Strategies for the reduction of vehicular conflicts in urban areas with great commercial activity through the use of simulation models

C. Pinedo, Bachelor of School of Civil Engineering[1], A. Quispe, Bachelor of School of Civil Engineering[1], M. Silvera, Master of School of Civil Engineering[1], and F. Campos, Master of School of Civil Engineering[1]
[1]Universidad Peruana de Ciencias Aplicadas, Perú, u201923088@upc.edu.pe, u201523@upc.edu.pe, manuel.silvera@upc.edu.pe, pccifcam@upc.edu.pe

Abstract— One of the main problems that occur due to poor planning of the infrastructure in a city is the diversification of the areas destined for commerce. The different activities and overcrowding of users in these areas directly affect the operational behavior of the roads due to the multiple conflicts that are generated between vehicle-vehicle and vehicle-pedestrian, in addition to increasing the probability of accidents. In Peru, the Panamericana highway is an important trunk road that connects various coastal cities in the country, including the district of Lambayeque. Here a great commercial and financial activity is developed that generates conflicts between the users who travel through the Panamericana. Many times these conflicts end in traffic accidents that put the safety of all people at risk. The objective of this research is to evaluate the implementation of strategies for the reduction of vehicular conflicts in a road section of the Panamericana in Lambayeque, through a microsimulation model in the PVT VISSIM program. The results showed that by incorporating actuated pedestrian traffic lights, a 55% reduction in total conflicts present in the study area was achieved. Also, by evaluating the probability of accidents, extreme risk conflicts can be reduced by 82% and high risk conflicts by 49%.

Keywords— Road Safety, Conflicts, SSAM, Vissim, actuated traffic lights.

I. INTRODUCTION

One of the biggest problems facing the transportation system is road safety, especially when a high-traffic highway crosses an urban area [1]. The coexistence of smaller and heavy vehicles (such as linear motorcycles and trucks), increases the possibility of accidents. Pedestrians, being the most fragile part of the system, need sufficient signaling and infrastructure to be able to cross without affecting their safety [2].

This problem is identified in the various cities that the Panamericana highway crosses, especially in Latin American countries [3]. In Peru, the Panamericana highway is one of the three most important national highways that crosses the coast longitudinally. This has the highest accident rate among all highways in Peru, in which 27% of all accidents registered on this road occurred in urban areas and 17% of these involved pedestrians [4]. It should be noted that the various entities in the field of transport lack of a methodology of standard management for the evaluation of road safety.

For this study, a road section of the North Panamericana highway was selected, which crosses the most important commercial and financial area of the district of Lambayeque, Peru. This section is made up of 4 blocks of approximately 220 linear meters. Considering the particularities of the study area, this research will evaluate the implementation of strategies that allow to guarantee road safety for users through a simulation in the Vissim program and the identification of conflicts through the Surrogate Safety Assessment Model (SSAM).

II. STATE OF THE ART

Conventionally, road traffic accident reports are the basic data for road safety analysis [5]. However, these are infrequent, random events and often lack the detail needed to understand the behavior of the users involved. Therefore, there is a need for an alternative method that allows an analysis based on recurrent events, even in cases where traffic conditions vary [6]. One of these methods was developed by the Federal Highway Administration of the United States of America (FWHA), which is based on the analysis of vehicular conflicts [7]. A vehicular conflict is a likely scenario in which two vehicles collide if one of the vehicles fails to take evasive action. The analysis to determine the conflicts is carried out by the SSAM tool, this is based on the determination of the collision time (TTC) and the post-invasion time (PET).

The TTC indicates the minimum value for two vehicles to collide if their current trajectories and speeds do not vary. It is calculated based on the following equation:

$$TTC_{n,t} = \frac{(X_{n-1,t} - X_{n,t}) - L_{n,t}}{V_{n,t} - V_{n-1,t}}$$

Where X represents the longitudinal position of a vehicle in a certain time, V the longitudinal speeds in a certain time and Ln the length of the vehicle in front. The sub index “n” denotes the front vehicle, while “n-1” the rear.

The PET indicates the time between the last time a first vehicle occupies a position and the moment when the second vehicle, which arrives later, occupies the same position. Both TTC and PET are expressed in seconds. [8]

III. METHODOLOGY

The procedure carried out for the evaluation of conflicts and the implementation of the actuated pedestrian traffic lights is shown in figure 1.

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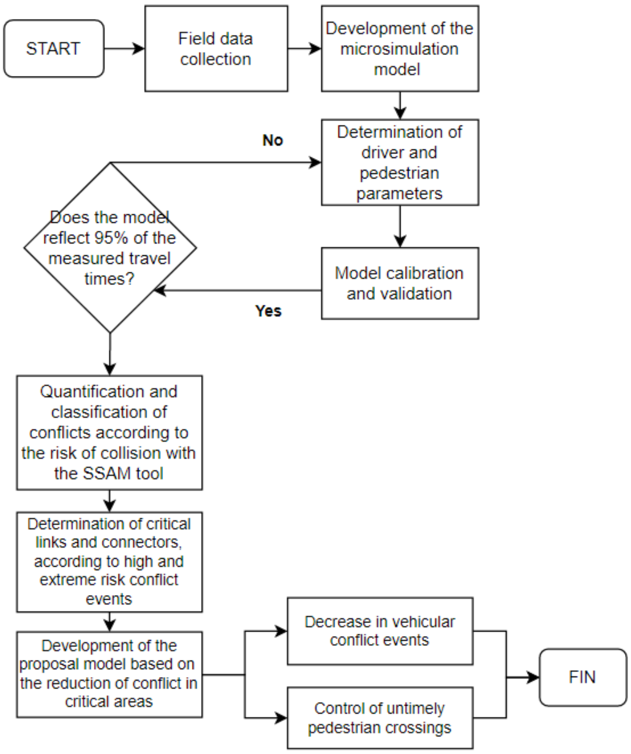


Figure 1 Research flow diagram.

A. Study Area

For this study, a section of Av. Panamericana Norte in the district of Lambayeque was used. The commercial dynamics of said city is concentrated in this area, specifically around the Mercado Modelo. In its surroundings we can find pharmacies, hotels, banks, commercial houses, etc. This section intersects Atahualpa and Vílchez Mercado streets, which are direct routes to the Brunning and Royal Tombs of Sipán museums. The delimitation of the study area is shown in figure 2.

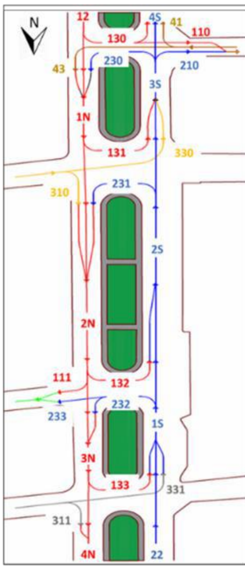
Figure 2 Delimitation of the study area.

This area of study was chosen because it has the following characteristics:

- It is a high-traffic road that crosses an important center of activities (commercial, tourist and financial area) of the Lambayeque district.
- Heavy vehicles (interprovincial buses, trailers and trucks) and smaller ones (linear motorcycles, motorcycle taxis, cars, vans and minibuses) circulate along the avenue.
- Vehicles circulating on the avenue have different purposes. For example, some take interdistrict, interprovincial, and local trips.
- DeThere is heavy pedestrian movement and walking trajectories at midpoints between intersections.

B. Data Collection:

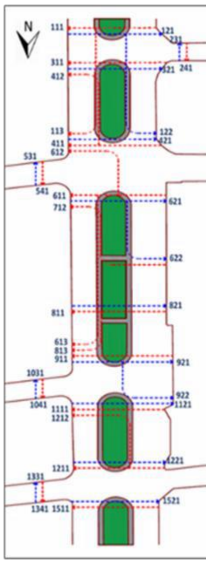
Vehicular and pedestrian capacity was carried out through the filmic record of a drone. Figure 3 shows the vehicular turns, named by codes, with their respective amounts. This was carried out based on the types of vehicles that circulate on this road, which were: linear motorcycles, motorcycle taxis, cars, vans, trucks, interprovincial buses and trailers.



Code	Flow
12	1014
110	24
130	18
3S	1842
210	60
230	84
4S	175
41	36
43	90
1N	1146
131	156
2S	1728
231	156
310	336
330	114
2N	1482
111	390
132	198
1S	1590
232	60
233	228
3N	954
133	192
4N	864
22	1026
331	102
311	372

Figure 3 Graph of vehicular turns of the section studied by code.

In the same way, in figure 4, the pedestrian routes in the study section are shown with the capacity quantities. It should be noted that the pedestrian routes were adjusted based on those with the highest incidence of crossing.



Code	Flow	Code	Flow
111	6	1111	14
113	6	1121	126
121	18	1211	54
122	66	1212	78
231	180	1221	30
241	156	1331	66
311	6	1341	78
321	30	1511	78
411	78	1521	54
412	12		
421	42		
531	72		
541	102		
611	66		
612	12		
613	12		
621	150		
622	24		
712	18		
811	36		
813	12		
821	30		
911	12		
921	246		
922	12		
1031	186		
1041	204		

Figure 4 Pedestrian flows of the section studied.

Data referring to the geometry, signaling and traffic lights of the section studied were also collected. The data that was registered to characterize the vehicular behaviors were the speeds of each mode of transport, the rules of priority of crossing and the speed reduction zones in the different turns. Figure 5 shows the graph of speed vs. accumulated relative frequency for each type of vehicle that circulates in the study area of the Panamericana. Likewise, for pedestrians, average crossing speeds were registered.

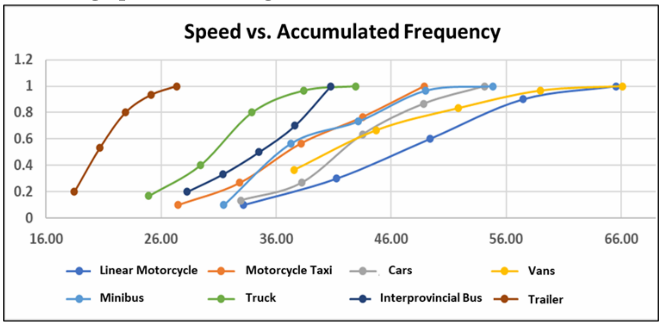


Figure 5 Graph of speed vs. accumulated frequency of the vehicles that travel in the study section.

C. Microscopic modeling of the current situation

After data collection, the modeling of the study section was carried out at a microscopic level in order to obtain the parameters and trajectories necessary for the analysis in the SSAM tool [9]. Multimodal microscopic simulation was performed through the PTV VISSIM 9 software in conjunction with its VISSWALK interface to characterize pedestrian behavior.

The calibration and validation processes aim to verify if the microsimulation model carried out represents the vehicular and pedestrian behaviors observed in the study section. Both processes were carried out based on a simulation with a duration of 4200 seconds according to the recommendations of the Federal Highway Administration (FHWA). Of this total, the first 900 seconds were not taken into account for the record, since they correspond to the stabilization period of the system called warm up. Before making the comparison between the simulated data and those taken in the field, we proceeded to verify if the number of runs of the microscopic model is optimal for the analysis. Therefore, a procedure recommended by the FHWA was carried out to evaluate the minimum number of runs through a T Student distribution. The model was run 18 times and the number of most critical minimum runs was found in the north-south direction (11 total).

The calibration and validation of the microscopic model was carried out through the vehicle travel time efficiency parameter. This analysis was carried out in both directions of the Panamericana Norte avenue for cars and motorcycle taxis. For both calibration and validation, the null hypothesis test of mean difference was used through the Randomization Test tool with an amount of 10,000 permutations. The model will be considered calibrated or validated if the applied mean difference statistical test has a reliability level of 95%. As an example, figure 6 shows the results of the mean difference test for motorcycle taxis in the North-South direction of Av. Panamericana Norte. With a significance of 0.05 and after evaluating the indicated permutations, a mean difference of 0.42 was obtained for this case. The non-rejection range was from -0.791 to 0.863, so, being within, the values evaluated for this type of vehicle in the evaluated area are accepted.

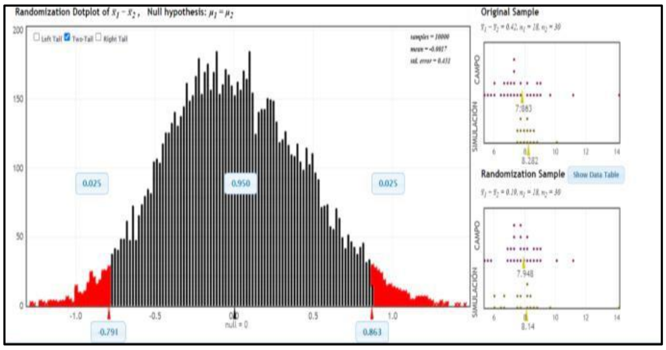


Figure 6 Graphic results of the null hypothesis test by mean difference for motorcycle taxi travel times from South to North of the area studied.

Likewise, the calibration and validation of the microsimulation model was carried out through the travel times of pedestrians as an efficiency parameter. The areas designated for this analysis were the intersections from east to west and west to east (areas where pedestrians cross both directions transversely through the Panamericana Norte).

The results of the mean difference tests applied to calibrate the model are shown in Table I.

Tipo	Sentido	Confianza	Limite inferior	Limite superior	Diferencia de Medias
Mototaxi	Sur a Norte	95%	-1.037	1.112	-0.04
Autos	Sur a Norte	95%	-0.853	0.905	0.49
Mototaxi	Norte a Sur	95%	-0.791	0.863	0.42
Autos	Norte a Sur	95%	-1.092	1.211	0.04
Peatones	Este a Oeste	95%	-4.881	4.931	-0.05
Peatones	Oeste a Este	95%	-4.169	4.275	-1.85

Table I Results of the mean difference tests for model calibration.

In the same way, the results of the mean difference tests applied to validate the model are shown.

Tipo inferior	Sentido	Confianza	Limite superior	Limite de Medias	Diferencia
Mototaxi	Sur a Norte	95%	-0.813	0.842	0.5
Autos	Sur a Norte	95%	-1.159	1.262	-0.007
Mototaxi	Norte a Sur	95%	-1.063	1.067	-0.24
Autos	Norte a Sur	95%	-0.737	0.798	0.14
Peatones	Este a Oeste	95%	-4.933	4.949	0.06
Peatones	Oeste a Este	95%	-4.141	4.315	-0.35

Table II Results of the mean difference tests for model validation.

D. Determination of vehicle-vehicle conflicts

The SSAM tool typifies the conflicts studied based on an approximate hypothetical angle of collision between two conflicting vehicles. This angle is calculated based on the directions and positions determined after the microsimulation [10]. Conflicts by reach or rear-end events will be represented in the threshold of angles in a range of 0° to 30°, lateral or by lane change events from 30° to 85° and by crossing events or frontal from 85° to 180° (Figure 7).

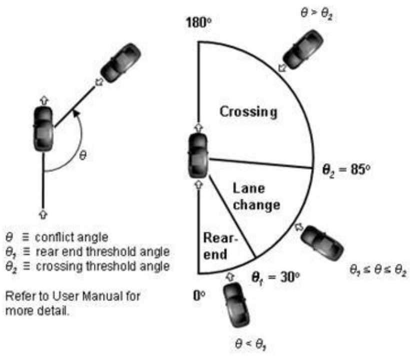


Figure 7 Threshold of angles to identify conflicts in the SSAM software. Adapted from SSAM - User Manual

It is also possible to define and categorize vehicular conflicts through the SSAM tool. This classification defines the severity of the conflicts based on the projected time until the collision occurs (TTC) and the time after the invasion (PET). First of all, the threshold must be defined to determine if a conflict is severe or not. For this, a threshold with values from 0 to 1.5 s for TTC and 0 to 5 s for PET was used, based on the FWHA recommendations for vehicular conflict studies [11]. Second, a subclassification of severe conflicts was defined, based on the risk of collision. This classification is based on ranges defined by the TTC and is as follows:

- Low collision risk (1 s to 1.5 s)
- Moderate collision risk (0.5 s to 1 s)
- High collision risk (0.1 s to 0.5 s)
- Extreme collision risk (0.1 s)

E. Determination of critical zones

The critical zones were determined based on the points of vehicle-vehicle conflict with the highest risk of collision on the section. These were identified at the endpoints of the connectors in U-turns and in zone 2, as shown in figure 7.

Figure 8 Sectorization and location of critical areas

Circles 1, 2 and 3 represent the end zone of the U-turn connectors. Extreme collision risk events were found in these, especially in circle 2. In circle 1, 2 extreme collision risk events were registered; in circle 2, 3 events were found and in circle 3 only 1. Circle 4 corresponds to the final part of the connector that represents the left turns of incoming vehicles from Leandro Pastor street, in this 2 frontal conflicts were found high risk of collision. Zone 2 obtained 63% of the total conflicts and 71% of conflicts of high and extreme risk of collision in the study section.

Next, the different strategies that will be implemented in the study area in order to eliminate vehicular conflicts will be detailed:

1) Implementation of pedestrian crossing

Due to the large number of trajectories that represent the pedestrian crossings in zone 2, it was decided to canalize a single route that crosses half of the study area. This route aims to connect the main door of the Mercado Modelo with the financial area to meet the pedestrian demand. To canalize the pedestrian flow, it was decided to place barriers along the front of the market. In this way, the pedestrian flow will be directed and untimely crossings that were observed during data collection will be avoided.

To avoid the unnecessary interruption of vehicular traffic, it was decided to implement an actuated traffic light system at the pedestrian crossing. This contemplates the use of 6 sensors and two phases, the first applies to vehicles and the second to pedestrians. The condition for the phase change from the first to the second is that sensor 2 detects the presence of waiting pedestrians for more than 35 seconds. The change from the second to the first phase is made when sensors 5 and 6 detect stopped vehicles (when queue length is generated in that area) or when phase 1 has lasted more than 20 seconds. The operation can be seen in figure 9.

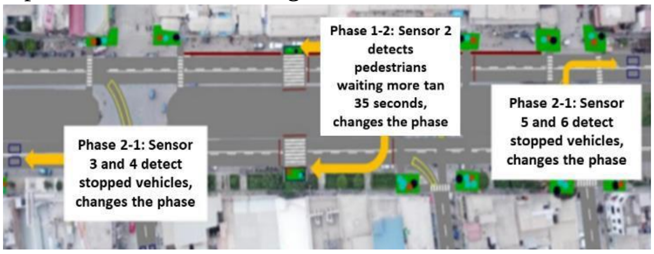


Figure 9 Operation of the programming of the traffic lights actuated at the pedestrian crossing.

2) Elimination of U-turns

Due to the high-risk events produced by U-turns, it was decided to restrict them in the study area. During the processing of the data collected in the field, it was observed that 77% of the vehicles that make U-turns are motorcycle taxis, 12% cars, 9% linear motorcycles and the rest minibuses and vans. Based on this measurement, the U-turn restrictions will prevent smaller vehicles that travel in the right lane, in both directions of Panamericana Avenue, from generating conflicts that interrupt the vehicular flow of the other lanes.

3) Optimization of the Cycle length of existing traffic lights

The intersection of Av. Panamericana Norte with Leandro Pastor has pre-programmed traffic lights. These were integrated into the microsimulation model together with the strategies for the reduction of vehicular conflicts after optimizing their traffic light cycle.

IV. RESULTS

Through the SSAM tool, the possible vehicular conflicts were classified and analyzed based on the trajectories obtained from the microsimulation. This was done for both the current situation and the proposed model. 18 scenarios were evaluated for each of the models. The results shown below correspond to the total average of these simulations.

For the current situation, 5405 conflicts were registered. Of these, 53.3% were low risk, 40.6% moderate risk, 5.2% high risk, and 0.9% extreme risk. The detail is shown in table III. Also, it was determined that the average TTC and PET were 0.90 and 0.95 seconds, respectively.

Type of conflict	Crossing	Rear-End	Lane Change	Total
Low collision risk (1 s a 1.5 s)	18	2546	315	2879
Moderate collision risk (0.5 s a 1 s)	1	1974	221	2196
High collision risk (0.1 s a 0.5 s)	3	236	42	281
Extreme collision risk (0.1 s)	6	34	9	49

Table III Results according to the type and severity of the conflict for the current situation.

For the proposal model, 2,439 conflicts were registered. Of these, 58.1% were low risk, 35.9% moderate risk, 5.8% high risk, and 0.2% extreme risk. The detail is shown in table IV. Also, the average TTC and PET were determined to be 0.98 and 1.01 seconds, respectively.

Type of conflict	Crossing	Rear-End	Lane Change	Total
Low collision risk (1 s a 1.5 s)	6	1264	145	1415
Moderate collision risk (0.5 s a 1 s)	0	784	89	873
High collision risk (0.1 s a 0.5 s)	0	123	19	142
Extreme collision risk (0.1 s)	0	4	1	5

Table IV Results according to the type and severity of the conflict for the proposal model.

According to the collision angle, a total of 6 total conflicts were registered, 2175 rear-end events and 254 lane change events for the proposal model. The comparison between the conflicts registered in the current situation and the proposal model is shown in figure 10.

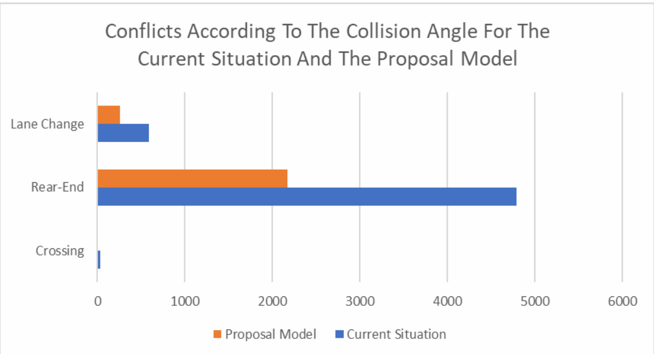


Figure 10 Comparison between the conflicts registered in the current situation and the proposed model, according to the collision angle.

Table V shows the percentage variations of the reduction of events of the proposal model with respect to the current situation of the study section. An 82% reduction in extreme risk conflicts was registered.

Scenario	Low Risk	Moderate Risk	High Risk	Extreme Risk
Current Situation	2879	2196	281	49
Proposal Model	1415	873	142	9
Percentage Variation	**51%**	**60%**	**49%**	**82%**

Table V Percentage variation of conflicts according to the type of risk.

The distribution of these conflicts in the study section can be seen in Figure 11.

Figure 11 Map of the location of conflicts according to the type of risk. The conflict events of the current situation are shown on the left and those of the proposal model on the right.

V. Conlusions

Due to the high incidence of pedestrians crossing Av. Panamericana Norte, it was decided to implement a pedestrian crossing with actuated traffic lights as a strategy to eliminate conflicts. Its purpose is to avoid interruptions in the vehicular flow of Av. Panamericana Norte and thus eliminate conflicts caused by untimely pedestrian crossings. This device works with a sensor that detects pedestrian demand based on waiting time.

Through the microsimulation model, it was possible to validate that the implemented strategies reduced the number of vehicle-vehicle conflicts by 55% in the study section. A reduction of 50.9% in low risk conflicts, 60.2% in moderate risks, 49.5% in high risks and 89.8% in extreme risk conflicts was also observed. With this reduction, it can be concluded that there was an improvement in the safety standards of the section studied.

With the help of the SSAM tool, it was possible to determine the critical collision angle of the different vehicle-vehicle conflicts, thus reducing crossing events conflicts by 78.6%, rear-end events conflicts by 54.6%, and lane change events conflicts by 56.7%. In this way, moderate, high and extreme risk frontal conflicts were completely eliminated. Their reduction was prioritized because they represent the most critical crash projections between vehicles.

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