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Proposal of a Model that Allows to Improve the Behavior of the Passenger Flow Inside the TransMilenio Stations

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Abstract

This study has been carried out with the purpose of qualitatively measuring and proposing aspects that are affecting the behavior of the flow of passengers within the massive transport system in Bogota, taking as reference in-situ samples and information provided by the company TRANSMILENIO S.A. for Calle 76 station. These factors correspond to turnstiles, ticket offices, reorganization of bus routes, operation of buses and distribution of passengers throughout the station, since the capacity of the Caracas corridor exceeds the passengers per hour per direction in peak hour that different metro systems around the world mobilize, unlike TransMilenio has BRT bus infrastructure and no metro infrastructure.

Keywords: BRT Station; mass transport system; passenger flow; TransMilenio; capacity.

1. Introduction

TransMilenio, the mass transport system of Bogota, Colombia, has been in operation since December of 2000 [1], also, due to Acuerdo 04 de 1999 which the complete management, organization and planning of mass public urban passenger transport service are granted to the company TRANSMILENIO S.A. [2], being a solution included within the government of Mayor Enrique Peñalosa (1998-2000) as a priority project. For instance, this implies that Bogota's BRT system, in its 17 years of operation, has grown not only the number of corridors within the city, but as the population of the city grows, the stations that are designed for the first lines, *Autonorte, Calle 80 and Caracas*, cause them to be in a design problem.

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As a result, there are inconveniences regarding the flow of passengers inside the stations, and one of the main reasons is that the internal space of these were designed for a population of 6 million inhabitants in the capital city [3], and nowadays it has grown more than 2 million people, being an important aspect that they did not consider when it was released. This problem arises when there are more people going in and out the stations in peak hours; therefore, the Institute for Transportation & Development Policy [4] says that there are elements in which they can increase the corridor capacity and reduce station saturation, such as platform-level boarding, fare collection, doorways and station platforms.

Therefore, the main purpose of this article is to make a proposal for a station model where an improvement in the flow of passengers can be seen inside a model station of the Caracas corridor, that uses Calle 76 station as a reference, since it is a station that is located in a sector of Bogota where there are several workers and students, causing a congestion when passengers try to move from one sub-stop to another, or simply to go in or out the station and wait in docking-bays for articulated buses to arrive in peak hours.

This study aims at improving of satisfaction rate of the users of the system. Since in the last survey (2016) conducted by the National Consulting Center S.A. [5], where there is a concern regarding the general service, which obtains a score of 2.62 out of 5, and specifically in the stations a rating of 2.81 out of 5, it must be taken into account that this survey hired by TRANSMILENIO SA had the answer of 1747 users in-situ during 7 consecutive days and in different stations of the BRT corridors. In addition, another study done in 2017 by Ipsos Napoleón Franco entrusted and financed by Bogotá Cómo Vamos, where 60% of citizens said that last year TransMilenio system service has worsened, and just 10% mentioned that it has improved, while the rest 30% of the people surveyed thought it still the same [6].

Nevertheless, in the present work it will take into account the dimensions that are currently located in the Avenida Caracas corridor, although there are problems in the design of these stations regarding to internal space for passenger’s flow.

Based on what was mentioned above, the design will be carried out without modifying the space, since being a narrow avenue, there are buildings on both sides, and it could not be possible to modify it, since it will make the work more complicated and the idea is to focus especially on the proposal to improve the flow of users of TransMilenio system on Calle 76 station.

However, different studies and implementations have been made in different cities around the world regarding to BRT system. Therefore, stochastic models have been created with percentiles of the number of passengers waiting and duration per station, platform and the average waiting time of passengers, where the order of arrival of the buses to the Thibault station in Cape Town is considered in order to generate different scenarios and realize that the percentage of the percentile goes correspondingly with the cost of it, that is, if it wants to be managed with a higher percentile, it will need more space [7].

Moreover, there is a linear relationship between the berthing time of buses and the time that passengers spent on getting off or on, also the time of each user going in to the station is longer than when leaving it and there will be a delay for each passenger going in when the amount of people inside the BRT increases [8], as it could be demonstrated with different surveys and models of line 2 in Jinan city in China.

However, in Xiamen there is a solution to control the volume of passengers of BRT system, and the solution is making an elevated line, only for downtown, producing less times and distances, due the high speed of this corridor [9]. This was possible due the data recorded by the transport cards of the different users once they pass through the turnstiles.

Another study proposed an evacuation model in the BRT stations, analyzing existing evacuation simulation models, where the station is modeled and incorporates, conflict resolution mechanisms and pedestrian movement rules. The simulation provides the details of the dynamic evacuation process with clarity, where some phenomena such as bottling and the influences of obstacles inside the stations are observed [10].

Analyzing in detail the advantages and adaptabilities of different forms of disposal that can provide some references for the planning and construction of BRT stations, it makes that in several stations in different cities of China, planning and design based on local conditions such as principles of design, achieving better users satisfaction [11].

2. Methodology

The present investigation is carried out in three main phases, where the first one is developed specifically in the collection of information about the current behavior in TransMilenio stations, to consider the main factors to develop in the model. Although it must be clarified that it cannot have comparative concepts between the metro and the BRT system, it is possible to have certain aspects that make the flow of passengers able to transit without any problem, regardless of the number of people who are walking to get its transportation system, either bus, train or metro, so for this first phase is necessary to review 10 cities in other countries that have BRT system where different factors that could affect the mobility of users were reviewed.

As a second phase, the different factors that have been used for the development of the different BRTs around the world are compared. Also, it is necessary for this phase to collect information from the entity (TRANSMILENIO S.A.), which is related with the number of passengers going in and out the Calle 76 station, on both sides, as it has access to both sides from the north as the south of it. This information is provided in 15-minute intervals for business days (4:30 A.M. to 12:00 A.M.), Saturdays (5:00 A.M. to 12:00 A.M.) and Sundays and Holidays (5:30 A.M. to 11:00 P.M.). This phase is of vital importance, because it allows to know how the flow of passengers is currently behaving within this station, and thus being a key point at the time of the proposing the last phase, where aspects inside the station will be considered to improve the passengers flow. Also, it is necessary to compare those different BRT systems around the world and how are the people walking and waiting in Calle 76 station, to increase the users' satisfaction when taking Bogota's mass transportation system.

However, it must be considered that BRT service entity should allocate budgets so that a culture is generated in all the people who access the system, these improvements can be made to the system without increasing the rates of the itself constantly.

2.1. First Phase

Before comparing the different selected aspects about local and international BRT systems, it is necessary to know how the station object of analysis is currently distributed. To start with, Fig. 1 shows Bogota's BRT system map, to introduce all the corridors that are connected within the city. Thereby, Calle 76 station is located as the last one in Caracas corridor (A), from south to north.

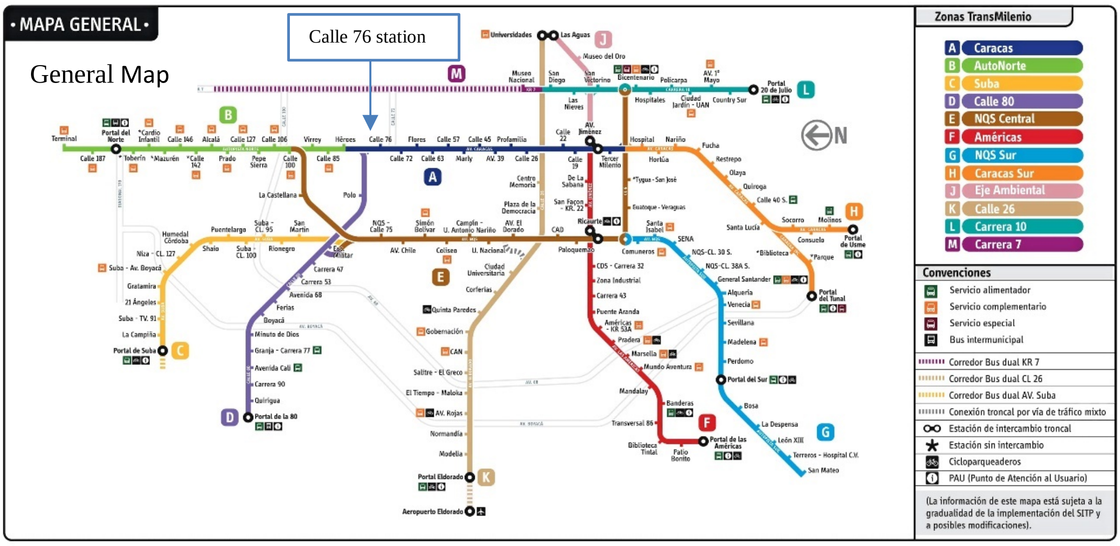

Figure 1: Bogota's BRT System Map [12]

Source: https://cldup.com/is8U1f6rNi.jpg

2.1.1. Basic information about Calle 76 Station

Fig. 2 shows that the station has two entrances on Calle 74 (south) and Calle 76 (north), also, it has three sub-stops and two walkways that allow passengers to move from one sub-stop to another, to take the bus route they want. The color, letter and number of routes that stop at each platform are assigned, which is made by the entity to identify where in Bogota the people are going to (corridor), having as passengers' point of origin Calle 76 station.

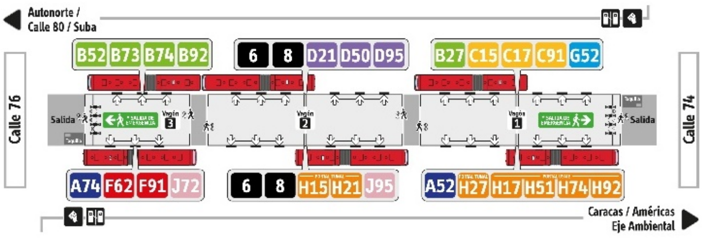

Figure 2: Location map of *Calle 76* station [13]

Source: http://www.sitp.gov.co/plano_de_estaciones_y_portales_de_transmilenio

Fig. 3, 4 and 5 show the current view of the station from south to north, this, with the aim of showing that sub-stops 1 and 2 (Fig. 3 and Fig. 4) have access to bi-articulated BRTs, which is the reason that makes it longer, while sub-stop 3 (Fig. 5) is only for articulated BRTs.

Figure 3: Sub-stop 1 – *Calle 76* station

Source: Author

Figure 4: Sub-stop 2 – *Calle 76* station

Source: Author

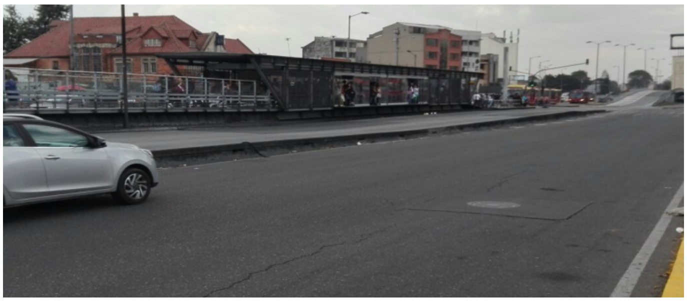

Figure 5: Sub-stop 3 – *Calle 76* station

Source: Author

Fig. 6 and 7 show a bottleneck inside the sub-stop 2 at Calle 76 Station at peak hours, in the morning and in the evening, respectively. Passengers are waiting in the docking-bays of the route they need to take, while other passengers are getting off the bus and need to walk to their respective destinations. But it must be considered that in the morning peak hours, people walk fast, even running, because they have to be on time, either to work place or universities, in other words, passengers are in a hurry in the morning, while in the evening peak hours, passengers' behavior is completely different, they are just waiting the bus they need to take to reach their destinations.

Figure 6: Inside sub-stop 2 in the morning peak hour – *Calle 76* station

Source: Author

Figure 7: Inside the sub-stop 3 in the evening peak hour – *Calle 76* station

Source: Author

It must be mentioned that all the routes shown in Fig. 2 do not work all day, since there are routes that work just in the morning peak hours but not at night, causing more people waiting in the docking-bays for a single route to the same destination. As it can be seen, in Fig. 8 there is one of the walkways inside Calle 76 station, and it is taken at evening peak hour but there are seldom people walking along it.

Figure 8: Walkway between sub-stop 1 and sub-stop 2 – *Calle 76* station

Source: Author

2.1.2. BRT systems around the world

As mentioned above, in this phase an inquiry was made regarding ten systems from other cities in the world and one national, being that of Curitiba, Amsterdam, Mexico City, Beijing, Bangkok, Quito, Istanbul, Jakarta, Lima, Johannesburg and the Cali system is considered within Colombia, which are reflected in the following page in Table 1. Aforesaid, with the data provided by the entity TRANSMILENIO S.A., it was possible to analyze the different behavior of the passengers inside the station, regarding to entrances and exits. Therefore, it is appropriate to represent the information as it is shown in Figs. 9, 10 and 11, where the first one is on business days, second one is on Saturdays and last one on Sundays or Holidays. This is one of the most important processed data, due it allows to know when the peak hours are, either in the morning or evening, being represented as the passengers waiting, going in or out the Calle 76 station.

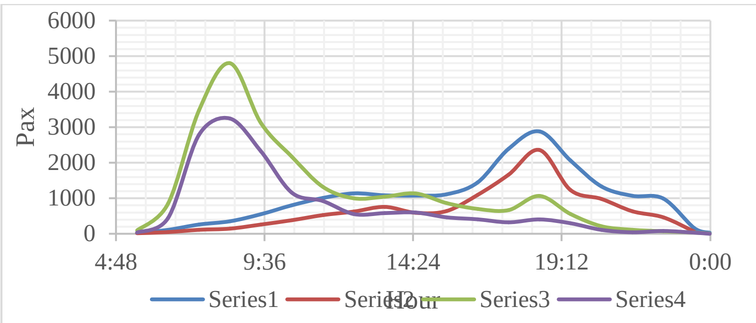

Figure 9: PAX getting on and off *Calle 76* station - Business days

Source: Author

Note: Series1: Passengers getting on to *Calle 76* station by the north entry – Business days

Series2: Passengers getting on to *Calle 76* station by the south entry – Business days

Series3: Passengers getting off from *Calle 76* station by the north entry – Business days

Series4: Passengers getting off from *Calle 76* station by the south entry – Business days

Table 1: BRT systems in different cities

City	**System name**	**Start year**	**Pax/day**	**Peak load (p/h/d)**	**Population (2017)**	**% use**	**Total length (km)**	**Corridors**	**Stations**	**Station boarding level ***	**Operation speed (km/h)**	**Long avg. distance (m)**	**Standard fare (US$)**	**Fare collection**
Bogota	TransMilenio	2000	2,455,705	48,000	8,080,734	30.39	112.9	12	138	HLP	26.2	600	0.8	Turnstile in station
Curitiba	Rede Integrada de Transporte	1974	566,500	20,500	1,908,359	29.69	81.4	7	106	HLP, LLP	26.7	699.1	1.3	Turnstile in station
Quito	Metrobus-Q	1995	745,000	11,700	2,644,145	28.18	71.4	3	126	HLP	17.8	566.7	0.25	Turnstile in station
Cali	Masivo Integrado de Occidente	2008	471,361	13,000	2,420,114	19.48	49	6	55	HLP	18	570	0.7	Turnstile in station
Mexico City	Metrobús	2005	1,100,000	12,000	8,555,500	12.86	125	6	188	HLP, LLP	20	664.9	0.32	Turnstile in station
Istanbul	Metrobüs	2007	750,000	30,000	15,029,231	4.99	52	1	44	LLP	35	1181.8	0.97	Turnstile in station
Amsterdam	Zuidtangent BRT	2002	4,0000	960	844,947	4.73	56.7	1	33	LLP	35	1718.2	3.19	Inside the buses
Jakarta	Transjakarta	2004	370,000	3600	10,764,580	3.44	206.75	12	240	HLP	19	971	0.27	Turnstile in station
Lima	Metropolitano	1972	350,000	22,800	11,181,700	3.13	26	1	36	HLP	25.5	700	0.76	Turnstile in station
Beijing	Beijing BRT	2004	305,000	8000	21,961,545	1.39	74.5	4	77	LLP	26	967.5	0.3	Turnstile in station
Johannesburg	Rea Vaya	2009	42,000	5760	5,294,265	0.79	43.5	2	13	LLP	30	1384	1.25	Turnstile in station
Bangkok	Bangkok BRT	2010	15,000	1200	8,750,600	0.17	15.3	1	12	HLP	26	1530	0.57	Turnstile in station

Source: https://brtdata.org/ and National Statistics Department of each country for 2017's population

Pax/day: Passengers per day. p/h/d: passengers per hour per direction, *HLP: High level platform, LLP: Low level platform

2.2. Second Phase

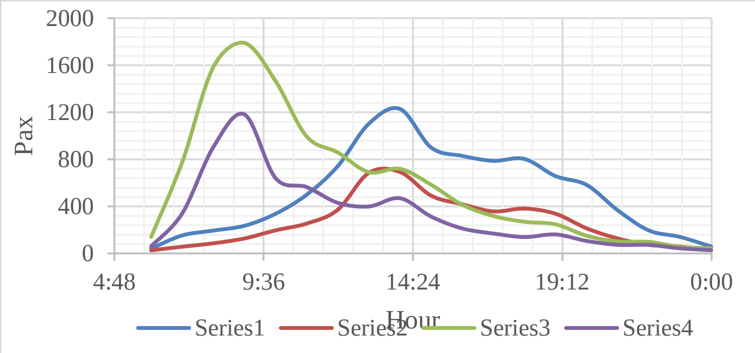

Figure 10: PAX getting on and off *Calle 76* station - Saturdays

Source: Author

Note: Series1: Passengers getting on to *Calle 76* station by the north entry – Saturday

Series2: Passengers getting on to *Calle 76* station by the south entry – Saturday

Series3: Passengers getting off from *Calle 76* station by the north entry – Saturday

Series4: Passengers getting off from *Calle 76* station by the south entry – Saturday

Seeing that in business days the average people getting on and off is more than 70,000 passengers, it is necessary to do a review of that information in-situ, first to make sure the amount of BRT buses arriving to each sub-stop of the station, second, to count approximately how many people are waiting in the docking-bays with its respectively hour, this, in order to have different scenarios during peak hours, and last, to time how long it takes for each bus since it stops, passengers get on and off the bus, and finally until it closes its doors.

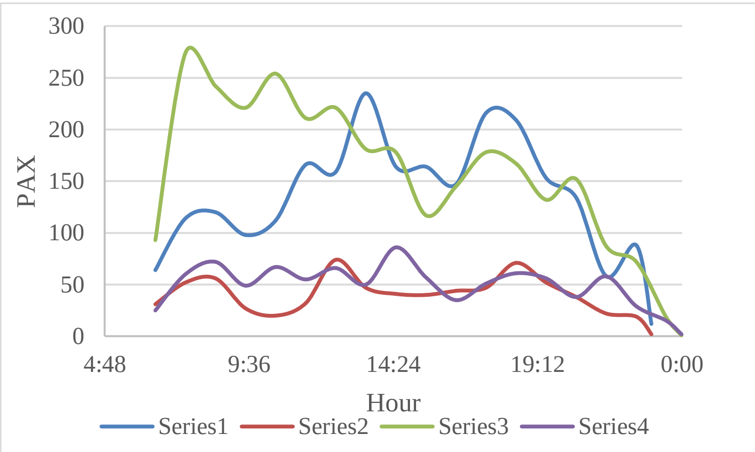

Figure 11: PAX getting on and off *Calle 76* station – Sundays or Holidays

Source: Author

Note: Series1: Passengers getting on to *Calle 76* station by the north entry – Sundays or Holidays

Series2: Passengers getting on to *Calle 76* station by the south entry – Sundays or Holidays

Series3: Passengers getting off from *Calle 76* station by the north entry – Sundays or Holidays

Series4: Passengers getting off from *Calle 76* station by the south entry – Sundays or Holidays

Although it is mentioned above, Fig. 9 shows that there are more passengers going out in the morning peak hours rather than going in in evening peak hours, around 2,800 more. This is also represented by the amount of buses arriving in the morning to *Calle 76* station, being more than 500 articulated and bi-articulated buses arriving within 2 hours (6:00 to 8:00 A.M.) in both ways, which are verified in-situ. This, shows the magnitude of this station, since there are 3 corridors which have connection with this station (*Calle 80, AutoNorte* and *Caracas* corridors). The average time spent for a bus in the station is 20 seconds. As it can be seen in Table 1, TransMilenio pphdp - passengers per hour per direction -, in peak hours are about 48,000, this value has highly relevance compared with metro system around the world, since the average capacity ranges between 25,000 to 40,000 pphdp [14]. Nevertheless, two of the metro's lines with the highest capacity are located within the Mass Transport Railway (MTR) in Hong Kong. In the Tsuen Wan Line during the morning peak hours, there is an 8-car trains with a capacity for 2,500 passengers with a frequency of 2 minutes and carrying 75,000 pphdp while in the East Rail Line 86,000 for 12-car trains with a capacity for 3,750 passengers each 2.5 minutes [15]. Also, the São Paulo Metrô exceeds the capacity of the mass transportation in Bogota with the Line 3 (Red), being the busiest in the system with 60,000 pphdp in peak hours [16]. Thus, the flow of passengers in peak hours is such an important value which has led to studies being carried out on the improvement of the capacity of metro's systems, and one case is the Sydney Metro, carrying 20,000 pphpd, and the new line is designed to carry 43,000 pphdp [17].

3. Station Model Proposals

After in-situ work, the locations within a section of the station where the problems, regarding to the passengers' flow are represented in Fig. 12, in other words, this allows to identify where the bottlenecks are along each sub-stop, especially in the evening peak hours, due their behavior.

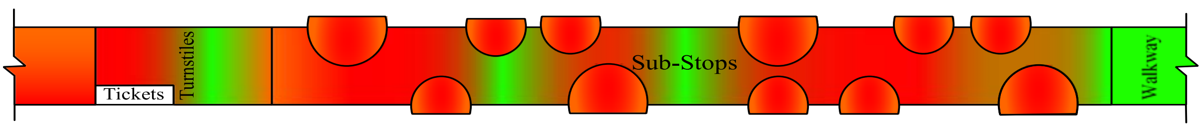

Figure 12: Bottleneck zones inside a section of *Calle 76* station

Source: Author

The areas where the red color is found are because there are a lot of passengers, especially walking inside the station in both directions, waiting in the docking-bays, making a queue to buy the tickets and access the system through the turnstiles. The orange color represents an average flow of passengers, where there is no bottleneck, but neither a free section to circulate. And the sections with green color, represent those small areas where passengers can walk without major complication, with the longest space in the walkways between each sub-stop.

In addition, Figs. 13 and 14 are the turnstiles located in the north and the south of Calle 76 station, respectively. First, has four turnstiles which work in both directions (entrance and exit), while second one has three turnstiles and one wheelchair accessible turnstile. Also, each entrance of the station has ticket office, where queues are generated.

Figure 13: Turnstiles located in the north of *Calle 76* station

Source: Author

Figure 14: Turnstiles located in the south of *Calle 76* station

Source: Author

3.1. First station proposal

As seen throughout the study, the main problem is bases in the internal operation of the station, i.e. from a queue is generated at the entrances, preventing people can walk without bottleneck. Thus, the main station model proposal considered is that in the entrances there is no ticket office, in this way, passengers enter and leave the station, for the width that is has currently designed. Also, since the space which is currently occupied by the ticket office and the first docking-bays are located close to the entrance, therefore, turnstiles should move at least 2 meters to each side of the station respectively, to have more space for passengers who already passed through it. To optimize the entry and exit of passengers from the station, a turnstile must be added on both sides, which means that queues shorter than those generated during peak hours are generated.

3.2. Second station proposal

Second sub-stop in Calle 76 station generates more passenger movements in both directions, and it was possible to corroborate after in-situ work. In this sense, a reorganization should be made regarding the routes, since the groups or people waiting in the docking-bays are being mixed generating a bottleneck during peak hours (especially in the evening). The main reason for this proposal, is because in the morning there are 4 routes operating B52, A52, A74 and D50 but not in the evening, causing that at night there are more people waiting in the docking-bays of the destination of those routes that do not work in the evening peak hours. Therefore, the redistribution of routes must be done considering that most BRT buses arrive at the second sub-stop in Calle 76 station.

3.3. Third station proposal

During the peak hours in the afternoon too many people accumulate in the docking-bays that make it difficult for users to get off the buses, since there is no culture of the passengers, regardless of the way they are going to get on the bus. Therefore, the proposal for this case, includes that the bus must spend double of the time, where, first people will get off the BRT, and then it moves to the next sub-stop so that passengers can get on the bus, as it is shown in Fig. 15, first and second stop, respectively, improving the behavior of two different passenger flows. Although this proposal would avoid the mixing of two passenger flows, which is generated by the BRT being twice the time in the station is a possible waiting queue in the buses in both ways.

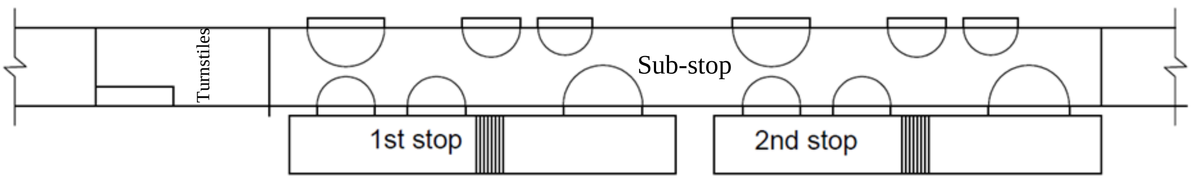

Figure 15: Third station proposal

Source: Author

3.4. Fourth station proposal

In Figs. 8 and 12 shown above, it is observed that there is a space of the station that is not being occupied by passengers' flow, and the station Calle 76 has two walkways which have no roof. It is necessary to mention that

Bogotá's weather tends to be rainy, which means that people who must walk from one sub-stop to another must carry an umbrella. Therefore, the proposal includes putting a roof on these two sections of the station and moving routes in those spaces, that is, optimizing the space offered by the current Calle 76 station, and in this way, be able to distribute more equally the passengers waiting throughout the station.

However, it should be mentioned that this proposed methodology has limitations to be projected in other cities that have BRT as a mass transport system, because of the conditions of population density and the infrastructure of the stations in different cities, mark specific items which should be considered as study parameters. In addition, another limitation is the cultural field, since each country has its different concept about the correct use of a public transport system

4. Conclusions and Recommendations

The capacity of a BRT system should be considered as a fundamental element in the design of the infrastructure of the stations, since TransMilenio is moving in rush hour more passengers than different metro systems around the world, but instead of car-trains by articulated buses and stations with limited space for the flow of passengers. The fact of mobilizing 48,000 passengers per hour per direction during peak hours demonstrates why Bogota's mass transportation system has the greatest capacity worldwide, regarding to BRT systems.

The above studies carried out at the Calle 76 station show that it is a station that more passengers are arriving than those that going on, that is, in the peak hours of the morning of the different TransMilenio corridors, there are more passengers leaving this station while in the afternoon there is a difference of 2,800 fewer passengers entering the station.

Moreover, statistics represents the possible activities of citizens for working days, Saturdays, Sundays and holidays. Although the number of users who transit Calle 76 station on business days is more than twice as many as those entering and leaving the station on Saturday, 70,721 and 32,505 passengers respectively, showing a tendency with peaks of exits of the station in the morning and entrances to the station in the afternoon, while the behavior for Sundays and holidays is totally different, where there is no specific peak throughout the day.

Based on the study conducted in-situ and the information provided by the company TRANSMILENIO S.A. it was possible to determine four aspects that determine each of the station model proposals for BRT systems. The first is related to the location of the ticket office and the turnstiles, which generate a congestion of passengers at the entrances of the station. The second, indicates that some of the routes must be relocated, the aim being to passengers are located throughout the entire station and not in specific points, which generate bottlenecks. The third proposal is a modification in terms of the arrival operation of the buses to the station, where the passengers get off the bus once it stops, and then make another stop at the same station making to those users waiting in the docking-bays can enter the bus, allowing the two user flows not to be mix. The last proposal is based on the fact that roofs must be placed on the walkways between each sub-stop, so that there can be a better distribution of all passengers at the station

It is recommended that further research should be carried out using software in where it can be simulated the

BRT users' behavior and buses arrivals, to test the above station model proposals mentioned and verify which one has the highest improvement regarding to passengers' flow. The simulation must consider all the decisions that a passenger must take from the moment when is going on the station, until they wait for the bus, also, make a probabilistic study that considers how many people are going to get off and get on the BRT, since that depends on different factors, with time being one of the main ones.

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