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Accessible road design aimed at vulnerable people at the Naranjal station of the Metropolitano

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Abstract*– Accessible Road design must meet the needs of people with reduced mobility (PRM), who face significant obstacles in BRT stations due to inadequate infrastructure. Although some improvements, such as ramps and signage, have been implemented, barriers persist, particularly for older adults and individuals with visual or motor impairments. This study focuses on improving the infrastructure of the Naranjal station of the Metropolitano, considering accessibility, travel times, pedestrian density, and safety. Tools such as VISSWALK and StatKey were used to validate simulations and model pedestrian flows with high precision. The proposals include a strategically placed new ramp, exclusive access points with appropriate signage, and the creation of a refuge island. The results demonstrate an average reduction in conflicts of 88%, a 23% decrease in travel times, and an improvement in the level of service, reaching category A in some areas.

***Keywords*-- BRT, Vulnerable Populations, Accessibility, Viswalk, Travel Times**

I. INTRODUCTION

Accessible road design is influenced by the specific mobility needs of people with reduced mobility (PRM). Similarly, the design of Bus Rapid Transit (BRT) stations often overlooks the mobility requirements of this segment, presuming universal accessibility without adequately addressing their needs. In this context, [1] indicates that 40.1% of Peru's population with disabilities are adults over 60 years old, making them the most vulnerable to issues of accessible design in transportation, as the incidence of disabilities tends to increase with age. On the other hand, BRT stations have shown significant improvements in accessibility compared to other modes of transport, incorporating elements such as tactile paving, ramps, and audible signage. However, individuals with reduced mobility report challenges during peak hours when high passenger volumes lead them to opt for private transportation, as they perceive that station services lack infrastructure tailored to their needs. Another major challenge is the presence of ramps with steep slopes, which hinder wheelchair use and comfortable access for those with mobility difficulties. Additionally, platforms misaligned with buses pose risks for users with reduced mobility, as level differences complicate boarding and increase the risk of falls.

The National Institute of Statistics and Informatics [2] reports that 1 in 10 Peruvians has some type of disability, with 48.3% experiencing visual impairments, 15.1% having difficulties using their legs, 7.6% hearing impairments, 4.2% cognitive or learning challenges, 3.3% social interaction difficulties, and 3.1% speech or communication impairments. This means that, despite the high prevalence of motor and visual disabilities, infrastructure deficiencies targeting these groups remain common. In the case of the Naranjal station of the Metropolitano in Lima, individuals with reduced mobility (PRM) face accessibility barriers due to the current inadequate infrastructure. In this regard, the contribution of this scientific article lies in the implementation of a multicriteria analysis that integrates the user's perspective, accessibility evaluation, and the feasibility of proposed improvements through a microsimulation conducted using Visswalk. This approach enables a comprehensive assessment that prioritizes user experience and needs while examining critical accessibility factors and the feasibility of proposed design enhancements. This contributes to generating an inclusive and optimized design for BRT stations with high pedestrian flow.

II. STATE OF THE ART

Literature on the dissatisfaction of vulnerable users highlights the study by [3], which classifies sidewalk obstructions and lack of safety at pedestrian crossings as critical discomfort factors, often stemming from signage issues and driver behavior. In this sense, one of the most important aspects for this group is the perception of safety in stations. Another study supports that inadequate pavements, noise, and poor lighting negatively impact user experience, with a high discomfort score of 23.7% [4]. Similarly, [5] identified that the sense of safety is crucial for the urban walkability of older adults, who particularly value the presence of traffic lights (50%) and pedestrian crossings (45.5%).

Regarding wheelchair users, [6] notes that a ramp slope of 1:8 is generally suitable for users of manual and electric wheelchairs, as well as for individuals with visual impairments assisted by canes or service animals. Likewise, the NACTO Transit Street Design Guide emphasizes that level or near-level platforms enable faster boarding and compatibility with most existing public transport fleets, facilitating access for individuals with visual impairments [7]. Furthermore, the guide mentions that, to be inclusive, tactile pavements must have reliefs of at least 4 mm in height, improving perception and safety for individuals with visual impairments.

Various studies have also evaluated the effectiveness of countermeasures in accessible infrastructure to enhance safety at high-demand crossings. In the study by Vignali [8], the impact of refuge islands and signage at roundabouts was analyzed, demonstrating that these elements increase the visibility and safety of pedestrian crossings. Additionally, it was observed that pedestrians with visual impairments improved their alignment and positioning at crossings when using tactile paving, avoiding dangerous deviations from their path. Similarly, another study examines how improving pedestrian infrastructure, specifically widening sidewalks, helps maintain social distancing and how this is synonymous with improvements in travel times. Moreover, it develops a microsimulation framework for pedestrian traffic modeling, establishing parameters for maintaining distance between pedestrians [9].

III. Materials and Tools

A. Visswalk y Vissim

Traffic and pedestrian microsimulation software is used to model the flow of people in the BRT station. This tool was essential for the detailed analysis of key indicators.

B. T-student Test

A statistical tool used to determine the minimum number of simulations required, enabling a more accurate evaluation of the correspondence between the simulation and the real conditions of the station.

C. StatKey

A statistical method employed for the calibration and validation of simulation parameters, adjusting the model to faithfully represent pedestrian behavior in the station.

D. Surveys

A Google Form was used to collect responses from station users, assessing their satisfaction and perception of accessibility in the spaces.

E. Blueprints Stations

Blueprints with cross-sections and floor plans of both the north and south access points of the station were utilized, allowing for a detailed evaluation of the current infrastructure and the identification of areas with accessibility limitations.

F. DJI Mavic Pro Dron

Two drones were used to estimate the number of pedestrians entering the station during peak hours and to collect travel speed data. The aerial perspective enabled accurate counting and analysis of movement patterns at the station's access points.

G. Manual measuring tools

Tools are used to measure crossing times in the field for individuals with reduced mobility and to compare these times with simulation results.

IV. Methodology

In Fig. 1, the flowchart illustrates the development of each stage of the study that is presented.

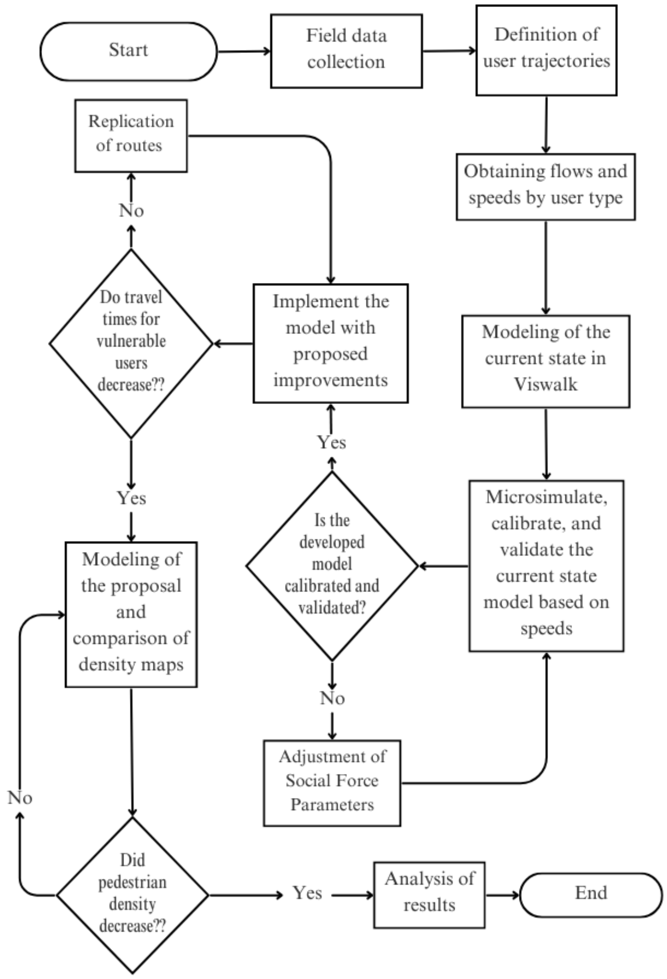

Fig. 1 Investigation methodology

A. Data Collection

A drone recording was conducted during the peak hour from 7:00 to 8:00 am at the Naranjal station. The drones were strategically positioned to cover the north and south access areas of the station. Additionally, a manual count was carried out during the same period to determine the percentage of people heading to each bus stop and to record their travel times. This analysis was performed for different types of users: individuals with motor or visual disabilities, older adults, mothers with children, and general users. Fig. 2 presents an image captured at a height of 50 meters with the drone, showing pedestrian flows and speeds outside the station. To obtain speeds for each type of passenger, the effective width of one of the pedestrian crossings at the north entrance was measured, covering 13.5 meters.

Fig. 2 Aerial shot with drone at the northern access

B. Definition of User Trajectories

For defining user trajectories, the four access zones of the station were mapped. Fig. 3 illustrates all the trajectories considered for passenger counting. Additionally, six feeder and trunk route stops of the Metropolitano are detailed. On the left side, there are 10 types of pedestrian movements corresponding to the north entrance, and on the right side, 8 movements belong to the south entrance.

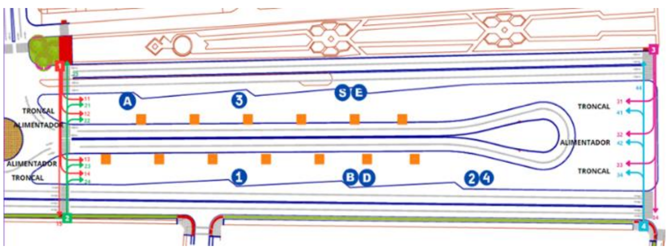

Fig. 3 Access routes to the Naranjal South and North station

C. Obtaining Pedestrian Flows and Speeds

The results of the pedestrian flow count for the first day are detailed in Table 1 and Table 2. This count was conducted by grouping different types of movements at the south entrance of the Naranjal station: the number of people entering the trunk line (1), those accessing feeder lines (2), those entering the trunk line again (3), and those who did not fall into any of the previous categories (4), opting to continue their journey. The count was carried out on the right side of the entrance to the station, recording data every 15 minutes to obtain more accurate figures.

TABLE I
PEDESTRIAN FLOW NORTH ACCESS DAY 1

HORA	TRUNK ROUTE				FEEDER BUSES				DIRECTLY	
	11	21	14	24	12	22	13	23	15	25
7:00 - 7:15	650	235	497	573	446	261	99	156	30	47
7:15 - 7:30	624	241	511	533	427	245	201	105	28	45
7:30 - 7:45	556	248	347	497	500	270	147	139	18	17
7:45 - 8:00	476	256	169	497	575	199	245	79	36	21
Total	2306	980	1524	2100	1948	975	692	479	112	130

TABLE 2
PEDESTRIAN FLOW SOUTH ACCESS DAY 1

HOUR	TRUNK ROUTE				FEEDER BUSES				DIRECTLY	
	31	41	33	43	32		42		34	44
7:00 - 7:15	52	113	25	450	45	15	96	118	34	15
7:15 - 7:30	58	109	15	435	25	27	105	102	33	9
7:30 - 7:45	35	11	47	442	36	28	94	116	33	17
7:45 - 8:00	48	91	23	365	21	29	173	61	29	13
TOTAL	193	324	110	1692	127	99	468	397	129	54

Fig. 4 illustrates the speed vs. cumulative relative frequency graph for each type of passenger entering the Naranjal station. The Range vs. H% graph will be input into Viswalk to simulate the behavior of each type of passenger more realistically.

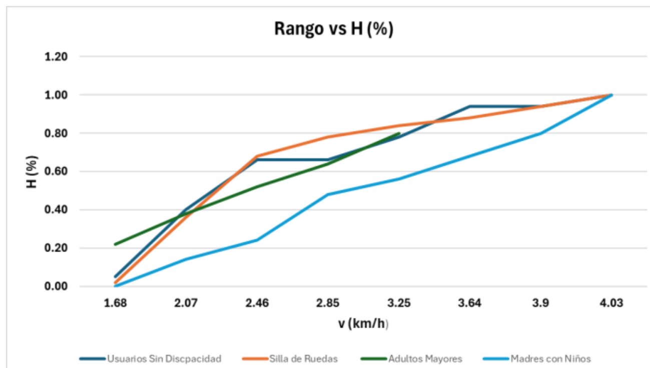

Fig. 4 Speed graph for each type of user

D. Modeling of the Current State

After data collection at the Naranjal station, the study area was modeled at a microscopic level using the Vissim 9.0 software. The characterization of pedestrian social force parameters was performed using the PTV Viswalk 9.0 software. Calibration and validation processes were conducted to verify whether the microsimulation model accurately reproduced the behaviors observed in the study area. For both processes, a simulation of 4200 seconds was run, following the recommendations of the Federal Highway Administration (FHWA), and the first 600 seconds corresponding to the system's stabilization or "warm-up" period were discarded. After several iterations adjusting the social force model parameters, the optimal values for individuals without disabilities were determined, where tau, lambda, and noise are 0.12, 0.05, and 0.2, respectively. Before comparing the simulated data with field data, it was evaluated whether the number of model runs was optimal for analysis, following the procedure recommended by the FHWA using a T-Student distribution. For this test, a confidence level of 95% was used, with degrees of freedom calculated based on the number of simulations minus one (n-1), resulting in 2.145 from the T-

Student table (two-tailed distribution). Once the minimum number of simulations was validated, the model calibration was verified. For this, 1000 permutations were performed using a two-tailed distribution with the StatKey statistical tool as part of the calibration process. On Fig. 5, 6, and 7 present hypothesis tests for the difference in mean pedestrian travel speeds, focusing on individuals with motor disabilities and mothers with children, to identify significant differences between these groups.

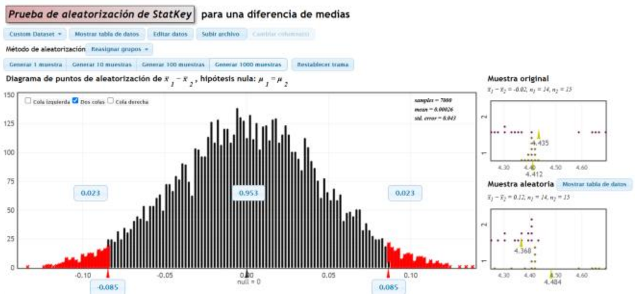

Fig. 5 Hypothesis test for the difference in means of pedestrian travel speeds

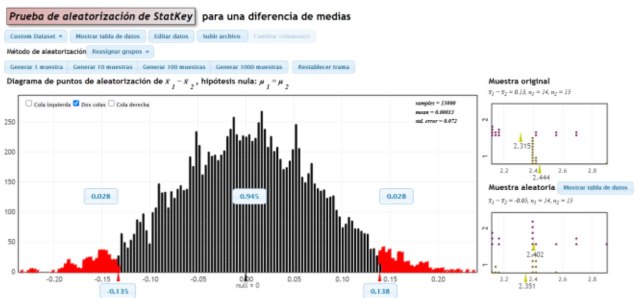

Fig. 6 Hypothesis test for the difference in means of pedestrian travel speeds with motor disabilities.

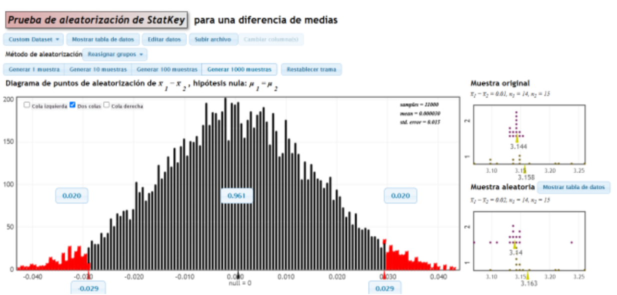

Fig. 7 Hypothesis test for the difference in means of travel speeds of mothers with children

TABLA 3
CALIBRATION RESULTS

Calibracion del modelo							
Types of Pedestrians	Sample size	GDL	ΣV^2	S	5.00 %	Number of runs	Mean difference
General pedestrians	15	14	0.224	0.127	0.122	5	-0.02
Persons with motor disabilities	15	14	0.224	0.127	0.122	5	0.13
Persons with visual impairments	15	14	0.0038	0.017	0.15	1	0.02
Mothers with children	15	14	0.0038	0.006	0.157	1	0.01

The validation process was conducted similarly to the calibration. For this test, data collected from a second sample were used to input into the already calibrated model. Thus, with the new data collected, the verification of means was performed, ensuring they fell within the 95% confidence interval used in the null hypothesis test of StatKey.

V. CONTRIBUTION/DEVELOPMENT

A. Creation of Refuge Islands and Curb Extensions

As part of this redesign, it is proposed to reduce the lane width from 3.5 meters to 3 meters, allowing for a more efficient redistribution of available space. According to the BRT Planning Guide Manual (2010), successful BRT systems have been built in areas with only 3-meter-wide lanes. This reduction will provide the necessary space for the creation of a 1.5-meter-wide refuge island, exceeding the minimum requirement of 0.8 meters established by REDEVU. Additionally, to optimize pedestrian flow channeling, the installation of curb extensions with vegetation along the sidewalks is proposed, guiding people to use crosswalks exclusively, following Jan Gehl's guidelines.

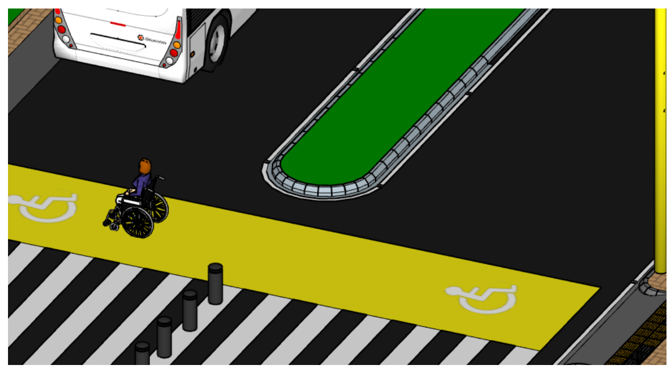

Fig. 8 Sardinel located at the North access

B. Traffic Signal Phase Adjustment

Long waiting times at crossings lead to disorderly pedestrian behavior, with individuals often crossing outside designated crosswalks. Therefore, a modification to the traffic signal phase is proposed, increasing the duration of the green light to allow pedestrians to cross safely and smoothly. This extension of the green time has been designed to maximize pedestrian safety without significantly impacting vehicular efficiency.

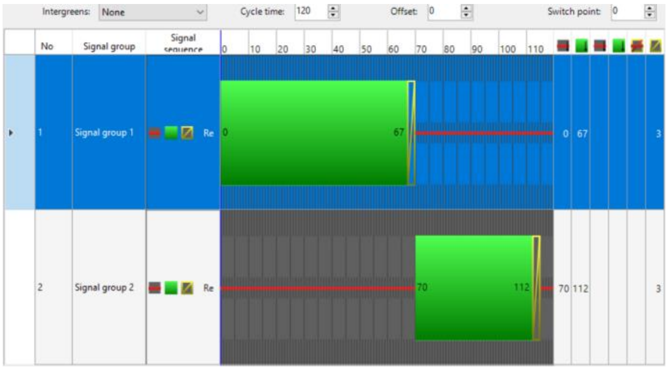

Fig. 9 North entrance traffic light cycle

C. Creation of Exclusive Access Points

Given the high pedestrian density and space constraints, the NACTO "Transit Street Design Guide" indicates that designing exclusive access points helps reduce accident risks, avoid conflicts between pedestrians, and facilitate transit for these groups, minimizing exposure to high-congestion areas [7].

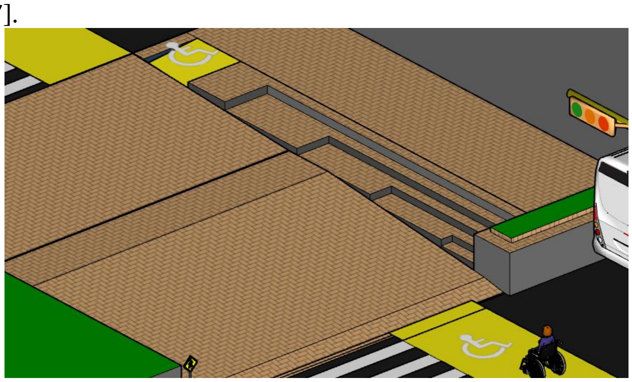

Fig. 10 Traffic light cycle and exclusive access at entrances

Furthermore, access points within the station will be created, incorporating tactile and visual signage, as well as intuitive guidance systems that direct users effectively. This enhances accessibility and promotes a more inclusive environment within the station.

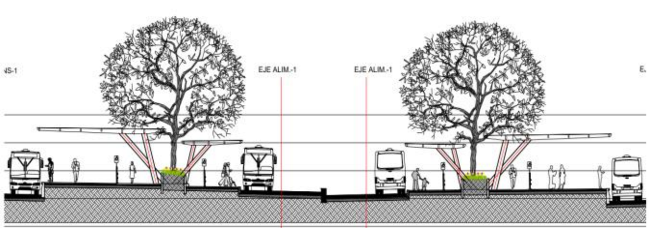

Fig. 11 Exclusive access inside the station

V. Results

For the analysis and comparison, we will focus on conflict numbers, pedestrian density, level of service, and travel times. Each of these aspects will be studied independently to better control the influencing factors.

A. Average Conflict Numbers in the Station

Following the implementation of a route segmentation system, which includes a pathway specifically designed for individuals with reduced mobility and other needs, a notable reduction in conflicts has been observed in the four sectors of the station, as shown in Fig. 12.

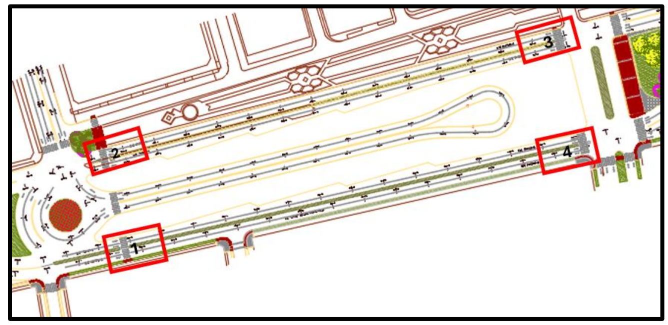

Fig. 12 Conflict zones at the station

Using the Vissim software, data on conflict numbers for vulnerable individuals were obtained, as illustrated in Fig. 13.

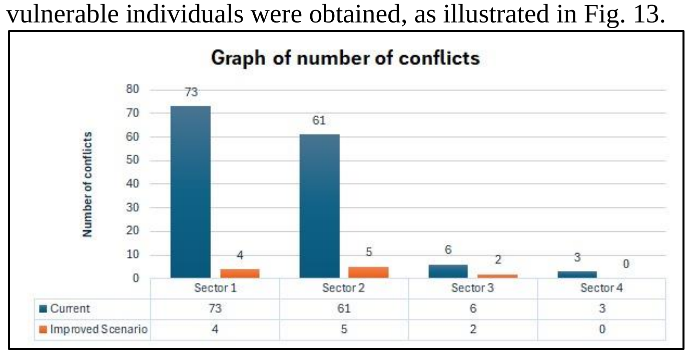

Fig. 13 Comparison graph between number of conflicts

B. Average Densities in Areas of Interest

The average pedestrian density in the station determines the ratio of pedestrians per square meter. For the station model in the Vissim software, seven areas of interest were evaluated, as shown in Fig. 14.

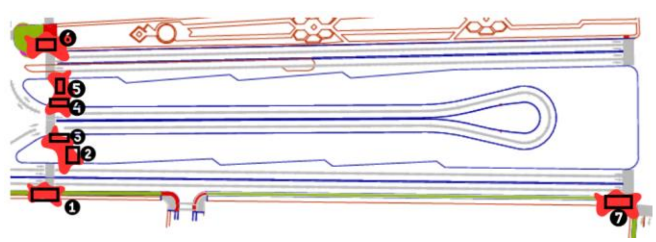

Fig. 14 Areas of interest

Based on the simulations conducted, the following comparative graph for the seven zones was obtained.

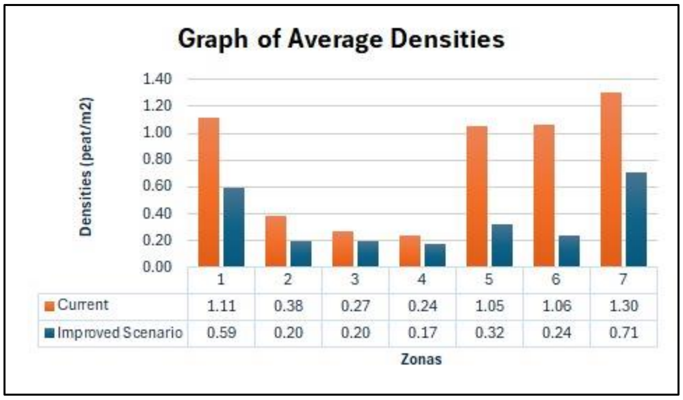

Fig. 15 Average Density Comparison Chart

C. *Level of Service in Areas of Interest*

According to the HCM 2010 Highway Capacity Manual, a detailed level of service (LOS) rating is presented for pedestrian corridors in both conditions: the current situation and the proposed improvement, Table 4.

TABLE 4
LEVEL OF SERVICE FOR AREAS OF INTEREST

	Areas						
	1	2	3	4	5	6	7
Current	E	C	B	B	E	E	F
Improvement	D	B	B	A	C	B	D

D. *Average Travel Times for Vulnerable Individuals*

Average travel times were determined for four specific routes, as shown on Fig. 16.

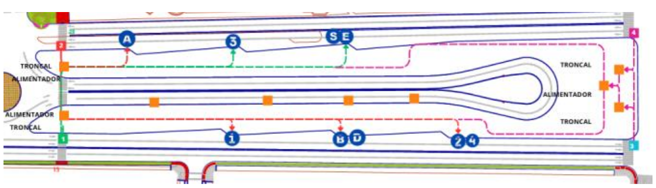

Fig. 16 Travel Routes within the Naranjal station

This comparison represents the culmination of the previously analyzed aspects, such as density and conflict numbers, as it reflects all the proposed improvements. Tables 5 and 6 present a comparison between the travel times in seconds for the current situation and those obtained through modeling in VISSIM 9.0, highlighting the positive impact of the optimizations implemented in the station.

TABLE 5
AVERAGE TRAVEL TIMES VISSWALK 9.0

NORTH ENTRANCE			
	1	BD	24
Route 1	79.86	133.49	206.45
	A	3.00	SE
Route 2	43.39	87.39	140.99
SOUTH ENTRANCE			
	1	BD	24.00
Route 3	153.24	110.29	98.14
	A	3.00	SE
Route 4	182.35	162.56	103.74

TABLE 6
AVERAGE TRAVEL TIMES CURRENT SITUATION

NORTH ENTRANCE			
	1	BD	24
Route 1	98.56	146.86	216.35
	A	3.00	SE
Route 2	53.62	111.03	167.32
SOUTH ENTRANCE			
	1	BD	24.00
Route 3	198.21	155.23	112.25
	A	3.00	SE
Route 4	214.85	189.12	152.35

Table 7 shows the percentage reduction in travel times for the four analyzed routes. The data reflects how the modifications in design and pedestrian flow have resulted in a significant decrease in travel times, contributing to greater fluidity and comfort for users in each sector of the station.

TABLE 7
DECREASE IN TRAVEL TIMES IN %

NORTH ENTRANCE			
	1	BD	24
Route 1	23.42%	10.02%	4.80%
	A	3.00	SE
Route 2	23.58%	27.05%	18.68%
SOUTH ENTRANCE			
	1.00	BD	24.00
Route 3	29.35%	40.75%	14.38%
	A	3.00	SE
Route 4	17.82%	16.34%	46.86%

IV. CONCLUSIONS

The sectorization of the station entrances successfully reduced conflicts in sectors 1 and 2 by 95% and 92%, respectively, and in sectors 3 and 4 by 67% and 100%, significantly improving pedestrian flow organization and accessibility.

Average pedestrian densities decreased by up to 46.9% in zone 1 and 45.4% in zone 7, reflecting a significant improvement in pedestrian flow distribution following the interventions.

The implemented improvements, evaluated according to the Highway Capacity Manual (HCM), significantly increased the pedestrian level of service in all areas of interest, transitioning from lower categories such as E and C to higher levels such as D, B, and A.

The modifications in design and pedestrian flow achieved an average reduction of 22.8% in travel times for vulnerable individuals, with notable reductions in the analyzed routes, enhancing user fluidity and comfort in each sector of the station.

The improvements implemented in the station, such as the creation of 1.5-meter refuge islands and curb extensions, adjustments to traffic signal phases, and the establishment of exclusive access points, significantly optimized the operability of the Naranjal station. These changes streamlined travel times for both vulnerable individuals and average users, enhancing accessibility and pedestrian flow efficiency.

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