Inclusive infrastructure design to reduce cyclists travel time during pandemic COVID 19

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Abstract – Lima (as is the case of other parts of Peru) has declared a state of health emergency due to the COVID-19 pandemic. According to scientific reports, infections occur in public transportation. This has forced the government to promote the use of sustainable means of transportation, such as bicycles. This alternative has been widely accepted since, according to the economic newspaper "Gestión," the pandemic has increased the demand for bicycles by 282% and for electric scooters by 58% [1]. However, bicyclists feel insecure as a result of poor infrastructure. The most prominent were the lack of connectivity, conflicts between bicyclists, pedestrians and vehicles, and long travel times for bicyclists. Therefore, this article seeks to assess simulations of cycling-inclusive alternatives in the district of Miraflores, carried out using the Vissim software, based on geometric redesigns and accompanied by Intelligent Transportation Systems (ITS), such as the use of actuated traffic lights aimed at bicyclists. Finally, all alternatives proposed succeeded in creating an inclusive infrastructure for all types of bicyclists. This was verified through the use of Vissim, with a decrease in average travel time of bicyclists by 24.48%.
Keywords—Vissim, Social Force, Cycling, Inclusive Transportation, Pandemic.

I. INTRODUCTION

In the city of Lima, Peru, the most popular mode of transportation is the public transportation system. However, this means of transportation has been affected as a result of the pandemic. Faced with this problem, the use of bicycles to move around has been recommended in cities across Europe, North and South America, including Paris, New York and Bogota [2]. This recommendation ensures social distancing, which is mandatory in order to reduce the number of infections.

In Lima, some municipalities have responded to this trend promoted by bicyclists and implemented emergency bike lanes and other measures that allowed distributing space so as to provide safety to bicyclists. This gave a new perspective in terms of the inclusion of bicycling as a means of transportation.

But the numerous conflicts between bicyclists and pedestrians and bicyclists and vehicles was one of the main problems identified in the Miraflores roundabout. In addition, there is a need to connect the existing bike lanes to ensure a smooth and safe traffic flow for its users. Moreover, travel times for bicyclists tend to be high due to these problems. For this reason, this research seeks to develop a microsimulation of the Miraflores roundabout, taking into account the behavior of pedestrians, vehicles and bicyclists through the Social Force model.

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Said simulation allows understanding the current situation and proposing geometric improvements as well as ITS and standards to ensure efficient transportation for bicyclists.

II. STAT-OF-THE-ART

The article "Improving people's accessibility through a fully actuated signal control at intersection with high density pedestrians" focuses on the study of a high-traffic intersection with very high pedestrian density. The authors proposed the use of actuated signal control to prioritize pedestrians and reduce waiting times [3]. To evaluate pedestrian behavior, they used waiting times and service level of the intersection as efficiency parameters. The results were positive, as the crossing time was reduced by 6.84% and the service level of the intersection changed from E to D.

The article "Psychological-Physical Force Model for Bicycle Dynamics" proposes a social force model with path choice. The authors based their hypothesis on a combination of both models so as to achieve a behavior similar to that of a real bicyclist. Both models were selected as the social force model is based on Newton's second law and the trajectory choice model allows individuals to ride in response to changes in their environment [4]. Results showed that the social force model allows describing the nonlinear force between bicyclists as close to reality as possible, and that the segregation effect is the result of the interaction between the users' trajectories.

The article "Cycling and disability: A call for further research" discusses how the lack of inclusion in bike lanes affects people with disabilities by making it difficult for them to access the latter. Even though bicycles adapted for disabled people already exist, their dimensions are not considered in design manuals [5]. In addition, the authors interviewed a group of bicyclists with disabilities in order to understand their concerns with regard to the current bike infrastructure. They concluded that despite the fact that some manuals consider the use of adapted bicycles, there are still issue with bike lanes.

III. METHODOLOGY

A. DATA COLLECTION

In terms of data collection, the authors used Google Maps to evaluate vehicle volumes and determine the appropriate time to perform the gauging. Based on the latter, the authors determined that traffic intensity in the study area was from 4 to 7 p.m. and that, during which period the highest number of conflicts between bicycles, vehicles and pedestrians occurred. To this end, a video was taken with a drone flying over the area for 3 hours. The data allowed determining the flow charts, speeds and trajectories necessary to model the current situation in the area.

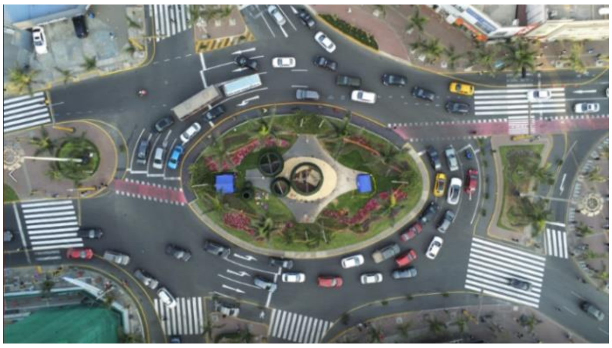


Figure 1: Study area taken from the drone. Author's own source.

There is a need to collect data to truly represent the behavior of bicyclists in the area of analysis. For Social Force it can be used distinct parameters for calibrating and validating the simulation, which are delays, queue lengths and densities. Any of these situations were present in the study area. However, travel times were the most suitable and trustworthy as parameters.

The authors proceeded to count the number of bicyclists and vehicles traveling through the area, as shown in Table I. The vehicular composition was compound by particular cars, motorcycles, big and small buses.

TABLE I
NUMBER OF VEHICLES PER INTERSECTION

Avenue	Cyclist	Cars	Buses	Motorbike
Arequipa	445	2233	96	437
José Larco	632	2112	240	359
Ricardo Palma	61	1402	69	267
José Pardo	169	1484	198	210

In terms of speed, the accumulated relative frequencies were calculated and entered into the Vissim software, as shown in Table II.

TABLE II
CYCLIST CUMULATIVE RELATIVE SPEED AND FREQUENCIES IN KM/H

Speeds (km/h)	Absolute Frecuency	Relative Frecuency	A. F. Accumulated	R. F. Accumulated
11.41 - 13.57	4	0.13	4	0.13
13.57 - 15.72	6	0.20	10	0.33
15.72 - 17.88	6	0.20	16	0.53
17.88 - 20.03	8	0.27	24	0.80
20.03 - 22.19	1	0.03	25	0.83
22.19 - 24.34	5	0.17	30	1.00
Total	30	1		

B. MODEL GENERATION IN VISSIM

A microsimulation model of the study area was made using the Vissim software. The software allowed to use data obtained from the field to represent the bicyclists. Based on said data, the authors modeled the routes traveled by cyclists. In these areas, bicyclists encounter obstacles on the road, such as traffic lights, pedestrians, other bicyclists and vehicles in order to travel through the area.

The cumulative relative frequencies shown in Table II were used to generate graphs representing the speeds in Vissim. Figure 2 shows the distribution of the speed range for Av. José Larco.

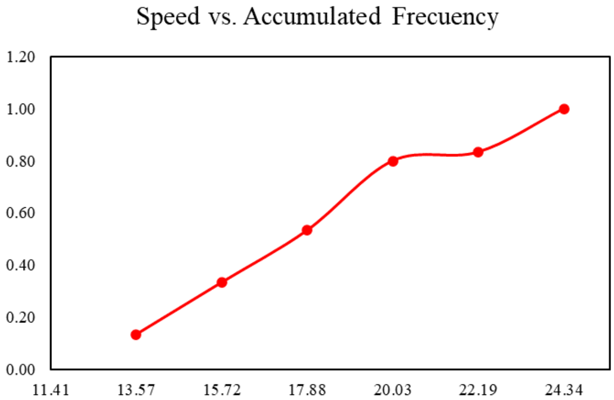


Figure 2: Frequency chart of cyclists on José Larco Ave.

C. SOCIAL FORCE MODEL

This model is based on the psychophysical movement of bicyclists generated by psychological and physical forces. It also includes the choice of trajectories, which is guided by the perceived density on both sides of the bicyclist and the analysis of their response to obstacles [6].

In order to describe the behaviors of bicyclists, Liang [4] proposes that the model obeys Newton's second law, based on the following equation:

$$m_i \frac{d\vec{v_i}(t)}{dt} = \vec{F_i}(t) = \vec{F}_i^{psy}(t) + \vec{F}_i^{phy}(t) \qquad (1)$$

$$= \vec{F}_i^{drv}(t) + \sum \vec{F}_i^{ca}(t) + \sum \vec{F}_i^{att}(t) + \sum \vec{F}_i^{cont}(t) + \sum \vec{F}_i^{fr}(t)$$

The software includes variables from the social force model that allows modeling the behavior of bicyclists with their environment, as follows: Tau (τ) is the variable that models the acceleration or reaction of bicyclists, which helps them reach their desired destination. Lambda (λ) represents the interaction between pedestrians or bicyclists and Noise focuses on the intensity of random force and avoids dead spots [7].

D. WIEDEMANN 74 MODEL

The Rainer Wiedemann model is used for microscopic studies and for analyzing the operational behavior of vehicular flow [8].

This vehicle tracking model is also included in Vissim, and its objective is to replicate the vehicular flow with the help of its variables as shown in (2).

$$AX = L_{n-1} + AXadd + RND1_n \cdot AXmult \qquad (2)$$

Where, AX is the desired distance between vehicles, whereas AXadd and AXmult are the calibration parameters and RND1n is a normal distribution parameter depending on the driver.

$$ABX = AX + BX \quad con$$

$$BX = (BXadd + BXmult \cdot RND1_n) \cdot \sqrt{v} \quad (3)$$

Where ABX is the minimum following distance at low speeds, whereas BXadd and BXmult represent calibration parameters.

The speed v is defined as:

$$v = \begin{cases} v_{n-1} & para\ v_n > v_{n-1} \\ v_n & para\ v_n \leq v_{n-1} \end{cases} \quad (4)$$

E. PROBLEM IDENTIFICATION

Due to the increase in the number of bicyclists, planning for adequate bike lanes must face the challenges of non-inclusive infrastructure.

At present, some issues in the study area highlight the scarcity of inclusive infrastructure for bicyclists.

Conflicts between bicyclists and vehicles occur mostly at all intersections. In addition, on Ricardo Palma and José Larco Avenues, the bike lane is located on the road, which puts the users at risk.

Some conflicts between bicyclists and pedestrians also occur in the bike lanes located on the pedestrian zones of the Arequipa and José Pardo Avenues. The latter is mainly due to the lack of space for shared-use paths for bicyclists and pedestrians. Therefore, users risk hitting each other.

F. GEOMETRIC INCLUSIVE REDESIGN

In order to include bicyclists in the transportation system, it is necessary to carry out geometric redesigns. To this end, the authors took into account the appropriate dimensioning and turning radii for bike lanes. For this reason, the complete geometric redesign was based on the Cycle "Infrastructure Design" manual prepared by the UK Department for Transport, which takes into account the dimensions of adapted vehicles [9].

Said manual provides details with regard to the typical lengths and widths depending on the type of bicycle. Even though the design dimensions are superior to the models shown in Table III, a comparison was made with the dimensions of adapted bicycles.

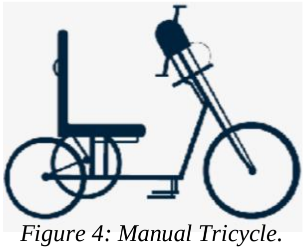
TABLE III
DIMENSIONS PER TYPE OF BICYCLE ACCORDING TO THE "CYCLE INFRASTRUCTURE DESIGN"

Type of Bicycle	Typical Length (m)	Typical Width (m)
Design Bicycle	2.80 (max)	1.20 (max)
Classical Bicycle	1.80	0.65
Bicycle with carriage	2.70	0.85
Tandem Bicycle	2.40	0.65

For the inclusive geometric redesign, three types of bicycles that are more likely to be used in Peru were taken into account. Said bicycles include the classical, manual and recumbent tricycle, as shown in Table IV. See also their respective lengths and widths. Based on said information, the authors were able to corroborate that the typical length of the designer bicycle of 2.80 meters, with a width of 1.20 meters, meets the dimensions of the bicycles considered for the inclusive design.

For this article, different types of bicycles with different dimensions were seen, such as:

TABLE IV
DIMENSIONS OF ADAPTED BICYCLES

Type of Bicycle	Length (m)	Width (m)
 *Figure 3: Tricycle. [10]*	1.90	0.80
 *Figure 4: Manual Tricycle. [10]*	2.05	0.86
 *Figure 5: Recumbent tricycle. [10]*	2.15	0.83

After corroborating that the data in the manual complies with the dimensions of adapted bicycles, the authors defined the widths of the bike lanes. Table V shows the dimensions that the lanes should have depending on the type of route and direction. The first one includes a protected area for bicyclists, such as protected and on-road bike lanes. Said lanes are present on all access roads and are bidirectional. Even though the minimum desirable width is 3 meters, the authors decided to use 2.50 meters, so as not to affect other modes of transport.

TABLE V
DIMENSIONS OF ADAPTED BICYCLES

Type of Lane per Bicycle	Direction	Desired Minimum Width (m)	Absolute Minimum (m)
Protected Area for Cyclists	One way	2.00	1.50
	Two ways	3.00	2.00
On Road	One way	2.00	1.00

G. ACTUATED TRAFFIC SIGNALIZATION

This Intelligent Transportation System seeks to make traffic more efficient by identifying the number of vehicles and prioritizing the roads with the highest volume of users. The tool that allows working with actuated traffic lights in Vissim is VisVAP. Said tool allows using the vehicle-driven programming language by creating and editing logics as a flowchart [11].

IV. CALIBRATION Y VALIDATION

This section of the paper presents the results of the research.

The final values of the calibration and validation parameters obtained within the framework of the Social Force model were Tau=0.200, Lambda=1.000 and Noise=1.000.

These values are used in the modeling in order to represent the real behavior of bicyclists and pedestrians in the study area. The vehicles were modeled with Wiedemann 74 and the following parameters were used for calibration and validation. The parameters used in this study were ax=05, bx add=2.25 and bx mult=2.

Subsequently, 30 runs were performed in the Vissim software obtaining results of travel times for vehicles, pedestrians and bicyclists.

The following table shows the results of the total travel time averages obtained with the selected parameters.

TABLE VI
AVERAGE TRAVEL TIME ACCORDING TO ITERATION WITH VARIOUS WIEDEMANN 74 PARAMETERS.

Iteration	ax	bx add	bx mult	Average Travel Time in Vissim (s)	Average Travel Time in the field (s)
1	1.00	1.50	1.50	4.87	
2	1.00	2.25	1.00	7.85	
3	0.50	2.25	2.00	4.71	4.753

In order to calibrate pedestrians and bicyclists, the authors used the Social Force model. The parameters with which it was possible to achieve a behavior as close to reality as possible are shown in Table VII.

TABLA VII
AVERAGE TRAVEL TIME WITH SOCIAL FORCE PARAMETERS

Avenue	Study Travel Time (s)	Vissim Travel Time (s)	Travel Time Diference (s)	Error rate (%)
José Larco	4.1623	4.1767	-0.01	0.35%
Arequipa	4.2527	4.2127	0.04	0.94%
Ricardo Palma	4.5477	4.7047	-0.16	3.45%

As a next step, the model is validated. The number of runs is evaluated based on the results obtained in the calibration process with the statistical results of the following table. The probability distribution selected for this study was T Student because the sample presented was of 30 cyclists per road, which means the sample was small compared to other probability distributions requirement, as in Normal distribution.

TABLE VIII
STATISTICAL RESULTS OF VEHICLE VALIDATION

Mean	Stand. Dev.	Sample	T Student	Error
4.709	0.09	30	4.025	0.05

$$N \geq \left(2 * 2.045 \, \frac{0.09}{0.05 * 4.709}\right)^2 = 2.367$$

According to the aforementioned equation, the number of runs is acceptable. The same result was evaluated with the StatKey tool. The two-tailed test was used and a mean difference of 0.009 was obtained, which was within the acceptance interval of -0.081 to 0.082, as shown in the following figure.

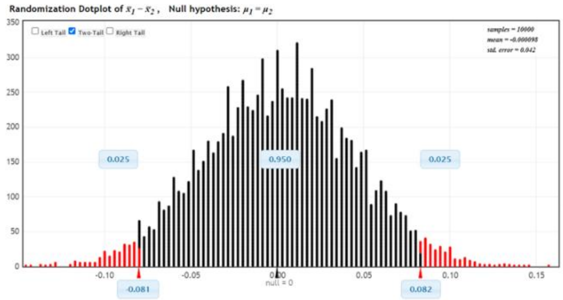


Figure 6: Null hypothesis for vehicle validation. Author's own source.

The same procedure was performed for bicyclists and pedestrians, obtaining the following results.

TABLE IX
STATISTICAL RESULTS OF VEHICLE VALIDATION

Mean	Stand. Dev.	Sample	T Student	Error
4.077	0.07	30	4.025	0.05

$$N \geq \left(2 * 2.045 \, \frac{0.07}{0.05 * 4.077}\right)^2 = 1.91$$

Based on the statistical results shown in Table IX, the minimum number of runs in the above equation was verified [12]. As deemed acceptable, the two-tailed null hypothesis test was performed. The mean difference was 0.18, which is within the acceptable interval of -0.363 to 0.378, with a reliability of 95%.

The same evaluation of the number of runs for pedestrian validation was performed with the results obtained from the Vissim report shown in Table X.

TABLE X
STATISTICAL RESULTS OF PEDESTRIAN VALIDATION

Mean	Stand. Dev.	Sample	T Student	Error
10.653	0.71	30	4.025	0.05

$$N \geq \left(2 * 2.045 \, \frac{0.71}{0.05 * 10.65}\right)^2 = 28.78$$

Upon verification that the formula did obtain a lower number of runs than the one used, the authors performed the double-tailed null hypothesis test. The acceptance interval was -0.284 to 0.283, whereas the mean difference was -0.24, thus validating the model.

V. IMPROVEMENT PROPOSALS

In order to include bicyclists in the current road system, infrastructure changes must be made. The latter will ensure that users have greater access and ride more safely.

The proposals for improvement were based on four issues identified in the Miraflores roundabout. The first is the lack of connection between bike lanes and the system. The second is how to reduce conflicts between bicyclists and pedestrians on the bike lanes of the Arequipa and Pardo Avenues. The third seeks to eliminate conflict between bicyclists and vehicles on the Ricardo Palma Avenue. The fourth and fifth proposals seek to reduce the average travel times of bicyclists.

1) Redesign of Bike Lane Infrastructure:

One of the most significant problems encountered in the study area is the lack of connection between existing bike lanes, which resulting in longer travel times for bicyclists and causing a feeling of insecurity when interacting with other modes of transportation.

It is key to solve this issue as the safety of pedestrians is affected. In effect, bicyclists often choose to use the sidewalks or crosswalks. In addition, the design took into account different types of bicycles to ensure that all bicyclists can ride without difficulty.

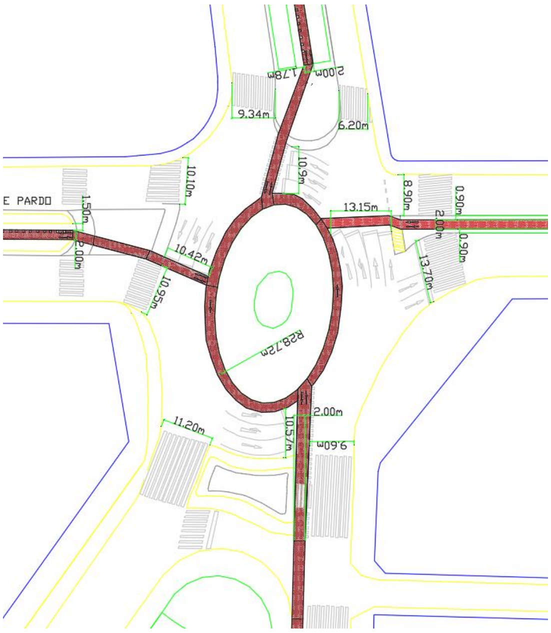


Figure 7: Map with Improvement Proposals. Author's own source.

This proposal consists of improving the connectivity of the existing bike lanes surrounding the Miraflores roundabout. This is currently the case in half of the lanes. The proposal is to surround the entire roundabout, making it a two-lane, one-way road, allowing for access to the Ricardo Palma and José Pardo Avenues. The proposed bike lane is 2.50 m wide so that bicyclists can get ahead of each other [9].

In addition, the proposal allows reducing travel times for bicyclists, which in turn allows them to travel safely as a result of the new infrastructure.

2) Segregation of Bike Lane:

Another issues that needs to be addressed focuses on conflicts between cyclists and pedestrians on the north and west bike lanes. The proposal consists of segregating the road and providing adequate signage. The proposed bidirectional bike lanes of both avenues were designed to be 2.50 meters wide. The remaining space is for pedestrians and is 1.25 meters on the Arequipa Avenue and 1.00 meters on the José Pardo Avenue.

As the bicyclists were modeled using the Social Force model, they also use pedestrian areas.

For this reason, different areas were developed for each one to move along their corresponding lane. This way, pedestrians and bicyclists remain segregated, obtaining the same behavior as with the proposals.

3) Relocation of the Ricardo Palma Ave. Bike Lane:

East of the roundabout, a bicycle lane was built on the roadway using one of the vehicle lanes. This is considerably dangerous for the bicyclists, as the lanes are segregated with safety cones only. In addition, many linear motorcycles tend to invade the bicycle lane, thus endangering the users.

The proposal consists of relocating the bicycle lane on the existing central pedestrian lane on the Ricardo Palma Avenue. This way, cyclists would have exclusive access to safe lanes. The proposed bidirectional bike lane has a width of 2.50 meters.

4) Traffic Signal Optimization of the Intersecction:

The authors considered the optimization of the intersection's traffic signal cycle in order to reduce its current duration of 120 seconds. By decreasing the time between each phase, bicyclists would wait less. This way, travel times could be further reduced. The optimum traffic signal cycle obtained was 90 seconds.

5) Actuated Signaling Implementation:

This proposal was implemented through the VisVap tool, which is an extension of Vissim. A signaling control logic was created using a flowchart. A minimum green of 7 and 20 seconds was taken into account for vehicles and bicyclists respectively.

The green cycle should be so in order to ensure that the bicyclist can cross the entire roundabout in a single traffic light cycle so as to optimize the traffic.

Subsequently, the authors created the control logic starting with the active vehicle phase. When bicyclists are detected in the queue, the wait is 15 seconds for the phase to change from vehicular to bicyclist and cross. Once they have crossed, the cycle will repeat and return to the vehicular phase.

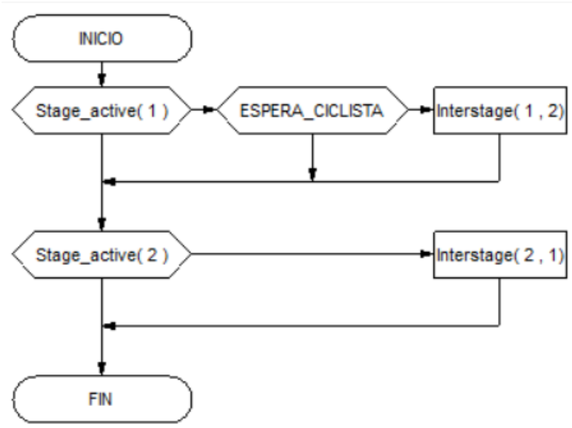


Figure 8: VisVAP Flowchart of the Actuated Traffic Signalization. Author's own source.

VI. Results

Once the proposals have been implemented in the microsimulation model, the respective runs were performed. This way, the authors were able to make a comparison between the current situation and the models with the improvement proposals, as shown in Table XI.

TABLE XI
COMPARISON RESULTS BETWEEN THE CURRENT SITUATION AND THE IMPROVEMENTS.

Avenues	Calibration	Geometrical Improvements	Total Improvements
Arequipa - José Pardo	132.84	125.58	84.14
Arequipa - Jose Larco	97.91	96.83	96.55
Arequipa - Ricardo Palma	88.47	154.35	78.69
Jose Larco - Ricardo Palma	108.84	122.68	97.87
José Larco - Arequipa	98.16	98.66	96.79
José Larco - José Pardo	119.82	14459.00	98.60
Ricardo Palma - Arequipa	85.11	98.58	86.63
Ricardo Palma - José Pardo	166.98	123.68	105.21
Ricardo Palma - José Larco	111.47	99.45	107.05
José Pardo - José Larco	119.01	101.62	86.76
José Pardo - Ricardo Palma	164.81	99.67	91.01
José Pardo - Arequipa	115.78	89.08	86.19

The results obtained from the models including geometric improvements, traffic light optimization and actuated traffic lights were encouraging due to the large reduction in the average travel times of bicyclists. Table XII shows that travel times of bicyclists are reduced by 3.86% with geometric improvements and traffic signal optimization only. In contrast, the average travel time of bicyclists was reduced by 20.84% with all improvements implemented, including the actuated traffic signalization.

TABLE XII
PERCENTAGE COMPARISON TO VALIDATION IMPROVEMENT.

Phases	Average Travel Time (s)	Time Reduction (s)	Time Reduction (%)
Calibration	117.43		
Geometrical Improvements	112.90	4.54	3.86%
Total Improvements	92.96	24.48	20.84%

VII. CONCLUSIÓN

The improvement proposals consisted of geometric redesign, traffic light optimization and traffic signalization to obtain an inclusive infrastructure for bicyclists. Initially, the Miraflores roundabout had only two bike lanes that connected, 3 bike lanes with conflicts between bicyclists and pedestrians and bicyclists and vehicles, and a 120-second traffic light cycle. With the implementation of the improvements, it was possible to connect the four bike lanes in the study area, adequately segregate the bike lanes that presented high numbers of conflicts, and optimize the traffic light cycle to 90 seconds. All improvements provide much safer roads for bicyclists and reduce the number of existing conflicts.

The proposal that had the greatest impact on travel times for bicyclists was the actuated traffic signalization. With the current infrastructure, the average travel time for bicyclists is 117.43 seconds. When geometric improvements and traffic signal optimization were applied, trave time was reduced by 4.54 seconds. However, when actuated traffic signalization was employed the average travel time was reduced by 24.48 seconds. This means that with all the proposals implemented it was possible to reduce the average travel time of bicyclists by 20.48%.

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