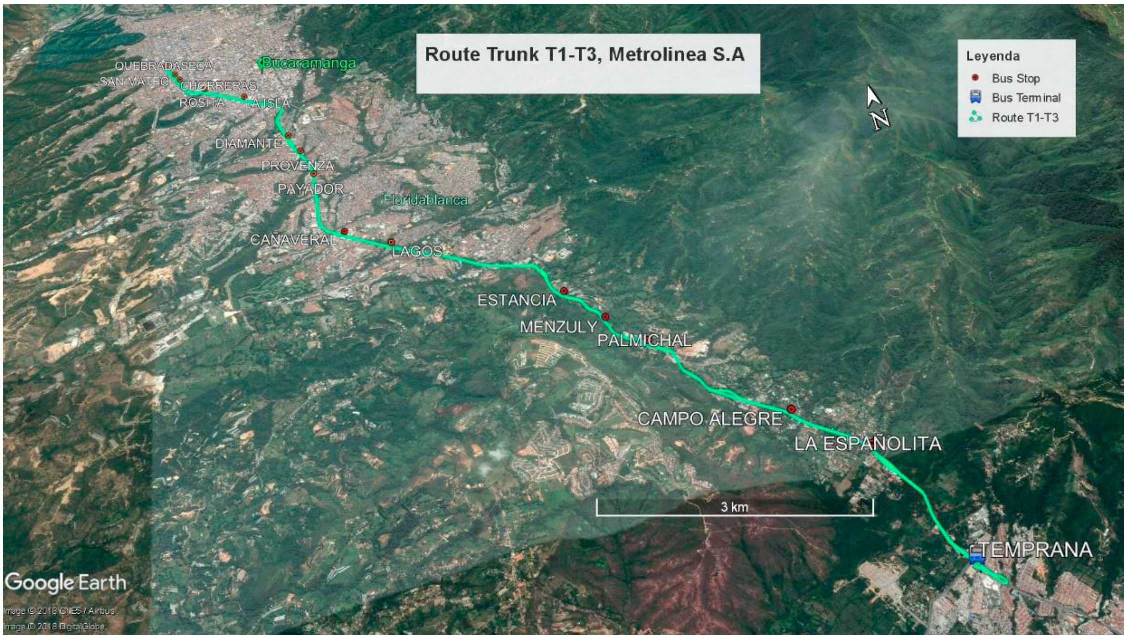

Fig. 1. Bus stops, trunk route T1 y T3. Source: Google Earth.

3. Analysis of preliminary information and the section with greater demand

Concerning the gathering of primary information, the task was carried out and presented to the Metrolinea company in Bucaramanga, where it was possible to demonstrate, by analyzing the data history from 2012 to 2016, the stops at which the largest number of trips were validated. It was also discovered that the trunk routes T1 and T3 are the routes with greater passenger demand, and that on these routes, articulated buses with a capacity of approximately 160 passengers circulate, that run along exclusive lanes, as is analyzed by the methodology of the TCQSM. From there, it is established which the stops have the highest passenger demand along the corridor, which was then compared to the data collected in the field during previous tours, which were carried out in order to verify the information provided and to better understand the system's behavior.

It was finally established that although the stops identified as San Mateo and Cañaveral have the highest number of ticket validations, the stop where the highest transfer of passengers per hour is made is the what we will name Provenza stop and this is due to several reasons, the principal being its geographic location as shown in Fig. 1. It functions, then, as a connection for different feeder bus routes within the system, as the users that join the system in feeder buses will in turn validate their tickets, all with destination to Provenza. It is in this way that the highest transfer of passengers is recorded at this stop, thus making it the one with the highest demand.

Once trunk routes T1 and T3 have been identified as those with the highest demand, the different stops within these routes are identified given that the two routes correspond to the same round trip circuit on the trunk. Therefore, the analysis section is singular, although the round trips do not share the same stops as shown in Fig. 1, but if they share the same geometric route, they are also express routes that circulate through the main corridor of Bucaramanga and its suburbs. The trunk has an approximate length of 16.8 km and the distance between each of its stations varies from 230m to 2980m. Throughout this, there are 15 stations of stop and a terminus "Early Station of Piedecuesta", however the latter was not considered at the time of conducting the analysis as it presented behavior very similar to that of a passenger terminal.

4. Methodology and data capture

The methodology used to calculate the theoretical capacity is contained in the TCQSM manual. It distinguishes itself by having strong scientific backing and was developed from the gauging model with access to intersections of the HCM (Highway Capacity Manual, 2010). In this way, the capacity per load area can be calculated using the following equation:

$$B_s = B_l \cdot N_{el} = \frac{3600 \cdot \left(\frac{g}{C}\right)}{t_c + \left(\frac{g}{C}\right) \cdot t_d + Z \cdot C_v \cdot t_d} \cdot N_{el} \quad (1)$$

Nomenclature

Bs	bus stop bus capacity (bus/h)
Bl	loading area bus capacity (bus/h)
g/C	effective green time ratio
tc	clearance time (s)
td	average dwell-time (s)
Z	standard normal variable corresponding to a desired failure rate
Cv	coefficient of variation of dwell-time
Nel	number of effective loading areas

The relation of effective green (g/C) as it increases its value directly affects the capacity in stop since it maintains a directly proportional relation, in this case the system contains bus lanes, therefore, the value of this relationship is one. According to the literature, a failure rate of 25% is recommended to estimate capacity (Jacques and Levinson, 1997), the probability of failure is a function of the admitted failure rate if the data is adjusted to a normal distribution. The coefficient of variability is determined as the standard deviation on the average delay.

For the data collection campaign, joint field techniques were used, by means of visual observation, spreadsheets records and GPS data capture of the position and speed of the buses, all with the purpose of obtaining data that will permit a better analysis of the system's behaviour. The first method was to board the articulated bus, recording the time spent on the trunk corridor route, registering the number of passengers getting on and off, the time taken to open and close the doors, and any presenting incidents. This method was used during a determined period of time where primary information of the whole route and the behavior at each stop within the study section was recorded. Once this data was analyzed, the stop with the greatest flow of passengers was identified, represented by the greatest delays in the system.

As a result, the Provenza stop is the one with the highest record of passenger flow, therefore, we will proceed to expand the amount of field data and record the delay times. To do this, the data is recorded at the stop itself, the connection time, the time taken to and the number of passengers getting on and off, the clearing time, and interruptions or incidents that are atypical and that may affect the behavior of the system.

5. Sampling and statistical analysis

The sampling is carried out in two phases: the first allows us to define the dispersion of the main parameter, and the second, carrying the error committed to admissible values by expanding the sample. The minimum size and maximum error committed are obtained by applying the normal distribution for a confidence level of 95%, considering a good percentage of observations. See Table 1.

Taking a sampling of 10 pieces of data in the north-south direction and 10 data in the south-north direction, the following results were found:

$$n = \frac{3.84 * S^2}{e^2} \quad (2)$$

Table 1. Sampling in two-phase.

Description	Trunk T1-T3	Phase
Parameter	td (s)	1
Maximum error "e"	±3.61	
Observed deviation "S"	±8.25	
Minimum size "n"	20	
Final sample "n"	387	2
Deviation "S"	±5.06	
Absolute error "ea"	±0.51	
Relative error "er"	±0.03	

Increasing the minimum size to the total sample that is equivalent to 387, it can be observed that this is more representative and the error is considerably reduced to the value of 3%.

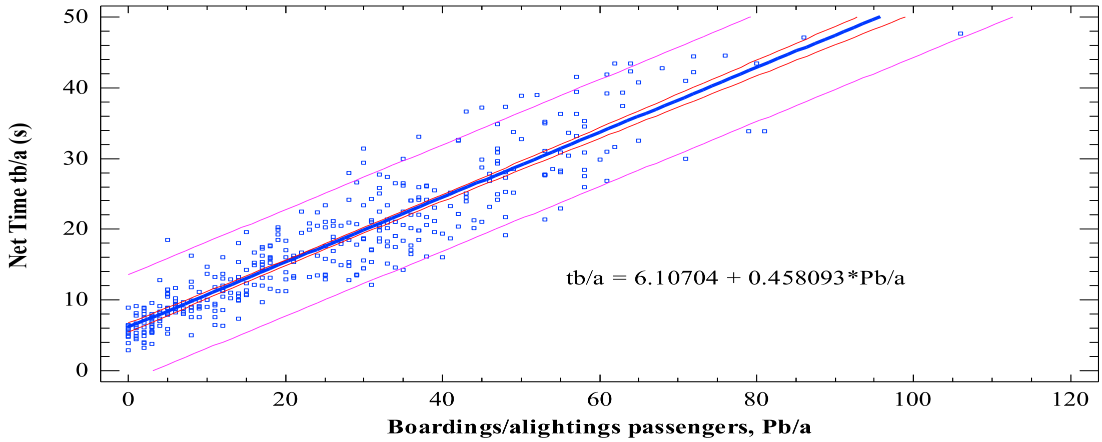

Fig. 2. Net time model by boardings and alightings passengers at bus stop.

Table 2 shows the results of adjusting a linear model to describe the relationship between tb/a and Pb/a, and the equation of the adjusted model is the one shown in Fig. 2. Since the P-value in the table ANOVA is less than 0.05, there is a significant relationship statistically speaking between tb/a and Pb/a with a confidence level of 95.0%.

The R-squared statistic indicates that the adjusted model explains 85.13% of the variability in tb/a. The correlation coefficient is equal to 0.9226, indicating a relatively strong relationship between the variables. The standard error of the estimate indicates that the standard deviation of the residuals is 3.81 within the tolerable limit. The average absolute error of 2.93 is the average value of the waste. The Durbin-Watson (DW) statistic examines the residuals to determine if there is any significant correlation based on the order in which they are presented in the data file, since the P-value is less than 0.05, there is indication of a possible serial correlation with a confidence level of 95.0%.

Table 2. Analysis of Variance

Source	Sum of squares	Gl	Mean square	Reason-F	Value-P
Model	31019.8	1	31019.8	2130.30	0.0000
Residue	5416.77	372	14.5612		
Total (Corr.)	36436.6	373			

This model result differs somewhat from what was found in systems with an analogous stop-transfer process (Moreno & Romana, 2012), as well as results obtained in Transmilenio (Peña & Moreno, 2014), this may be related to the type of city and the levels of congestion in the analyzed transportation system, given that Metrolinea does not have as many buses as Transmilenio and therefore generates longer loading and unloading times for passengers, since users will attempt to board the bus that is waiting at the stop, and this makes the behaviors different. Analyzing the model found for Metrolinea, it can be observed that there is an approximate delay of 6s, even when there are no passengers getting on or off the bus, and as the number of passengers in the operation increases, so does the delay, at a lower rate than the one observed at low demand.

6. Delay at bus stops and main parameters

Through the statistical analysis, the results and parameters necessary to estimate the dwell-time model, and in turn calculate the theoretical capacity of the existing trunk, are obtained. One of the parameters, the average articulated bus clearing time, was approximately 6.5s as measured in the field under normal operating conditions, see Table 3. The variable in the net time model corresponds to the number of passengers, adding passengers getting on and off. When talking about net time, reference is made to the time taken in the passenger's entrance and exit with the doors open, therefore it is necessary to take into account in the calculation of the delay in opening and closing the doors, a time that was determined in the field at an average value of 3s, identified as the average opening and closing time of doors.

Table 3. Dwell-time model and main parameters in Metrolinea.

Main parameters Metrolinea			
Stretch	Dwell-time (prediction model), td (s)	Clearance time, tc (s)	Variability coefficient, Cv
Troncal T1-T3	$dp = 0,458093 * P_{b/a} + 9,10704$	6.5	0.18

The bredth observed in the data is due to several scenarios, which were discounted for the purposes of analysis, such as:

- A full bus – this situation means that those passengers who are at the stop and are trying to board hastily hinder those attempting to get off, thus increasing the delay since the bus cannot continue its journey whilst the doors are open
- There is already a bus waiting at the stop - which means the arriving bus cannot open the doors and let passengers on or off.

There are also incidences due to defective doors that delay the usual process, as well as specific cases of passengers with disabilities or pregnant women that force the driver to wait until they are safely seated or off the bus.

The variability of these situations were analyzed separately to identify their influence on the delay, so that an analysis of means was performed according to the situations that were more frequent and that are more prone to recur, it is shown in Fig.3.

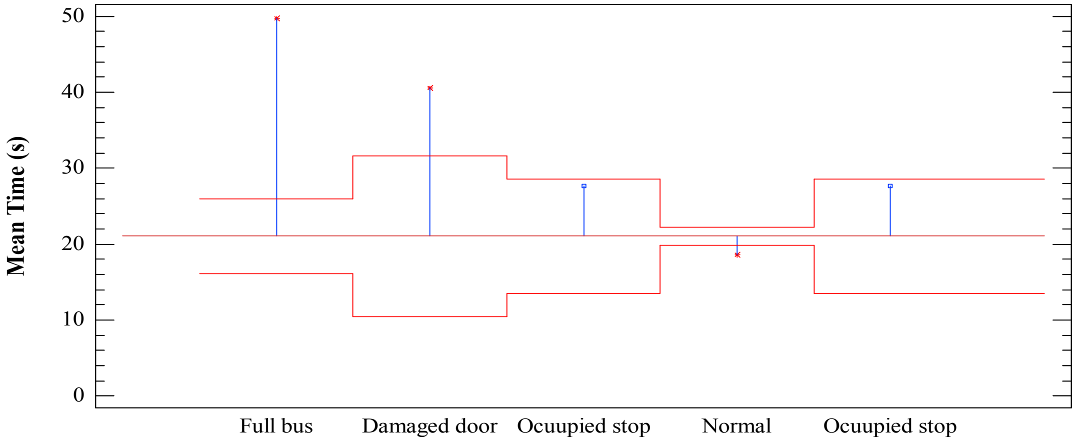

Fig 3. Analysis of means for additional conditions.

7. Capacity of the trunk T1-T3, Metrolinea

The closest model for calculating the capacity for this type of systems is described in the TCQSM methodology, it provides techniques and procedures that allow us to evaluate the transit capacity in different public transport systems. The capacity calculation methodology is developed through the gauging model.

The capacity in the loading area can be calculated using the following equation:

$$B_l articulated = \frac{3600}{6{,}5 + (0{,}458093 \cdot P_{b/a} + 9{,}1074) \cdot (1 + 0{,}674 \cdot 0{,}18)} \tag{3}$$

Metrolinea manages lanes exclusively for articulated buses, therefore the effective green ratio is equal to 1. According to the literature, a failure rate of 25% is recommended in estimating the capacity (Jacques and Levinson, 1997), the pobability of failure depends on the admitted failure rate if the data is adjusted to a normal distribution, the suggested failure rate of 25% corresponding to a normal distribution statistic of 0.674.

The nominal capacity of the articulated bus is 160 passengers according to the manufacturer's values; the estimated capacity based on the number of passengers obtained is calculated by multiplying the number of buses by the nominal capacity of the articulated bus, shown in Fig 4.

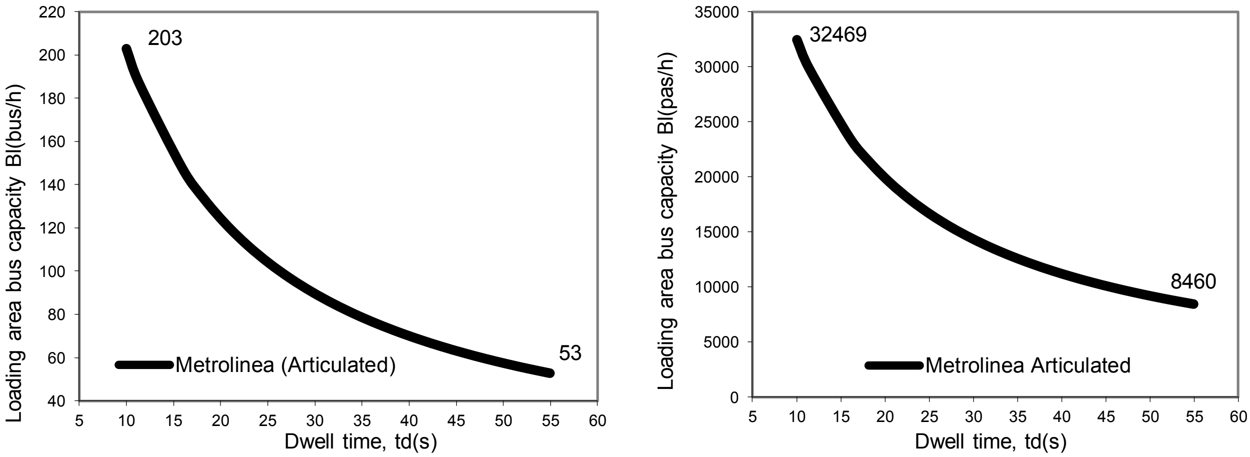

Fig. 4. (a) loading area bus capacity (bus/h), (b) loading area person capacity (pas/h)

8. Conclusions

The Provenza bus stop is the station with the highest number of passengers boarding and disembarking, therefore it is the station with the highest number of delays and incidents during peak hours. It is a special station due to the number of feeder routes that arrive there, which is why in the statistical data, passenger validations at Provenza are not considered relevant in the Metrolinea database because passengers validate their tickets on the feeder buses.

According to the analysis carried out, and using the data collected under normal conditions, it can be established that the model that best represents the behavior of the dwell time is the linear model, unlike other similar systems, which conform to the second order.

The maximum delay at a stop is directly related to the number of passengers who wish to get on and off the bus, the speed with which passengers get on or off (the speed is of the slowest passenger), occupation of the bus, among others, these incidents generate dispersions that alter the main parameters and behavior of the system, which eventually become additional delays.

According to the data obtained in the field, the defective door effect is the incidence that most affects the process of passenger movement, generating a slow transfer process, and when arriving at stops at peak hours it becomes more critical.

The results obtained in the modeling and calculation of the transport capacity of the integrated mass transport system in the existing trunk trunk are not similar to other systems studied, as is the case of Reilly and Aros-Vera (2013) and Peña & Moreno, (2014), which sees 105 and 93 articulated buses with a service time near of 30s.

9. Acknowledgements

The staff of, Metrolinea S.A. in Bucaramanga.

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