Optimization of passengers boarding in the BRT system based on the security protocols established by the Covid-19 pandemic

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***Abstract*— According to the National Institute of Statistics and Informatics (INEI), the city of Lima has more than 9,485,405 inhabitants. This causes problems of pedestrian crowding in public places. The Bus Rapid Transit (BRT) system called Metropolitano transports 650,000 passengers a day, of which 81,800 of them use the boarding platform of the Naranjal station located in one of the most populated districts of Lima. In this station are concentrated 12.6% users of the entire transportation system. This research proposes a pedestrian microsimulation model with the objective of optimizing the pedestrian area of one of the most demanded platforms in Lima, considering the security protocols established by the Covid-19 Pandemic. To obtain results, the parameters of pedestrian density, bus frequency and queuing time were considered. The effectiveness of the proposed design is validated using a model made with the software Vissim. The results showed that the maximum number of pedestrians that can occupy the Naranjal station following the Covid-19 security protocols are 4166 persons, considering a 180 second bus frequency on lines with the highest demand and a maximum queuing time of 764.51 seconds.**

Key words—microsimulation, boarding platform, pedestrian density, covid-19, BRT *(key words)*

I. Introduction

Lima is the most inhabited department in Peru with approximately 9,485,405 inhabitants [1], in addition of being the city with the most Covid-19 infections, reaching 84 994 positive cases updated to May 27, 2020 [2].

Metropolitan Lima has various public transport systems, including the Metro, bus lines and the BRT, which is a bus system that has an infrastructure composed of segregated routes and stations for Passenger boarding. This system is supplied by a series of feeder buses responsible for transporting users to the boarding stations. The Metropolitano connects the city of Lima from North to South, therefore, it is one of the most used transports by the population, reaching approximately 400,000 people per day [3].

Figure 1 details the complete route of the BRT system that begins at the Naranjal station, in the North of Lima, to the last station Matellini in the south of the capital, passing through a total of 38 stations.

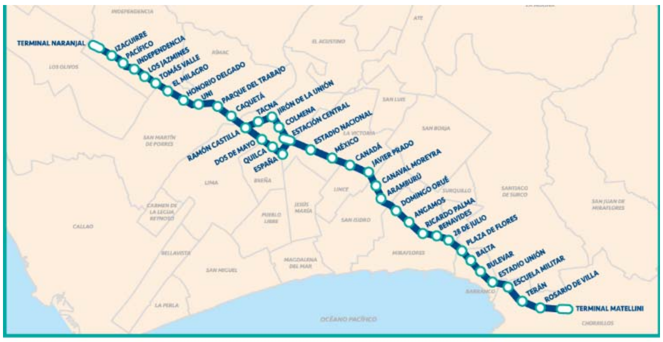

Figure 1: Location map of the stations of the BRT system.

One of the most critical boarding platforms in The Metropolitano is the Naranjal Station, located in the North of Lima. A large number of users of this system are concentrated here, mainly during peak hours of the day. On May 25, 2020, rapid tests were carried out to discard

Covid.19 at the Naranjal station. The results obtained showed that of a total of 150 samples, 15.33% were positive in the contagion of the virus [4]. Considering that in Peru the resumption of some economic activities has begun and the Naranjal station being the most used by the population, the application of social distancing protocols is recommended, to prevent the station from becoming a source of infection. On the other hand, considering that there are preventive measures against contagion regarding the maximum number of people who can travel on the buses, this may affect the waiting time of users at the station.

The OMS recommend some security protocols in public places with massive concurrence, such as keeping a meter and a half of distance between people, which is a method of preventing contagion due to the physical and dynamic characteristics of the Covid-19 virus.

The purpose of this article is to prevent the Naranjal station of the Metropolitano from becoming a source of contagion for the Covid-19. To achieve this, it seeks to improve the interaction of the pedestrian area at boarding through the optimization of the waiting times of the passengers. The effectiveness of the proposal will be validated with the generation of microsimulation model in Vissim of the Naranjal station.

II. STATE OF ART

For the development of the research, several techniques and theories related to pedestrian microsimulation and its behavior within mass occupancy establishments are considered

In the article "Simulation of the spatio-temporal distribution of pedestrians in underground spaces" [5] it is established that the determinations of pedestrian movements are important to evaluate and improve the spaces where people move.

The particularity of this research is the use of a pedestrian simulation within underground spaces where it was determined that in the morning rush hours, pedestrians experience a greater number of people in their environment, generating high pedestrian stress. In addition, interactions between people their space with respect to crows were studied.

In the article "Modeling and simulation of pedestrian traffic flow" [6] a stochastic model is presented, establishing that any pedestrian installation can be modeled as a queue process network, where each pedestrian is analyzed as an independent target.

Finally, in the thesis "Microscopic models and simulation of pedestrian traffic" [7] the author establishes that it is beneficial to predict future pedestrian flow conditions in transport stations. This is because, if management measures are not carried out in time to control pedestrian congestion, this can become a very costly problem to solve in the future. And to achieve this you need accurate quantitative pedestrian models.

III. METHODOLOGY

This chapter describes step by step the procedure used for data collection, information processing and generation of the microsimulation model. Next, figure 2 shows the flowchart with the procedure used in the investigation

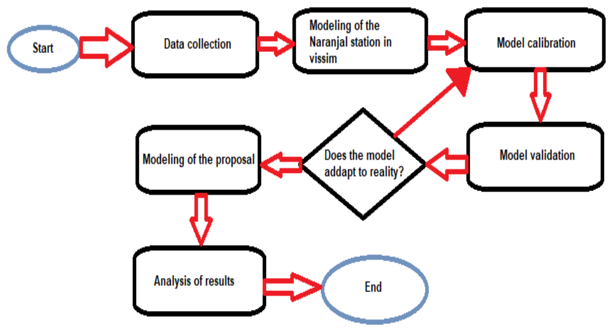

Figure 2: Flowchart of the methodology followed.

A. Data collection

To develop the microsimulation model of the Naranjal Station, the distribution plans were requested from the concessionaire in charge of the administration of the BRT Metropolitano.

Surveys were conducted at the station gates and during the disembarkation of people from the feeder buses. This information is used to know the destination of the users and thus determine the possible distributions and walking paths of pedestrians in the microsimulation model.

For the calibration and validation of the model, the speeds of the pedestrians within the station were calculated on two different days. To obtain the speeds, two points were located in the upper passageway and two in the lower passageway of the station, each one 15 meters as can be seen in figure 3. The walking time of a representative sample of 40 pedestrians was measured. With this information, it will be evaluated whether the simulation model developed in the Vissim software represents the real behavior of pedestrians at the station.

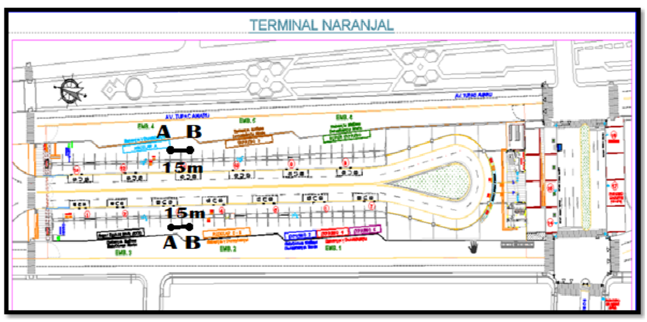

Figure 3: Measuring points for the calculation of pedestrian speeds.

B. Modeling of the Naranjal station in Vissim

With the help of the Naranjal station distribution plan, it can be represented within the model developed in Vissim the entrances to the station, the pedestrian areas, the bus routes, the stops according to the routes, the boarding areas,

the walls or fences of separation and the connection gates between feeders and BRT bus.
With the data collected from the surveys, the static routes and the distribution of the volume of the users within the station will be modeled.

C. Calibration

A statistical test of the 40 pedestrian speeds on the first day of data collection will be carried out, in order to validate the minimum number of samples required in the simulation. For this test, the "Minitab 19" software will be used, with a confidence range of 95%.With this data the accumulated frequencies of speeds will be calculated to adjust the Vissim option "Desired speeds distribution". For the calibration of the model, the pedestrian behavior [8] will be analyzed by iterating the parameters of the Social Force model tau, lambda y noise [9].
To check if the simulation model is calibrated, the pedestrian speeds will be extracted from the Vissim reports. In total, 21 speeds of upper passage and 21 speeds of the lower passage will be used from the reports.
With the Vissim data, a mean difference test will be carried out in the "StatKey" software at a 95% confidence level. As it can be seen in figure 4, the mean differences have a value of 0.64, being within the acceptance area. With this result, it can be stated that the microsimulation is calibrated

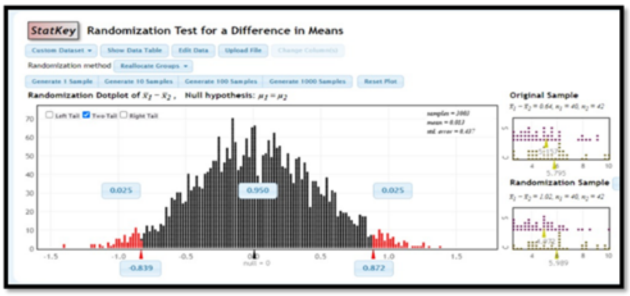

Figure 4: Evaluation of speed means for model calibration.

D. Validation

The procedure to validate the microsimulation model is similar to the calibration process. Here also a statistical test of the pedestrian speeds of the second day of data collection will be carried out, with a confidence range of 95%. This will serve to evaluate the minimum number of samples required in the simulation. Also within the microsimulation, the volumes and pedestrian speeds belonging to the seconds day of data collection will be entered With the reports obtained from Vissim, a test of the difference in means of pedestrian speeds will be carried out at a 95% reliability.

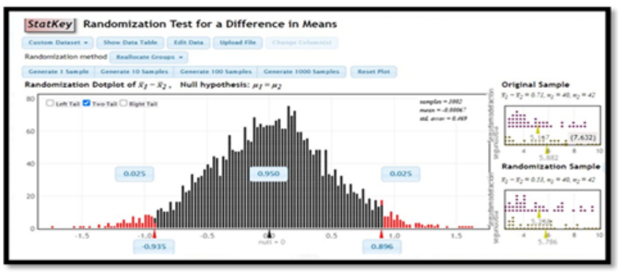

Figure 5: Evaluation of speed means for model validation

As can be seen in figure 5, the mean differences have a value of 0.72, being within the acceptance area. With this result it is stated that the microsimulation is validated.

E. Modeling the proposal

As a first proposal for improvement, separators were modeled for pedestrian flows, with the intention of channeling pedestrians walking in opposite directions as shown in Figure 7. This measure was taken to reduce the interaction of people when they move, ensuring a safe distancing in the walking paths.
As a second improvement proposal, pedestrian traffic lights were incorporated at the station gates to order both the entry of people coming from the feeders and the crossing of pedestrians who use the BRT lanes to move along the station. The application of this improvement in the microsimulation model can be seen in Figure 8.
In order to represent the 1.5 meter of social distancing in the microsimulation model shown in Figure 6, the pedestrians behavior parameters of the Social Fore model were modified. For example, the value of the parameter A_Social (Isotropic), which represents the intensity of the repulsive force between pedestrians, was increased from 2.7 to 7. The value B_Social (Isotropic), a parameter that represents the radius of the pedestrian's body, was also increased, from 0.2 to 2. The value of lambda, a parameter that represents the influence of people around, its value was increased from 0.8 to 0.9. The VD, a parameter that measures the relative speeds between pedestrians and contributes to the repulsion force with other people, increased its value from 3 to 5. Finally, the Noise value, which represents the randomness factor that optimizes the speeds of pedestrians, its value was also increased from 4 to 5.

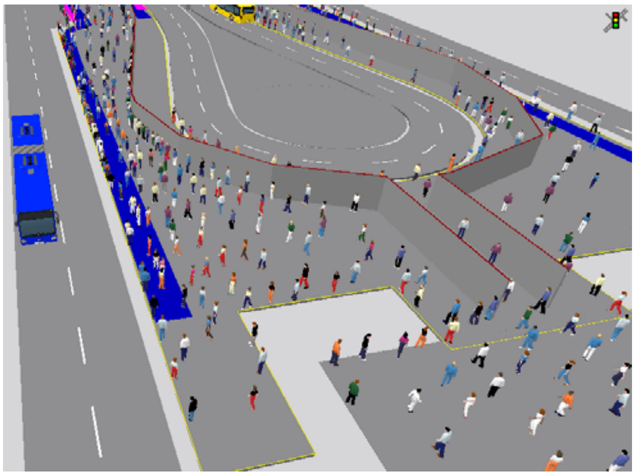

Figure 6: Optimization of the boarding area.

In order for the microsimulation model to represent the real characteristics of pedestrians, the distribution of people's walking speeds was modified. This is because pedestrian behavior is almost uniform in a social distancing scenario when people wait in line for their turn to board the BRT.

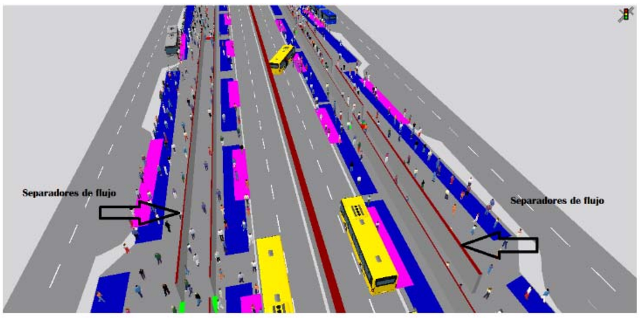

Figure 7: Flow separators

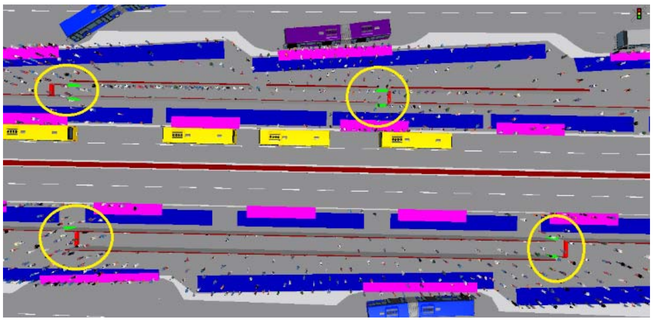
Figure 8: Pedestrian traffic lights

F. *Entry of pedestrian volumnes and evaluation of the station's operational behavior (Social Force)*

For the creation of the microsimulation model, it was necessary to measure the volume of people who enter the Naranjal station at the peak hour from 7:00 to 8:00am. The Table 1 shows the percentage distribution of all pedestrian entrances to the station, calculated with a total of 13,482 gauged people.

Table 1: Pedestrian distribution of Naranjal station.

Feeders	Main Entrance	Upper side Entrance	Lower side Entrance
19%	36%	27%	19%

Figure 9 shows the different inputs of the station.

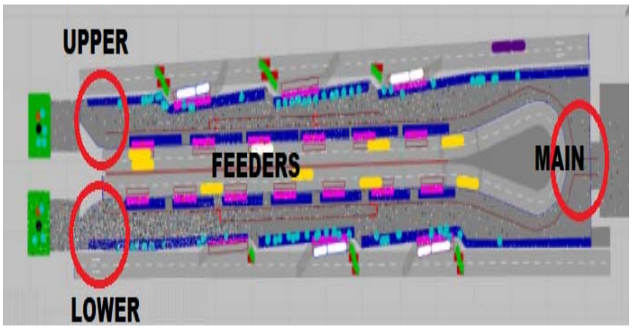

Figure 9: Naranjal station entrances

G. *Station capacity*

According to the security protocol for Covid-19, the minimum distance between people is 1.5m. Taking into account that the total area of the Naranjal station is 8,857.43 m2, the allowed capacity will be 3,937 people according to the equation to calculate the Occupational Risk Prevention Capacity [10] without considering the optimization of passengers boarding.

H. *Pedestrian queuing times*

The pedestrian queue times were measured, which are represented by the journey of people form the entrance of the station to the boarding area. Using the "Pedestrian Travel Times" tool, the delay of all users is obtained for the different walking paths present at the station.

IV. RESULTS

Taking into account a volume of 13,482 pedestrians entering the Naranjal station at peak hour and optimizing the BRT frequency to 3 minutes by bus for the lines with the highest demand (Express 2, Super Express North and Super Express) and 4 minutes for the lines with the lowest demand (Route A, Express 3, Route D), it was obtained the maximum capacity number of people at the station of 4166 pedestrians respecting the meter and a half of social distancing.

After evaluating the queue times of the BRT system users, the results shown in Tables 2 and 3 were obtained.

Table 2: Queuing times in seconds of BRT system users at each station door.

Entrance	Destination	Queuing time (s)
Lower	Super Express North	69.15
Lower	Route D	301.36
Lower	Express 2	411.22
Upper	Route A	103.11
Upper	Express 3	514.75
Upper	Super Express	745.79
Main	Super Express North	764.51
Main	Route D	559.60
Main	Express 2	163.44
Main	Route A	615.75
Main	Express 3	409.22
Main	Super Express	151.48

Table 3: Queuing times in seconds of BRT system users before Covid-19

Entrance	Destination	Queuing time (s)
Lower	Super Express North	51.23
Lower	Route D	114.22
Lower	Express 2	155.12
Upper	Route A	53.48
Upper	Express 3	102.39
Upper	Super Express	152.49
Main	Super Express North	220.21
Main	Route D	185.07
Main	Express 2	92.30
Main	Route A	190.31
Main	Express 3	147.04
Main	Super Express	96.65

Finally, a heat graph of pedestrian densities at the station was obtained as shown in Figure 11 according to the classification of Figure 10

Class bounds and colors:

Count: 6	LowerBound	UpperBound	Color
1	MIN	0.308	(255, 0, 0,...
2	0.308	0.431	(255, 0, 25...
3	0.431	0.718	(255, 0, 25...
4	0.718	1.076	(255, 255,...
5	1.076	2.153	(255, 255,...
6	2.153	MAX	(255, 255,...

Figure 10: Color range for pedestrian densities

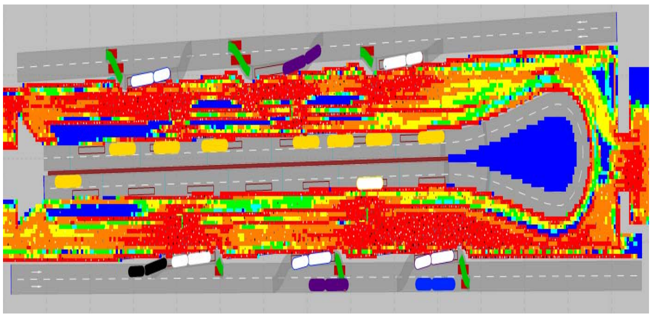

Figure 11: BRT station heat map

It can be compared to the situation the station had before the Covid-19 virus. As shown in Figure 12.

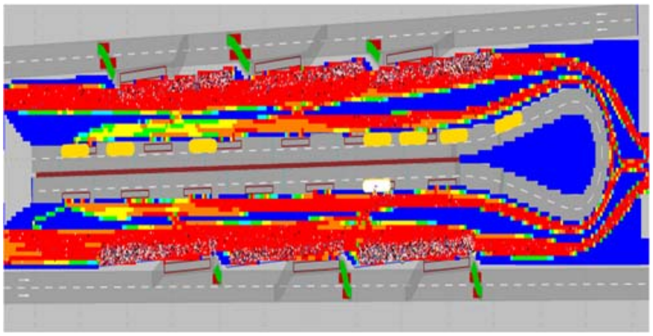

Figure 12: Heat map of the station before Covid-19

The maximum pedestrian density obtained is 0.54 people/m2 and a space module of 1.85 m2/p having a level of service D.

The maximum pedestrian density before covid-19 is 1.27 people/m2 and a space module of 0.70 m2/p having a level of service F.

V. CONCLUSIONS

The maximum estimated capacity of people at Naranjal station, considering social distancing, is 3,937 users. With the implementation of the proposed improvements in the simulation, a maximum of 4,166 users can be reached. These results demonstrate that the implementation of policies for the management of pedestrian demand in BRT stations, even considering the protection protocols of Covid-19, can improve the maximum capacity in areas with great pedestrian interaction.

People's maximum queue time within the simulation is 764.51 seconds. This time is measured from the main gate to the boarding area of the line with the highest demand from users called Super Express North. If we compare this result with the maximum queuing time before the pandemic is 220.21 seconds, there is a difference of 544.30 seconds. With this result it is concluded that although the average time in queue increases, this is due to the optimization of the station's pedestrian area considering social distancing measures, the designation of mandatory routes using the entire pedestrian area, the reduction of bus capacity to avoid overcrowding of people and the probability of contagion within the BRT.

Comparing the heat maps, we can see that the pedestrian density is higher in the situation before Covid-19 only in the main walkways and waiting areas. There are areas where the density is minimal, this due to pedestrian behavior to arrive as quickly as possible to board the bus. In the simulation of the proposal, it can be observed that the density has a lower intensity in addition to being distributed throughout the available pedestrian area. This is due to the optimization measure of the pedestrian area through mandatory routes and the social distancing of 1.5 meters.

It is shown in the heat maps of the proposal that the areas with the highest pedestrian density are the boarding areas of Super Express North, Express 2, Route A. Therefore, the optimization of the frequency of the buses mentioned routes it would have an even greater positive impact by increasing the outflow of pedestrians who are waiting longer due to the demand for their routes.

The maximum pedestrian density obtained from the proposal is notably lower than the situation before Covid-19 by 0.73 people/m2, obtaining a better level of service, this due to the optimization of the boarding area and increased frequency of buses.

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