Evaluation of an intersection with an exclusive traffic light phase to improve the displacement times of people with reduced mobility in urban areas with high commercial activity

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Abstract*– Currently, many cities in Latin America prioritize vehicular circulation in the design of road intersections, where the traffic light phases do not consider the total displacement time of people. This is where frequent pedestrian-vehicle conflicts occur before and during the pedestrian green interval. Against this background, the most affected are users with reduced mobility, since they spend more time in crosswalk. The present investigation selected an intersection located in a commercial area in the city of Lima. Here the time and behavior of people with reduced mobility when crossing the intersection were identified. Then, through microsimulation in the VISSIM and VISWALK programs, the effectiveness of a scenario with an exclusive traffic light phase that considers users with reduced mobility is evaluated. In the evaluation of the operational behavior of the intersection, the displacement time of people in 8 usual paths, the levels of both pedestrian and vehicular service and a list that compares the improvements in the infrastructure is considered. Here it is evident that the displacement time decreases from 12% to 40% in 6 of the 8 paths, the pedestrian service levels improve from 1 to 2 levels, the vehicular service level of the intersection is maintained in D and the improvements to the proposed design are verified.

Keywords*—People with reduced mobility, exclusive pedestrian traffic light phase, microsimulation in urban intersections, and displacement time.

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Abstract*– Currently, many cities in Latin America prioritize vehicular circulation in the design of road intersections, where the traffic light phases do not consider the total displacement time of people. This is where frequent pedestrian-vehicle conflicts occur before and during the pedestrian green interval. Against this background, the most affected are users with reduced mobility, since they spend more time in crosswalk. The present investigation selected an intersection located in a commercial area in the city of Lima. Here the time and behavior of people with reduced mobility when crossing the intersection were identified. Then, through microsimulation in the VISSIM and VISWALK programs, the effectiveness of a scenario with an exclusive traffic light phase that considers users with reduced mobility is evaluated. In the evaluation of the operational behavior of the intersection, the displacement time of people in 8 usual paths, the levels of both pedestrian and vehicular service and a list that compares the improvements in the infrastructure is considered. Here it is evident that the displacement time decreases from 12% to 40% in 6 of the 8 paths, the pedestrian service levels improve from 1 to 2 levels, the vehicular service level of the intersection is maintained in D and the improvements to the proposed design are verified.

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I. Introduction

In most Latin American countries, the development of the main activities has always been maintained in the city centers, which is why they constitute one of the scenarios with the highest pedestrian and vehicular flow. Innumerable commercial, financial and productive activities take place here, and the headquarters of government institutions are usually located [1]. In Peru, the center of Lima is one of the places that represents this context. Despite the large pedestrian presence in the city, 60% of the public space is destined for vehicular traffic and it is one of the reasons why Lima is one of the cities with the most registered traffic accidents in the region [2].

The third part of the pedestrians that move through the intersections of these urban areas are users with reduced mobility. These users are made up of people with some type of disability, children, the elderly and people who transport a large quantity of products or merchandise [3]. The proportion of pedestrians with reduced mobility increases on public holidays.

One of the problems that occur in the intersections of commercial urban centers is the short cross time assigned to pedestrians, which is critical for users with reduced mobility. Given the long crossing distances and the limited speed of these users, they often have to pause on the islands of refuge. Taking this problem into account, an intersection located in a commercial area in the center of the city of Lima was selected as a case study, which is characterized by its high pedestrian traffic due to its proximity to shopping centers and tourist places. This intersection has 4 lanes in the north and south accesses that represent 28 meters of crossing, and 3 lanes in the east and west accesses that represent 20 meters of crossing. In addition, the islands of refuge have dimensions of less than one meter, unsuitable for waiting of pedestrians with reduced mobility due to the space they occupy. This also shows that the design of the road infrastructure prioritizes vehicular circulation.

Faced with this problem, there are different solution measures to generate the pedestrian crossing priority. An example of this is the application of the diagonal crossing of Oxford Circus in England, where around 43,000 people pass a day, this managed to favor the pedestrian crossing. [4] The application of this measure reduces the frequency of pedestrian-vehicle conflicts, reduces displacement paths and increases road safety for pedestrians [5]

The present investigation evaluates the application of the pedestrian crossing with exclusive traffic light phase for the user with reduced mobility. In the field work, drones were used to record the capacity and displacement times of the users. With the recorded data, the microsimulation of the current state is performed in VISSIM and the simulation with exclusive traffic light phase is proposed. From the models developed, the generalized characterization of pedestrians is considered considering people with reduced mobility, using the VISWALK as a tool. The results were evaluated and it was validated that the proposal of the diagonal crossing with exclusive traffic light phase manages to improve the displacement time of people with reduced mobility.

characterization parameters used in the microsimulation for people with reduced mobility. They are based on the social force model to find the adequate capacity of a public space considering users with reduced mobility. They identified 5 parameters to generate a better representativeness of these users [11].

II. STATE OF ART

Studies carried out in the United States, Canada and Japan on diagonal pedestrian crossings with an exclusive traffic light phase present two types of approaches that analyze people's behavior.

The first is related to the evaluation of pedestrians through microsimulation. For example, for the diagonal crossing intersection in Oakland, California; Hussein and Sayed showed that, by means of microsimulation, a representativeness between 80% to 100% of the pedestrian behavior was achieved. [6] Another particular case is the study of Vu Tu and K. Sano at an intersection in Nagoya, Japan. There they simulated a scenario with a diagonal crossing and evaluated numerous situations varying the pedestrian demand. They determined that the intersection's service level was more stable with the diagonal crossing; and that, the higher the pedestrian demand, the lower the vehicular delay was in that scenario. [7]

The second approach is aimed at the analysis of road safety parameters. The studies make a comparison between the pre-state and post-state of the inclusion of crosswalk priority measures at an intersection. Evaluations have been made of the operation of the diagonal crossing, pedestrian-vehicle conflicts, and pedestrian and vehicular delays. In Alberta, Canada, the authors L. Kattan, S. Acherjee and R. Tay conducted a study on the operation of the Calgary diagonal crossing (PSO) and determined that, by including the exclusive traffic light phase crossing, it was achieved reducing the number of pedestrian-vehicle conflicts to almost 0. However, the perception of the increase in crossing time generates an increase in the number of infractions committed by pedestrians [8]. Regarding delays, C. Sobie et al. analyzed 3 intersections in Portland, Oregon. Here they evaluated the development of the pedestrian crossing priority in different traffic light operation scenarios with the VISSIM program. As a result, they found that by selectively reducing vehicle passing time, pedestrian delays decreased by 8% to 33% and vehicular delays by 5% to 14% compared to the baseline scenario [9].

On the other hand, studies of people with reduced mobility at an intersection are focused on users who are dependent (elderly and children) and those with some type of disability (wheelchair).

In the Peruvian case, F. Cabrera, F. Muñoz, and C. Pérez evaluate walking patterns in elderly, also identifying the characteristics of the road infrastructure that affect them. They determined that only the elderly under the age of 70 can accelerate their pace when crossing. They also observed that the main factors affecting the movement of these users and, point out the importance of characterization users with reduced mobility to improve investigations with microsimulation. [10].

In this sense, D. Vásquez, J. Castro, M. Silvera and F. Campos, present a study in relation to the pedestrian

III. METHODOLOGY

To validate the research results, within the methodology the evaluation between two scenarios was considered through the VISSIM/VISWALK microsimulation program. The first scenario considers the representation of the current operational behavior of the intersection and the second scenario considers the design of a diagonal pedestrian crossing accompanied by an exclusive traffic light phase for pedestrians. From the models carried out, the time taken by pedestrians with reduced mobility when moving from one point to another within the intersection is determined, the variation in the pedestrian service level and the vehicle service level is evaluated; and, the proposed changes are compared with a list of questions that verify the improvements of the road infrastructure.

The following flowchart is presented below that summarizes the processes carried out:

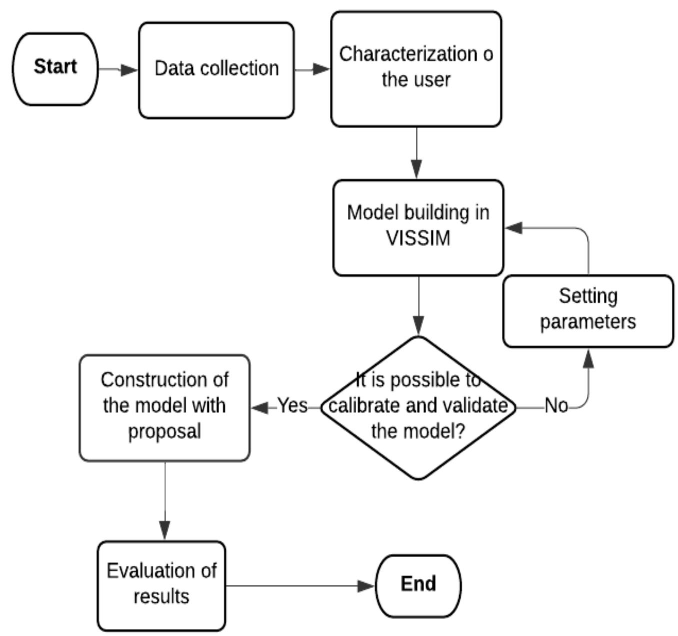


Fig. 1 Methodology flowchart

A. *Data collection*

For the development of this research, the intersection Av. Abancay with Av. Nicolás de Piérola located in the city of Lima, Peru was chosen. Around the intersection are shopping malls, parks, state agencies, and tourist spots. The infrastructure of the intersection is characterized by having a crossing width that ranges between 20 and 28 meters, and has between 3 to 4 lanes per access. Here both the vehicular and pedestrian counting is carried out and the geometric characteristics of the intersection are evaluated. In addition, representative behaviors of vehicles and pedestrians are recorded to group them into typologies. This information is collected through field visits and video recordings in a drone that was located at a height of 400 meters. From this information, both vehicular and pedestrian paths were identified to measure displacement times and calculate speed.

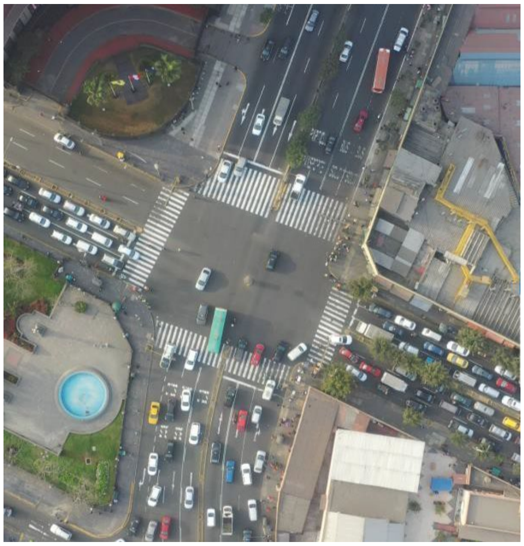


Fig. 2 Current scenario recorded from drone

B. *Characterization of user with reduced mobility*

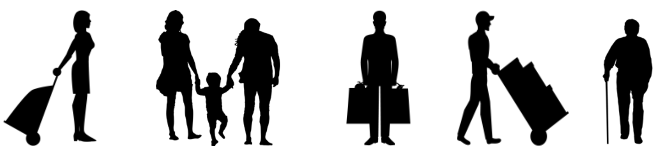


Fig. 3 Users with reduced mobility at the intersection

With the information collected in the field, it is identified that the user with reduced mobility represents more than 20% of the people present at the intersection. Its main characteristic is that these types of people develop very low speeds during their displacement. These users look for clear paths, since most of them transport merchandise or products that make their displacement difficult.

C. *Model building in VISSIM*

The microsimulation model is generated in the VISSIM program, where the collected data is entered. These consider the geometry of the intersection and the characteristic speeds of pedestrians and vehicles according to their typology. The traffic light cycle, the priority of passage is also entered and the fixed components of the intersection such as poles, kiosks, trees and signage are included.

Fig. 4 Current scenario model in VISSIM

D. *Setting parameters for calibration and validation*

The parameters evaluated in the vehicular case correspond to the Wiedemann vehicular tracking model 74; and, in the pedestrian area, the parameters of the social force model. For more representative cases, 5 social force parameters (tau, lambda, Asocmean, noise and VD) and the 3 Wiedemann parameters 74 (ax, bxadd and bxmult) were chosen. For the development of the calibration, the values of each parameter were modified until achieving an adequate representativeness of the current scenario. This is verified by means of the nonparametric random test of difference of means of travel times.

For validation, new data on vehicular and pedestrian volumes are entered into the calibrated model corresponding to a second capacity, which was developed during peak demand hours. In this way it is verified that the model responds to the real characteristics of the intersection.

The values of the calibrated and validated parameters of the intersection are shown below.

TABLE I
VALUES OF PARAMETERS CALIBRATED AND VALIDATED

Parameters	**Calibration**	**Parameters**	**Calibration**
Pedestrian		**Vehicular**	
Tau	0.2	Ax	0.5
Lambda	0.8	Bx add	0.7
Noise	5	Bx mult	4
Asoc_mean	0.8		
VD	20		

E. *Construction of the model with proposal*

For the construction of the microsimulation model with a diagonal pedestrian crossing, modifications are made within the intersection based on the 2017 Peruvian road safety manual. Here we consider the widening of the sidewalk widths for adequate pedestrian flow, the improvement of the design of ramps for users with reduced mobility and includes vertical and horizontal signage that gives priority to pedestrians. [12] Also, the recommendations of the Peruvian road geometric design manual DG 2018 were followed for modifications in the geometry of the intersection. For this, vehicle speeds, turning radii and lane widths were analyzed. [13]

In this way, greater safety and comfort in pedestrian displacement is achieved with a shorter crossing distance at the intersection. Likewise, the VISTRO program is used to obtain the time of an optimized traffic light cycle that includes an exclusive pedestrian phase. Thus, a redistribution of the initial 210-second traffic light cycle was generated. This cycle is included in the proposed model. Then, the interaction of the road users is evaluated and iterations are carried out until a unique cycle appropriate for the intersection is obtained.

Fig 5. Scenario model proposed in VISSIM

F. *Evaluation of results*

1) *Displacement times*

To compare displacement times in both scenarios, the Pedestrian Travel Time tool was used to evaluate the displacement time between certain points of the intersection.

Points of origin and destination were placed, which are detailed in Fig. 6, where 8 routes are identified that generate the diagonal and "L" paths of both scenarios.

Then, evaluations are carried out within the microsimulation program to obtain the displacement times of users with reduced mobility in both the current and proposed scenarios. The average and standard deviation of the travel times for each path are calculated. The results demonstrate the effectiveness of the diagonal pedestrian crossing.

2) *Service levels*

Then, the evaluation of the level of pedestrian and vehicular service is carried out. For the pedestrian case, the ratios granted by the HCM 2016 were used, where 4 types of evaluations are defined. In this study, the evaluation that indicates the level of service is selected according to the number of pedestrians per area during 15 minutes on the sidewalks of the intersection [14].

In the vehicular case, the VISTRO program is used to calculate the service level of the intersection and of each of its accesses.

3) *Infrastructure improvements*

A list of questions was drawn up in order to assess the current status and implementation of the improvement that includes the complementary infrastructure that facilitates the displacement of people with reduced mobility. This questionnaire refers to the design of the intersection, the exclusive traffic light and the priority of the crosswalk. [12]

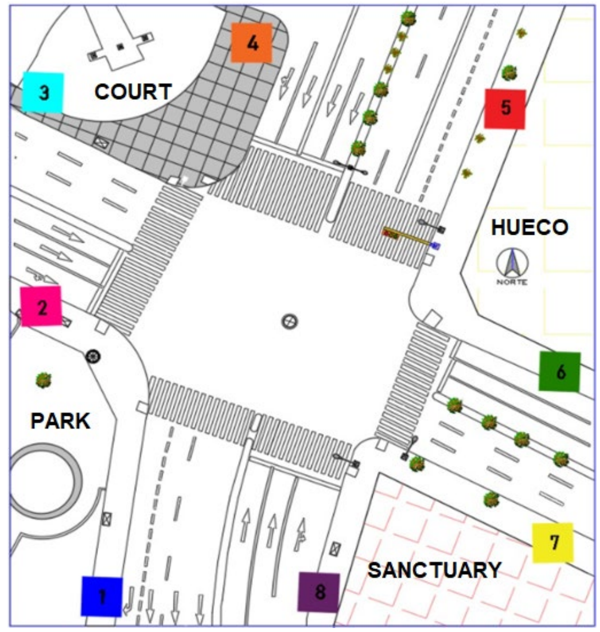


Fig. 6. Map with Origin - Destination points

IV. Results

A. *Displacement time results*

From the evaluation carried out, different distributions of displacement time per path at the intersection are obtained. The difference between the results of the base model and the model with exclusive phase is observed. Linear graphs were made where the displacement times for each simulation are presented. Three representative chart types are highlighted here, as shown in Figs. 7, 8, and 9.

Fig. 7 corresponding to path 3 - 7, shows a similar data dispersion in both distributions. But, the scenario with the exclusive phase proposal presents lower values of travel time.

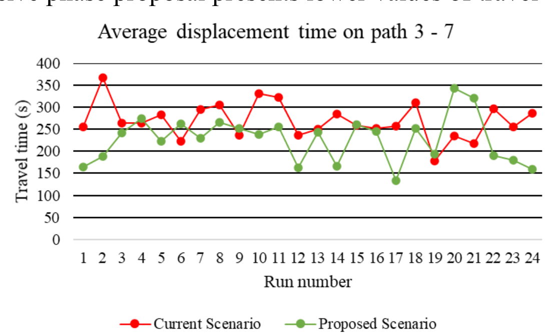


Fig. 7. Graph of average displacement time per run on path 3 - 7

The second graph corresponds to path 3 - 8 (Fig. 8), the results show that both distributions have a similar behavior. However, there is a difference in displacement times, here it is observed that the scenario with the inclusion of the exclusive traffic light phase, allows people to present a shorter time when crossing in most of the simulations.

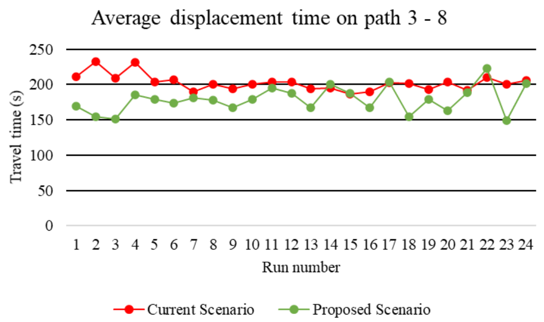


Fig. 8. Graph of average displacement time per run on path 3 - 8

The third graph (Fig. 9) shows a large variation in the data dispersion of the displacement times of the current scenario. On the other hand, the distribution of the proposed scenario remains almost constant in all simulations.

It should be noted that most of the paths (4-8, 2-5, 2-6 and 4-7) present graphs with these characteristics.

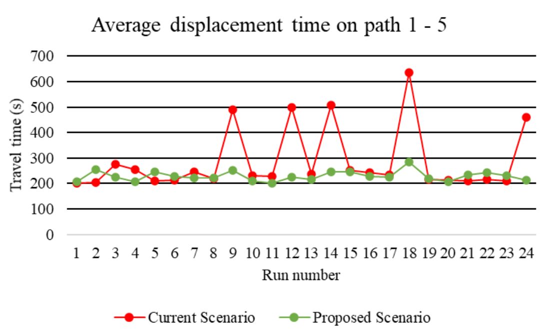


Fig. 9. Graph of average displacement time per run on path 1 - 5

Next, in table II, the summary of the average travel times in the selected paths is shown. Here it is observed that, of the 8 paths analyzed, 6 have a shorter displacement time in the scenario with an exclusive phase for pedestrians. This shows a 14% to 40% reduction in displacement time compared to the current scenario.

TABLE II
AVERAGE DISPLACEMENT TIMES BY EVALUATION PATH IN SECONDS

Scenario	Average crossing time per path (s)							
	1 - 5	1 - 6	2 - 5	2 - 6	3 - 7	3 - 8	4 - 7	4 - 8
Current	286.0	279.9	246.2	334.9	276.9	202.0	294.3	325.7
With proposal	228.6	320.2	385.2	222.9	245.0	178.6	228.5	197.9

Likewise, the standard deviation of the displacement times of each of the paths is determined. With this information it is possible to evaluate the variation in the data dispersion of the distributions in both scenarios, current and with the inclusion of the traffic light phase exclusively for pedestrians.

TABLE III
STANDARD DEVIATION OF DISPLACEMENT TIMES BY EVALUATION PATH IN SECONDS

Scenario	Standard deviation of times per path (s)							
	1 - 5	1 - 6	2 - 5	2 - 6	3 - 7	3 - 8	4 - 7	4 - 8
Current	125.3	121.2	56.7	139.3	66.1	11.3	198.8	179.4
With proposal	19.3	20.9	17.5	21.8	53.0	18.3	35.8	11.9

B. Results of service levels

The results obtained through the HCM 2016 determined that the sidewalks located next to the intersection accesses increase the level of pedestrian service. In addition, it is observed the improvement of the operational conditions of pedestrian traffic regarding the density and the volume in the proposed model.

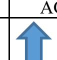
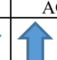
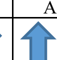
As can be seen in Table IV, the areas with the greatest increase in the level of pedestrian service were the Park and the Sanctuary (see Fig. 6). The other points of the intersection also improved their level of service to a lesser extent.

TABLE IV
PEDESTRIAN SERVICE LEVELS IN CURRENT AND PROPOSED SCENARIO

	Analysis areas			
SCENARIO	PARK	COURT	HUECO	SANCTUARY
CURRENT	C	D	D	E
PROPOSED	A	C	C	C

On the other hand, for the analysis of the accesses, the level of service is calculated by movement group where there are variations in the north and south directions when the proposal is included. These variations do not generate a representative change in the vehicular operation of the intersection, maintaining its level of service at D.

TABLE V
SERVICE LEVELS BY MOVEMENT IN CURRENT AND PROPOSED SCENARIO

	NORTH ACCESS		SOUTH ACCESS		EAST ACCESS		WEST ACCESS	
SCENARIO								
CURRENT	C	C	D	D	E	E	E	F
PROPOSED	D	D	C	D	E	E	E	F

C. Results of infrastructure improvements

To implement protection measures for users with reduced mobility, an intersection design is carried out that prioritizes pedestrian displacement. The following questions were identified that compare the changes considered when including the proposal.

TABLE VI
QUESTIONNAIRE TO VERIFY IMPROVEMENTS IN INFRASTRUCTURE

	Current Scenario		Improvement proposal	
	Yes	No	Yes	No
Do the sidewalks have the physical conditions in dimensions, continuity without obstacles, visibility and signaling, to be a safe alternative for displacement?		x	x	
Does the studied intersection meet the safety requirements for the displacement of people with reduced mobility?		x	x	
Are the displacement times of people with reduced mobility in commercial urban areas sufficient to guarantee their accessibility?		x	x	
At the intersection, is the pedestrian crossing prioritized over vehicular traffic?		x	x	

V. Conclusions

From the application of the diagonal pedestrian crossing with exclusive traffic light phase, it is determined that the average crossing times of people with reduced mobility decreased in a range of 12% to 40% in 6 of the 8 paths analyzed. This is due to the possibility of direct crossing during an exclusive traffic light phase for pedestrians, improving accessibility unlike the current scenario where a person could extend their crossing time up to 3 traffic light phases.

In the evaluation of the displacement times, different degrees of dispersion of the data were also observed, which is understood as an indicator of uncertainty in relation to the delay time. The results of the standard deviation in the scenario with exclusive phase present lower values compared to the current scenario. Therefore, we can affirm that there is less uncertainty in this scenario and this reduces the possibility that users with reduced mobility commit infractions.

In the proposed scenario, infrastructure improvements are included that consider the expansion of the sidewalks. This generates an increase in the level of pedestrian service. In the case of the Hueco and Court areas, an improvement is achieved from D to C, while in the Park and Sanctuary areas it increases from C to A and from E to C respectively. On the other hand, the vehicular operational behavior maintains a level of service D.

Finally, it is recommended in future researchers to use other alternatives that generate the priority of crosswalk with an inclusive approach to users with reduced mobility.

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