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Methodology for Parking Bays Design for Urban Public Transport Vehicles, in streets of the city of San Juan de Pasto - Colombia

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Abstract

In the present work, a viable methodology for the design of parking bays is shown, to be implemented within a public transport system at an urban level. For this purpose, the city of San Juan de Pasto has been taken as a reference, which is within the so-called intermediate cities within the Colombian territory. Taking into account that there is no formal methodology that allows the design of the parking bays, it has been considered opportune to propose a strategy through which these structures can be dimensioned. This has been achieved in the present work, based on the results obtained from speed and vehicle capacity studies, applied specifically to the case of buses that make use of the public passenger transport system; and also considering some criteria established by the AASHTO for the geometric design of roads.

Keywords: parking bays, buses, urban transport, bus stop, urban mobility

I. INTRODUCTION

The accelerated processes of the last century have influenced the urbanization of cities, causing their consolidation, thanks to economic, social, cultural and political changes, added to demographic growth, especially in developing countries. However, these rapid growths also bring with them the deficiency of some services, due to the slowness in the creation and implementation of the same, making their capacities less than the demands generated by the cities at a certain moment and thus causing significant injuries to the inhabitants [1].

A sample of the above is presented in urban transport, where it can be observed that as cities grow, so does the demand in transport systems, which is why interventions are not carried out that expand capacity of the system, over time there will be a deficit in the mobility of the city. Transport is a service that has always existed in the life and daily life of peoples. The changes that occur in it are based in most cases, on the needs and demands of the population, in search of better conditions for commercial and individual mobility [2]. In addition, it must be borne in mind that transportation is an essential public service for most of the inhabitants, regardless of whether it is provided by a private or official company [3]. In large cities in the developing world, travel times are generally high and increasing, congestions are reducing mobility for the car user, and in many areas, for the public transport user, mobility is declining even more [4]. The urban transport crisis seems to be in strict association with the globalization processes that cities are experiencing [5].

Transportation can be considered as a system made up of two main elements: the physical infrastructure and the operational component. In Colombia, transportation infrastructure and services have been deficient, largely due to difficulties and large investments for their implementation. In the first decades of the last century, Colombia had one of the most backward systems in the entire Latin American continent in terms of transportation and infrastructure; only until the end of the century, the situation changed [6]. The problem of public transport in Colombian cities is a consequence of the combination of a decentralized offer that provides a low quality service and an inadequate infrastructure offer in a context of low capacities for regulation and the exercise of the transport authority [7]. Colombia's urban road network requires important changes and updates in its physical environment, in order to generate a more comfortable and safe environment for road users, especially for pedestrians who are the most vulnerable.

The service provided by various actors, who act in an uncoordinated manner, has been characterized by the use of obsolete buses, inadequate route design and operation, and an oversupply of frequencies. The infrastructure and institutional capacity of local entities to regulate the operation have not responded to the needs of public transport [8]. Urban transport in small and medium-sized cities is characterized by environmental problems, difficulties for the mobility of pedestrians and cyclists, the deficiencies of collective public transport and taxis, the appearance of the non-legalized service of passenger transport by motorcycles, and the increase in negative effects produced by the growing number of cars and motorcycles (the growing number of cars in the hands of individuals) [9].

The search for solutions that alleviate this deficit in the urban road system is a necessity that cities require and that needs an in-depth study. A solution that can help alleviate mobility problems in many cities is the implementation of parking bays for the public transport system; which would allow the

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reduction of mobility conflicts and congestion generated by the waiting, ascent and descent of passengers on public transport buses [10].

The objective of this work has focused on implementing a methodology for the design of parking bays, which is a complementary part of the structure of the road, used as a transition zone between the road and the platform, intended for the temporary parking of vehicles safely and without obstructing vehicular flow or pedestrian mobility [11]. The aim is therefore to have a tool that can be used for the dimensioning of the parking bays, based on the physical characteristics (dimensions) of the beneficiary vehicle fleet, as well as on their circulation speeds in the nearby area to the bus stop. In a complementary manner, a methodology is established to determine the critical points where the parking bays should be implemented, according to the particular conditions of the area and the needs of the environment; as they are, the vehicular flow, the location of the control points of the public transport buses and the space available in the area in which the parking lots will be implemented.

II. MATERIALS AND METHODS / EXPERIMENTAL DESIGN, MATERIALS AND METHODS

II.I Study area description

The city of Pasto is located in the southwest of Colombia, it is the capital of the department of Nariño, and it is located on a plateau of the Andean mountain range and at the base of the Galeras volcano (Fig. 1). The city, which is located on the shores of the Pan-American Highway, functions as a commercial and distribution centre for first-rate merchandise for the surrounding agricultural region, and also maintains an important trade with the neighbouring country of Ecuador [12].

Pasto is located at a height above sea level of 2,559 meters, the average temperature is 14 degrees Celsius, its area is 1,181 square kilometres and its average annual rainfall is 700 millimetres. Its relief is very varied, it presents flat, undulating and mountainous terrain. The main orographic accidents are: the Galeras volcano, at 4,276 meters above sea level, the Cerro Bordoncillo, Morasurco, Patascoy, Campanero, Pan de Azúcar, Putumayo. There are medium, cold and moor thermal floors [13].

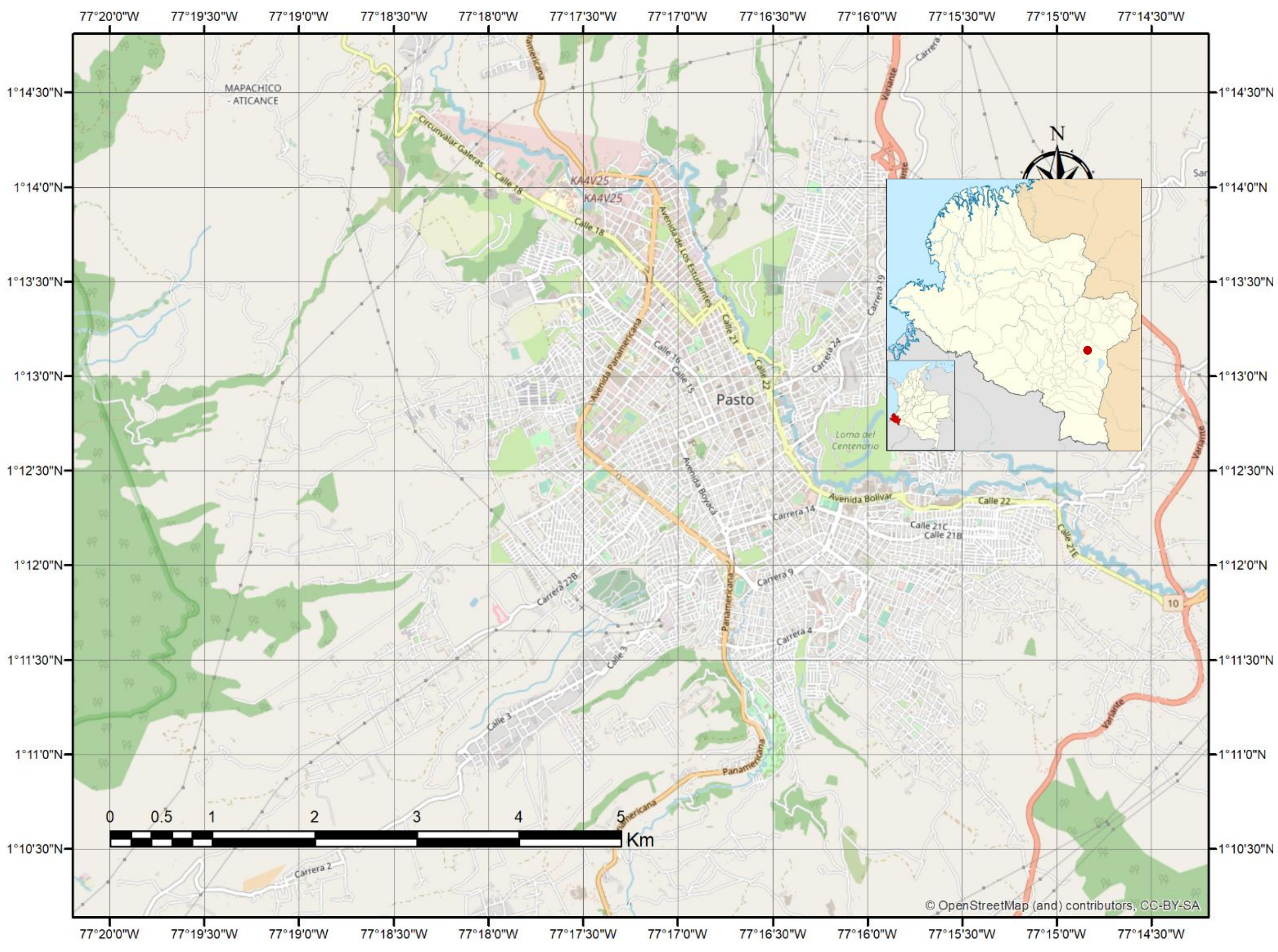

Fig. 1. Location of San Juan de Pasto city

The roads under study are called Collector Tracks. These roads distribute traffic within the different areas that make up the city, that is, they allow direct accessibility to residential, institutional and recreational areas. They constitute the vital element where the operation of the collective urban passenger transport system is allowed. The distribution and location of the collector roads must coincide with the public transport corridors and may at the same time be neighbourhood corridors [10]. In Fig. 2 the typical section of a collector road is shown, according to the regulations of the city of Pasto (Territorial Ordering Plan). And in Fig. 3 a map of the city of Pasto is shown, in which the urban streets are demarcated, highlighting the Collector Roads in green.

Fig. 2. Cross section of collector tracks

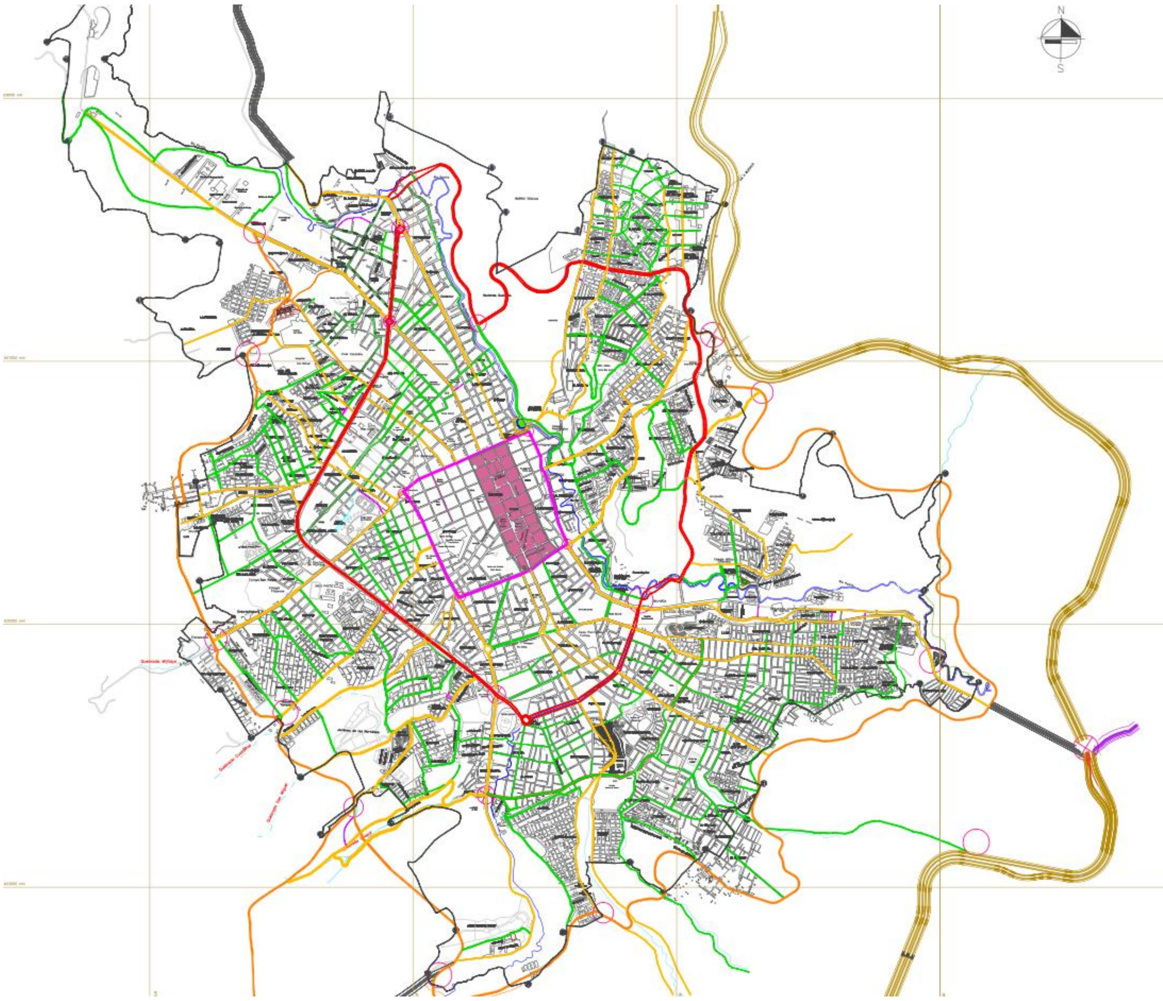

Fig. 3. Collector roads in the city of Pasto

II.II Material and methods

The present work seeks to obtain information on the current arrangement of the parking bays located on the collector roads of the city of Pasto. With this information it is intended to obtain sufficient parameters that allow the design of typical bays, which guarantee safety and comfort, adapting to the urban characteristics of the city. Similarly, some sites are identified on the collector roads, in which the implementation of parking bays is required, in order to improve mobility. The information required for the development of the work is the following:

- Information related to the design, construction and arrangement of the existing parking bays.

- Identification of the existing parking bays in the collector roads.

- Topographic survey of the existing bays that are used by the public bus transport system.

- Identification of places and characteristics of the sites where the implementation of new parking bays is required.

- Methodology and design of parking bays.

- Elaboration of diagrams and recommendations.

For the parking bays there is no methodology that allows their dimensioning, for which they must be designed in such a way that they can be coupled to the characteristics and needs of a certain place.

For the development of this research, the following procedure was carried out:

- Determination of the importance, the need, the number and the location of the parking bays, for the ascent and descent of passengers, on the collector roads for the use of public transport buses.

- Compilation of information on the layout of the existing parking bays.

- Identification of parking bays that require redesign.

- Development of parking bay designs that improve vehicular mobility.

- Elaboration of diagrams of typical bays.

The compilation of general information corresponds to information on the design, construction and location of the existing parking bays, for which the National Land Traffic Code, investigative articles related to the design and construction of urban roads, The Plan of Territorial Planning, Accessibility Manual, information obtained from field visits in the streets of the city of Pasto, among others.

The inventory of the existing parking bays was carried out based on a previous investigation of the routes of the public transport route of the city of Pasto. Based on this information, the bays that exist along the different routes could be located. These bays, which are used by the public bus transport service, were outlined through a topographic survey in the field, with which dimensions, entry and exit angles, road widths, platforms, existing furniture and urban equipment were obtained; which was taken as a reference for the realization of the designs of the new projected bays.

The identification and diagnosis of the parking bays was carried out using the city's POT, in which the typical structures of the collector roads are drawn, in such a way that when locating them we raise plan meters of the topography of the bays in the map of the city, these could be easily identified.

The identification of the places where parking bays are required was made based on the routes proposed by the city's public transport companies, in the sections of collector roads. After identifying these routes, the sites with the highest bus co-management were analyzed. Additionally, information related to the location of the public service stop sites was obtained through the Pasto city hall.

The method used to locate the bus stops is called "Up and Down", and it consists of monitoring any route for a week and analyzing the environment where the route passes, it is decided to locate a bus stop in the places where they are greater number of passenger boarding and stops.

The design of the parking bays consists of five steps detailed below:

The first step consisted of taking the speeds of the buses, when approaching the parking bays, for which the chronometer method was used. The procedure was supported with the use of two stopwatches and white paint, with which a length of 20 to 50 meters was demarcated (depending on the space available at each site). Two observers, with a stopwatch in hand, activated them when the front axle of the bus passed the first reference mark and stopped when the same bus passed said axle through the second mark. In this way, several measurements were taken, to later determine the speed, with the equation:

$$V = \frac{d}{(T_1 + T_2)/2}$$

Where:
V: speed (km / h).
T1: time recorded in stopwatch 1, when traveling the preset distance.
T2: time recorded in stopwatch 2, when traveling the preset distance.
d: preset distance.

The second step consisted of a statistical analysis, taking as input the speed values measured in the field, in such a way that the average point speeds could be obtained for each sector where it was planned to design a parking bay.

The third step resulted in the determination of the entry and exit radii of the parking bays, for which the speed values calculated in the previous step were used, classifying the speeds according to the place where they were measured (commercial area and residential area), thus working with two point speeds. To determine the radii, the following equation was used:

$$R_{\min} = 0.007865\left(\frac{V^2}{e_{\max} + f_{\max}}\right)$$

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Where:
Rmin: radio mínimo de entrada (m)
emax: peralte máximo (adimensional)
$f$max: coeficiente de fricción lateral
V: Velocity (Km/h).

It must be taken into account that since the parking area does not present superelevation, its value was taken equal to zero. In addition, for the assignment of the value of the coefficient of lateral friction, the recommended by the AASTHO was used, in accordance with what is expressed in Table 1.

Table 1. Coefficient of lateral friction, depending on the design speed

Project speed (km/h)	Lateral friction coefficient
30	0,28
40	0,23
50	0,19
60	0,17
70	0,15
80	0,14
90	0,13
100	0,12
110	0,11
120	0,09

Source: AASHTO - Guides, Manuals, and Guide Specifications for highway geometric design, construction, maintenance, and pavement management

The fourth step consisted of sizing the bays themselves, for which the characteristics that were considered were the maximum number of buses that coincide at a certain moment in the parking lot, the space available in the sector and the location of the control points of the buses. From these data, the dimensions and minimum radii of the bays were established.

Finally, the fifth step consisted of determining the equipment and signalling that the designed bays should have, for which the recommendations given by the signalling manual of the National Institute of Highways of Colombia (INVIAS) were followed.

The elaboration of diagrams corresponds to the final stage of this document, in which the figures for the typical bays designed for the different cases of parking bays are presented.

III. RESULTS AND DISCUSSIONS

The inventory carried out within the urban area of the city of Pasto, revealed a total of 25 existing bays along the city's roads, of which only 10 are located on the collector roads. The study to identify the sites with the greatest congestion and candidates to implement parking bays on the collector roads, yielded five road sections with these characteristics [10].

According to the results of the field velocity measurements, two zones of different behaviour could be defined: the commercial zone and the residential zone. This is due to the fact that the speed difference was something important, which is why two different statistical analyses were carried out, one for each sector.

To obtain the mean speed of point or temporal mean, frequency distributions were used, for which the total amplitude was divided into a total of 5 classes. These values were then tabulated and frequency histograms, observed velocity frequency curves and cumulative velocity curves of point velocities were obtained. In the same way, the mean speed, the standard deviation of the data and the standard error of the mean could be determined for each of the sectors. The results obtained are shown.

Determination of speed in the residential area

Table 2 presents the values to calculate the frequencies of the speeds in the residential area. In Fig. 4 the frequency histogram and polygon for the point velocities are shown. In Fig. 5 the velocity frequency curve and the warhead representing the accumulated point velocity for the residential area are presented.

Table 2. Spot speed frequency distribution in the residential area

Class Interval	Class Mark	Observed Frequency		Accumulated Frequency		Vi²	fiVi
		Absolute	Relative [%]	Absolute	Relative [%]		
25.0 - 26.8	25.9	12	11.11	12	11.11	670.81	310.80
26.8 - 28.6	27.7	27	25.00	39	36.11	767.29	747.90
28.6 - 30.4	29.5	45	41.67	84	77.78	870.25	1327.50
30.4 - 32.2	31.3	17	15.74	101	93.52	979.69	532.10
32.2 – 34.0	33.1	7	6.48	108	100	1095.61	231.7
Total:	n:	108	100				

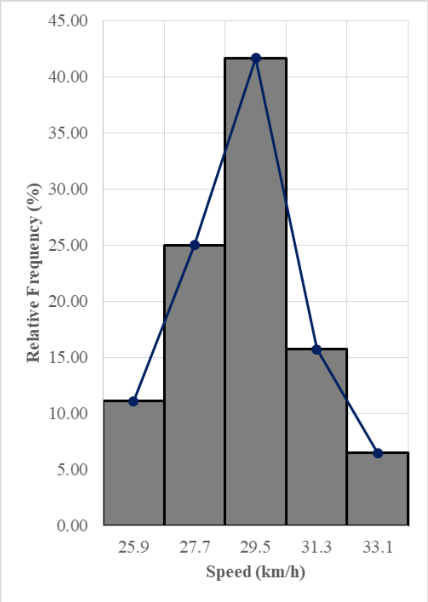

Fig. 4. Histogram and polygon of spot speed frequencies for the residential area

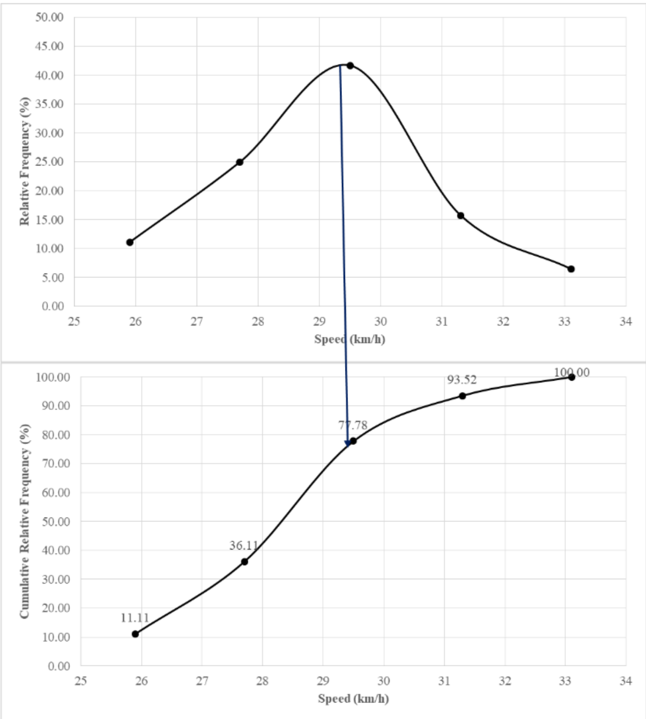

Fig. 5. Observed and accumulated frequency curve of spot speed in the residential area

Based on the data, the following is obtained:

Average spot speed:

$$V_t = \frac{\sum_{i=1}^{N}[f_i V_i]}{n} = \frac{3150}{108} = 29.17 Km/h$$

Standard deviation:

$$V_t = \sqrt{\frac{\sum_{i=1}^{N}\left[f_i (V_i - V_t)^2\right]}{n-1}} = 1.87 km/h$$

Standard error of the mean:

$$E = \frac{S}{\sqrt{n}} = 0.18 km/h$$

The average point speed for the residential area, in the neighboring sectors where it was determined that the parking bays for buses should be installed, gives as a result a value of 29 km/h, which is quite in line with the expected speeds for urban road sections, where the most common types of vehicles are cars and buses, with almost no presence of trucks.

Determination of speed in the commercial area

Table 3 presents the values to calculate the frequencies of the speeds in the commercial area. Figure 6 shows the frequency histogram and polygon for the point velocities. In Fig. 7 the velocity frequency curve and the warhead representing the accumulated point velocity for the commercial zone are presented.

Table 3. Spot speed frequency distribution in the commercial area

Class Interval	Class Mark	Observed Frequency		Accumulated Frequency		Vi²	fiVi
		Absolute	Relative [%]	Absolute	Relative [%]		
13.0 - 13.8	13.4	4	5.48	4	5.48	179.56	53.6
13.8 - 14.6	14.2	23	31.51	27	36.99	201.64	326.6
14.6 – 15.4	15.0	25	34.25	52	71.23	225.00	375
15.4 – 16.2	15.8	19	26.03	71	97.26	249.64	300.2
16.2 – 17.0	16.6	2	2.74	73	100.00	275.56	33.2
Total:	n:	73	100				

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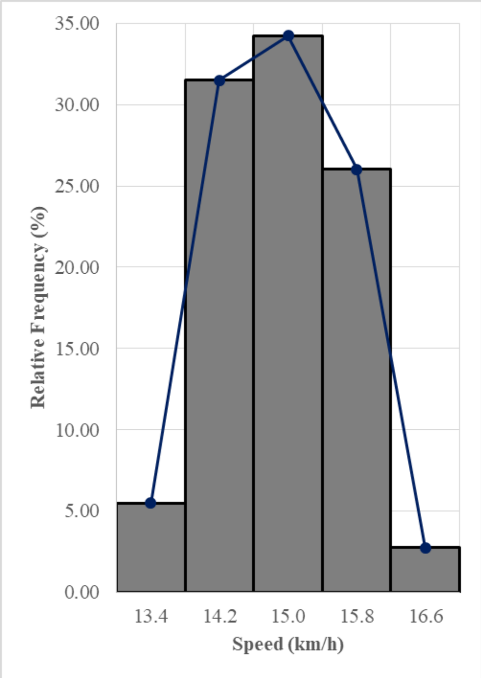

Fig. 6. Histogram and polygon of spot speed frequencies for the commercial area

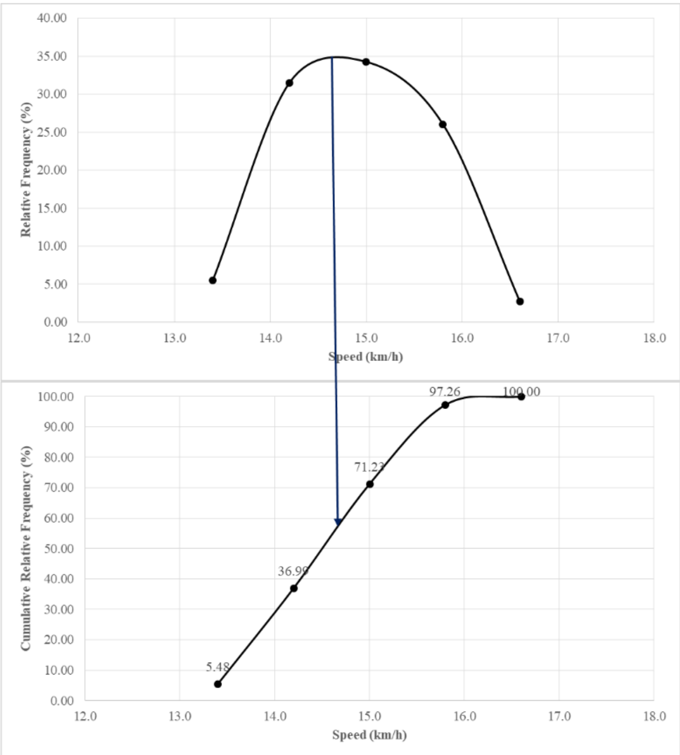

Fig. 7. Observed and accumulated frequency curve of spot speed in the commercial area

Based on the data, the following is obtained:

Average spot speed:

$$V_t = \frac{\sum_{i=1}^{N}[f_i V_i]}{n} = \frac{1088}{73} = 14.91 Km/h$$

Standard deviation:

$$V_t = \sqrt{\frac{\sum_{i=1}^{N}\left[f_i (V_i - V_t)^2\right]}{n-1}} = 0.76 km/h$$

Standard error of the mean:

$$E = \frac{S}{\sqrt{n}} = 0.09 km/h$$

With the previous results, the values of the radii of the parking bays can be established, being able to appreciate that the speed in the commercial area is significantly lower (almost half) than that of the residential area. Taking into account that the higher the speed, the greater the size of the radius that the parking bay must have and the greater the availability of spaces in the most critical places, it was determined that the speed at which the entry radius should be calculated and exit from the parking lot corresponds to the 15Km / h.

Below is a summary of point speeds, design, minimum radii, and other supplemental radius data for the parking bay design.

Table 4. Parameters for determining the minimum radius of the curves

Variable	Residential area	Commercial area
Spot speed (km/h)	29.0	15.0
Design Speed (km/h)	15.0	15.0
fmax	0.28	0.28
emax	0.00	0.00
Rmin (m)	6.15	6.15

To determine the length of the bays, it is necessary to know the characteristics of the buses. Fig. 8 shows the selected type bus (Chevrolet NKR) for the bays under study and Fig. 9 and Table 5 shows the dimensions of the mentioned vehicle.

Fig. 8. Chevrolet NKR design bus
Source: Microbus NKR Reward datasheet

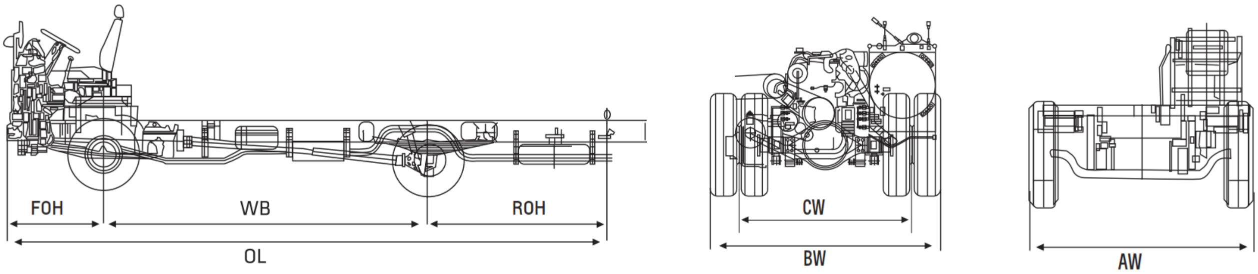

Fig. 9. Design bus dimensions

Table 5. Design bus dimensions

Truck part	Measure (mm)
OL (Overall Length)	6.030
WB (Wheelbase)	3.345
FOH (Overhang - Front)	1.110
ROH (Overhang - Rear)	1.575
BW (Rear Axle Width)	1.860
CW (Track - Rear)	1.425
AW (Front Axle Width)	1.475

To calculate the length of the parking bay for the project area, the characteristics taken into account are the following:

Operating speed = 15 km / h
Bend Radius = 6.15 (m)
Type bus length = 6.03 (m)
Type bus width = 2.30 (m)
Ascent ramp width = 1.20 (m)
Space that between buses when parked = 1.00 (m)
Entry angle to parking bay = 30 °

$$Lt = CA + Te + Ts + Nb \times Lb + (Nb - 1) + Ra + CA + Ts + Te$$

Where:

Lt = Total length of the bay
CA = Total length at the entrance of the parking lot
Te = Tangent of entry (m)
Ts = Tangent of exit (m)
Nb = Number of buses that can reach the parking bay at the same time.
Lb = Length of bus type, 6.03 (m)
(Nb-1) = Number of spaces that must exist in the parking bay, depending on the number of buses.
Ra = Ascent ramp width, 1.20 (m)
Since Te = Ts Simplifying and calling it T, we have:

$$Lt = 2CA + 4T + Nb \times Lb + (Nb-1) + Ra$$

In Table 6, a summary of the dimensions of the bus parking bays is presented based on the number of buses that can coincide in them at a given time.

Table 6. Dimensions of parking bays

Number of Buses	Bus Length (m)	Bays Length (m)	Bays Width (m)
1	6.03	22.5	2.5
2	6.03	29.5	2.5
3	6.03	36.6	2.5
4	6.03	43.6	2.5

Bay sites must be equipped with the following elements: ascent and descent ramps, to guarantee safety, comfort and well-being for the movement of people, especially disabled people. The bays must also be demarcated with their own bus parking marks, lines and legends. Additionally, it is proposed that an urban facility be contemplated, in which booths that are equipped with benches should be available, as long as the available space allows it.

Based on the calculated dimensions, taking into account the geometry of the bays, the operating speeds and the dimensions of the buses that will use them, it was possible to build diagrams with the bay sizing, as shown in the figures. 10, 11, 12 and 13.

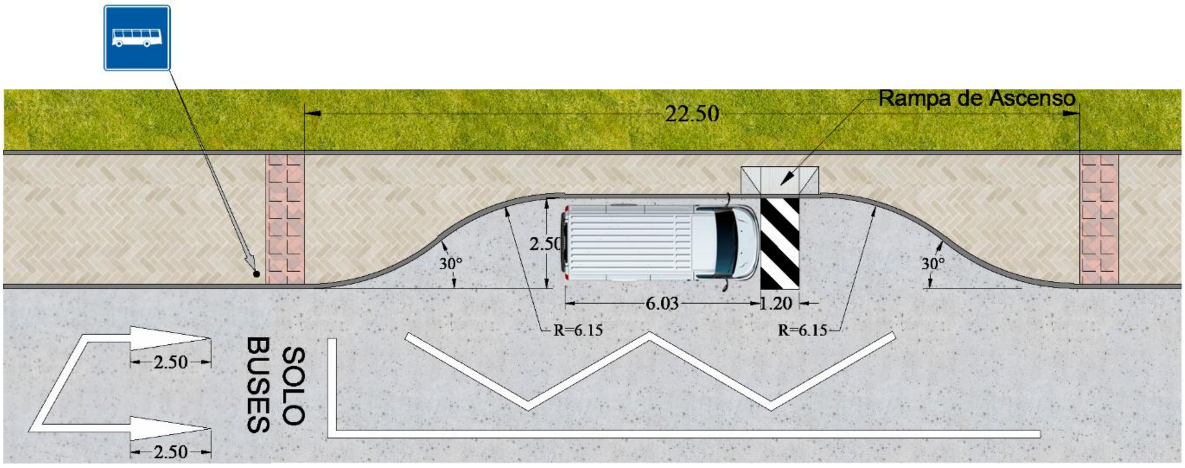

Fig. 10. Typical parking bay, to house a public transport bus

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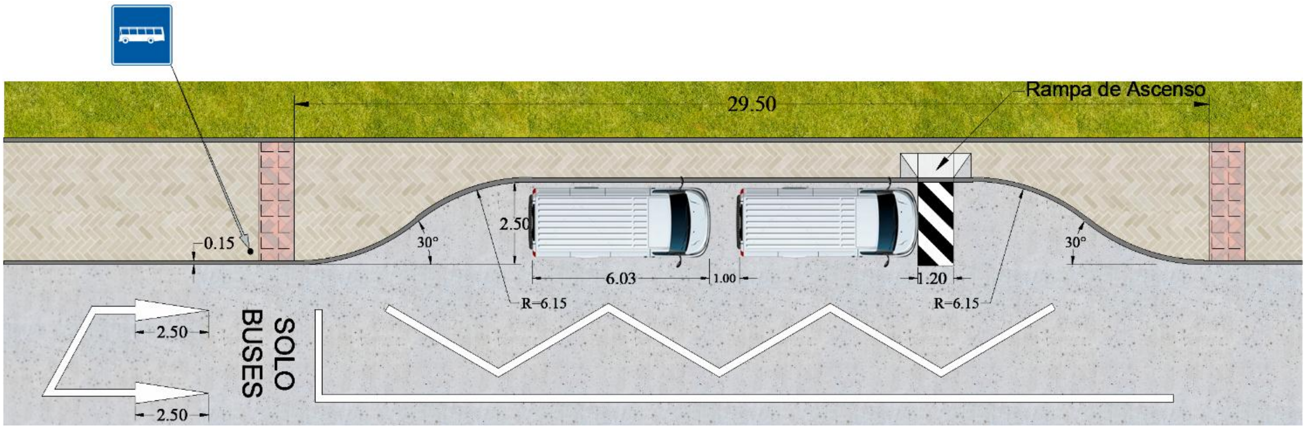

Fig. 11. Typical parking bay, to house two public transport buses

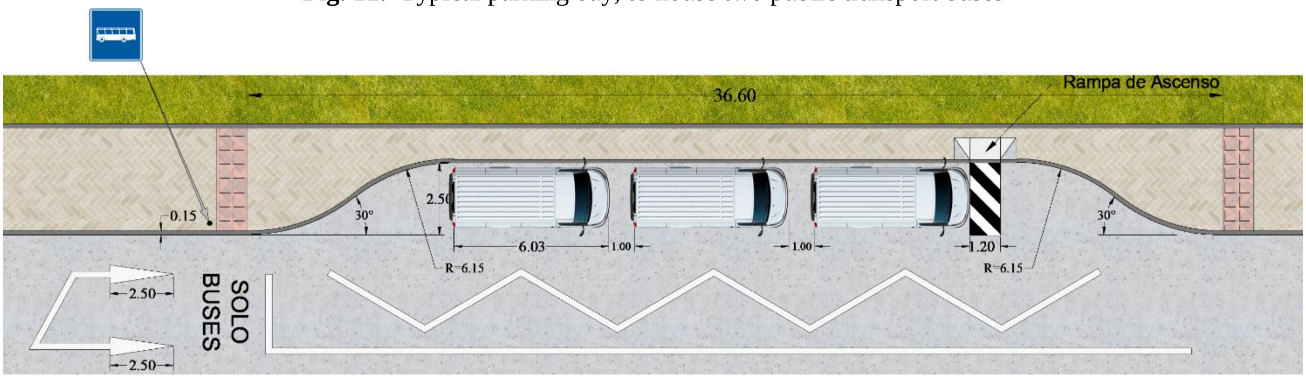

Fig. 12. Typical parking bay, to house three public transport buses

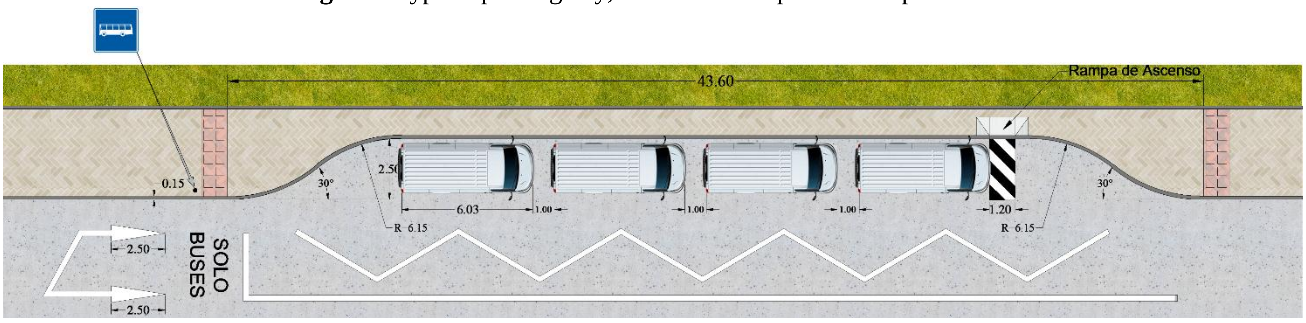

Fig. 13. Typical parking bay, to house four public transport buses

IV. CONCLUSIONS

For the sizing of bus parking, the following parameters must be taken into account as selection criteria: number of buses that accumulate in the sector, available space between buses when parked, the radius of entry and exit of the sector, ramp of ascent, dimensions of the type bus and physical equipment, as established in the accessibility manual.

It is possible to appreciate that the entrance and exit radii of the parking lot are a direct function of the operating speeds, which is why it is a very important variable for the sizing of the bays; in this way, at lower speeds, less space is used, thus providing a visually pleasing structure. Additionally, the parking bays must be equipped with speed bumps, which guarantee the minimum speed when approaching said structure.

Parking bays are of vital importance in reducing mobility conflicts, as well as helping to protect the physical integrity of people who use the urban public transport service.

An important aspect to take into account in the parking bays is related to the need to provide access ramps, which eliminate the unevenness between the road and the platform, in such a way that it can allow accessibility to people with reduced mobility.

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