USAGE AND RESULTS OF MICRO-SIMULATION TO IMPROVE ROAD SAFETY IN LIMA - PERU

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ABSTRACT

1. Objective

This paper presents the results regarding the usage of micro-simulation, employing it as an analysis tool in road safety inspections and adaptability of micro-simulation to driving and pedestrian deployment patterns in Peru.

2. Data/Methodology

For purposes of this study, three intersections with particular characteristics of Lima City have been analyzed during rush hours, one with special geometry, other with a great number of pedestrian and the last one with all turns allowed. On those intersections a field survey using video cameras and measuring all parameters required for model calibration was conducted. Later, models were created to show the observations by using the micro-simulation software Vissim 5.3; and to check the result of other traffic software. Finally, proposals were made by using calibrated and validated micro-simulation models in order to improve traffic management but specially emphasizing road safety for all users.

3. Results/Findings

It was verified in analyzed intersections that certain software showed queue lengths and saturation flows that did not agree with reality, partly due to the risky behavior of drivers and pedestrians making reality hard to be shown even with micro-simulation. Thus, it was necessary to not consider the pedestrian element in calibration of the models in order to calibrate them and to show the real vehicle traffic; nevertheless, it was in the proposals where pedestrians could be added and the traffic and road safety parameters could be improved.

4. Implications for Research/Policy

Case studies in developing countries show a behavior with special characteristics with the risks the people use to take, different to those observed in other realities and which many times are hard to express in micro-simulation models developed in other realities, which is why this work helps to identify those difficulties in order to deepen micro-simulation study and its usage in road safety audits.

Keywords: Road Safety Audits, Road Safety Inspections, Micro-simulation, Developing Countries.

INTRODUCTION

According to The Federal Highway Administration (FHWA) in its "Road Safety Audit Guidelines" (2006) a Road Safety Audit (RSA) is defined as follows: "An RSA is a formal safety performance examination of an existing or future road or intersection by an independent audit team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users." More recently in many countries has been made a difference of concepts between Road Safety Inspections and Road Safety Audit, using the first one for an examination of an existing road, intersection or any transportation infrastructure and the second one for an examination of a project (in their different phases) of a future road, intersection or any transportation infrastructure. Nevertheless, in this article we will use the term Road Safety Audit (RSA) to refer to both types of concepts.

As indicated in the Road Safety Audit Guidelines, developed by the Transportation Group of the University of New Brunswick (1999) "The cornerstone of the RSA process is: preventing a problem is more effective than its cure", and in this sense road safety audits and inspections seek to get ahead of eventual issues and risks that may occur in roads to every type of users; therefore, this research seeks to help improving road safety and take advantage of available tools such as micro-simulation applied to road safety, as an effective means in which it can be verified as infrastructure and traffic changes that may influence not only in the improvement of approaches and traffic from the vehicle perspective, but in road safety including all road users, such as pedestrians, cyclists and drivers.

The methodology applied to this research will be described first. Next, case studies are presented as this study has focused on three intersections in each of which a traffic study has been conducted, and with which micro-simulation models have been developed using the Vissim software. Models were calibrated and validated with field data. Later, proposals were made for the improvement of vehicle traffic and road safety, the new models proposed were compared with models based on real data using at least one efficiency measure.

Then, the new micro-simulation models proposed were compared in order to observe if there were significant improvements for road safety, emphasizing that improvements had an effect on all road users, especially on the most vulnerable, such as pedestrians.

Another objective of the research was to contrast how available tools can be used such as the usage of micro-simulation in road safety audits for which intersections were audited and some solutions were expressed in the proposed improvement models; in addition, it was observed if the software or procedures developed in other realities may be used to reflect the reality of developing countries.

Finally, after the corresponding analysis and the results of the three cases corresponding to the three intersections studied, conclusions and recommendations are presented herein.

METHODOLOGY

Selection of Case Studies

The study focused on three intersections of Lima Metropolitan Area adequate for the usage of micro-simulation given their characteristics; in the first case it is a cross-intersection in which all turns with traffic lights are allowed acting only two phases in this intersection are found two trip attraction centers, in addition there is a residential complex and 200 meters away from the intersection is a public hospital; the second intersection analyzed is located around the National University of Engineering in which intersection crosses the Bus Rapid Transit (BTR) known as Metropolitano and in which surroundings a significant number of pedestrians can be found due to the proximity to the main pedestrian access to the university and the location of one of the Metropolitano stations; and the last intersection studied is one that has special geometric design characteristics as well as two auxiliary lanes and three main lanes per direction, in addition to two BRT lanes for buses in the Túpac Amaru Ave. in this intersection of the National University of Engineering is located the main vehicle access to the university. A characterization of intersections is carried out in each selected case.

Traffic Study

Video recorders located in strategic points were used to collect field data in all the intersections for both vehicle counts and pedestrian counts, in order to obtain a view of all the movements and the vehicle queue lengths were covered all the intersection approaches.

In each case it was first determined the rush hour in which field studies would be conducted in all these cases, which was in the morning. Capacities were taken for two days in the three cases, using data of one day for calibration and data from other day for validation, both of the demand as well as of the efficiency parameter to be used in micro-simulation. The efficiency parameter considered was the average in meters of the vehicle queue length in each of the approaches every 15 seconds during rush hour.

For the counting, vehicles were classified according to the type of vehicles that cross the analyzed intersection, that classification was the same used in the preparation of its respective traffic model in micro-simulation; in the case of the Metropolitano buses (BRT) it was observed the need of using micro-simulation with the VISSIM software, as it allows to simulate the bus system with exclusive corridors. Compiling and measuring of operational aspects data of the Metropolitano bus corridor (frequencies, routes, occupancy, stopping times to leave and board passengers) were also performed; also, the measuring of speeds in each approach of the analyzed avenues was performed using speed limit radars per type of vehicles.

Collection of additional data was also performed, of cars parking next to the approaches; the time that buses, vans (public transportation) and taxis block approaches; the number of pedestrians circulating by all intersections up to a distance of 70 meters from the intersection was also counted.

Likewise, an inventory of existing pavement markings and vertical traffic sign was prepared, as well as traffic light implementation in the intersection. The duration of the traffic lights cycles were also observed.

Similarly, saturation flow rates were calculated, in some cases, using the Highway Capacity Manual (HCM 2000) formulae and when a deeper analysis was required a field saturation flow measurement was made using the methodology proposed in Appendix H of Chapter 16 of the HCM 2000: "Direct measurement of Prevailing Saturation Flow Rates", according to TBR (2000).

Information Processing and Creation of Traffic Micro-simulation Models in Vissim to Reflect Reality.

In order to create micro-simulation models from data obtained in traffic studies, the Micro-simulation software: Vissim 5.3 has been used for the advantages shown in conditions observed in the field and in those previously described.

With appraised data of the quantity of vehicles according to the type of vehicle in each approach, as per the type of movement in intersections and its routes, micro-simulation models were created in which also pedestrian data and their routes in the intersection were created. Histograms were used for each type of vehicle resulting from measuring the speed in free flow hours as desired speeds within the micro-simulation model.

The traffic light cycle times, their vehicle and pedestrian phases were used in the calibration and validation of the model including the offset presented between intersection 2 and intersection 3, as only one network was created for both cases.

For the adaptation of the public transport system, data obtained from frequencies for each bus route of the Metropolitano Bus Corridor were used, as well as histograms of stopping times of buses at each bus stop as per station and route. Also, an average quantity of the number of passengers in buses was used for each route, according to field observations.

Several models were developed until reaching the demand calibration (number of vehicles crossing each approach of the intersection according to the type of vehicle) and the calibration of the efficiency measurement for which vehicle queue lengths measured in meters was used.

Calibration and Validation of Micro-simulation Models.

The procedure employed in the model calibration, both of demand and of efficiency measure was made using data of one of the appraised days, while the other appraised day was used for model validation. These procedures follow the methodology employed by Cabrera (2011).

Demand Calibration

For demand calibration, counters were used in the Vissim Model located in each lane in all approaches of intersections in studied avenues. Counters grouped the sum of all lanes of each approach, it was verified that the total sum of vehicles was the same, statistically, that the one observed in the field.

Several seed numbers were used for calibration, each one followed this process:

1. Data of field counts and results obtained for each seed number in each of the approaches of the VISSIM model were compared.

2. Statistic calibration used the GEH statistics to compare if field data were statistically equal to those of the Vissim Model.

   $GEH=\sqrt{[(E-V)^2/((E+V)/2)]}$ Where: E= Quantity of Vehicles Estimated by Vissim
   V= Vehicles Measured in Field

3. It was verified that the GEH for the sum of flows of all approaches is less than 4 and that the “Sum of All Flows is Less than 5%”, in which case the results of the assessed seed number were accepted.

4. This procedure was performed for all assessed seed numbers and its fulfillment with all cases was verified.

5. Next, from the results of each run for all seed numbers it was verified that the sample was enough to provide statistic value for which the t-student curve was used; when the number of runs was not acceptable, more runs were made until having a significant defined error in quantity of vehicles and an established alpha (0,05).

6. Finally, it was verified that the GEH is less than 4 for 85% runs.

Calibration of Efficiency Measure

For the calibration of an efficiency measure, the vehicle queue length was calibrated measure in meters, and there were used queue counters located in the intersection approaches of the network.

For the queue length calibration several seed numbers were used, each one followed this process:

1. Queue lengths were measured every 15 seconds in the micro-simulation model which were compared with field data.

2. From samples, both of field and of model, the mean, standard deviation and sample quantity were obtained for each calibrated queue.

3. In order to verify the calibration of queues, an average of the micro-simulation model runs of current situation was assessed against the field data, checking if they had equal queue length averages, for which the mean equality test was used considering the normal curve, since almost 240 data samples were obtained in field (queue assessment every 15 seconds). The statistics employed were:

$$Test\ Statistics = \frac{(\bar{x}_1 - \bar{x}_{2)}}{\sqrt{\left(\frac{sn_1}{n_1}\right) + \left(\frac{sn_2}{n_2}\right)}}$$

4. For the statistic assessment the following null or alternative hypothesis are used, respectively:

   Ho = Queue length averages are equal

   Ha = Queue length averages are not equal

5. With the main data used in the queue length calibration statistical test, the standard deviation, variance, statistical result, alpha used, "z", rejection zone were obtained, it is finally accepted when queue length averages are the same. This is performed for each queue assessed in each model run corresponding to each seed number.

6. Later, from all the results of each run (each one corresponding to its seed number) it was verified if this sample was enough to provide statistical validity regarding field data, for which a t-student curve was used, when the number of runs was not acceptable, more runs were made until the number of runs were valid with a defined error in meters and an established alpha (0,05).

7. Finally, it was statistically verified if the sample of the queue length averages of all runs against field data are the same for each of the analyzed approaches. Results were used until they were statistically equal with which the efficiency measure was calibrated.

Validation of the Current Situation Model.

In the model Validation the same procedures described in calibration were used both for the demand validation and for the efficiency measure validation (queue length), using the same current situation model but taking the data appraised in a day different from those used in validation.

Creation of Micro-simulation Models with Proposals to Improve Road Safety.

Once the micro-simulation models of current conditions were calibrated and validated, they served as a basis to create new models where improvement proposals were presented, mainly from the road safety view (thinking of all road users), as well as traffic improvements, in some cases different models were compared and in some cases only a comparison improvement regarding the previous model was added and improvements that would contribute to the intersection considering a balance between road safety and vehicle efficiency. Finally, the model of the final proposal was compared (which included the presentation of all proposed improvements) against the initial situation model. Results and special details are exhibited in each of the case studies.

Analysis and Results of Case Studies.

It is in case studies, of the three cases corresponding to the three intersections studied, where each finding and result of assessments conducted with micro-simulation models are presented; difficulties encountered in its adaptability in developing countries as Peru are discussed, as well as the peculiarity of each case.

Finally, conclusions and recommendations of this study were prepared based on the results of the micro-simulation application to road safety audits.

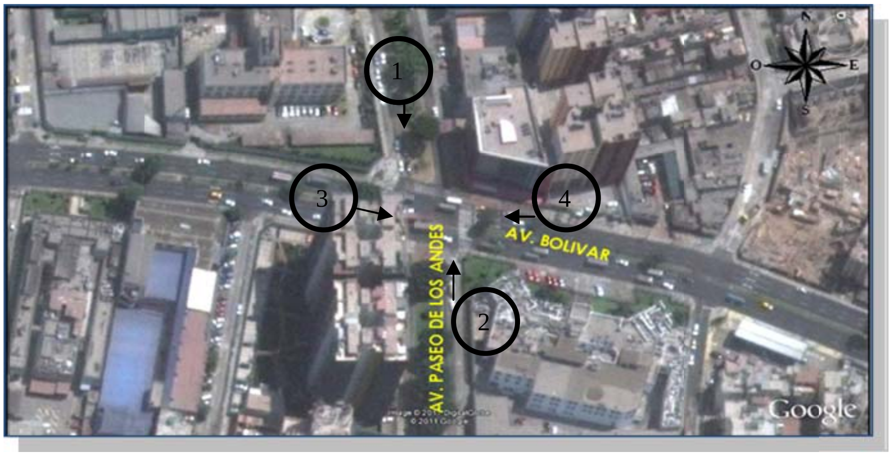
CASE STUDIES

The analysis of each intersection studied in the city of Lima will be analyzed next. A characterization of each intersection describing the location, surroundings and peculiarities will be made. Next, the analyses conducted will be exhibited as well as the results of the traffic study necessary for micro-simulation. Micro-simulation models and their comparison with current situation will be also discussed. Later, proposals are described taking into account road safety audits.

Intersection 1: Bolívar Ave. with Paso de los Andes Ave. (Pueblo Libre District)

Characterization of the Intersection

It is a cross intersection where two trip attraction centers are located: a 5-floor building where a language institute is located and the Stella Maris Clinic; also there is a residential building complex of 17 floors, in addition the intersection is about 200 meters near another trip attraction center, Santa Rosa Public Hospital. Figure N° 1 shows a satellite image of the intersection with circled numbers corresponding to denominations considered in the traffic study for approaches of the intersections used to prepare models.



Source: Google Earth
Figure N° 1 – Satellite image of Bolívar Ave. with Paso de los Andes Ave. intersection

The main avenue (Bolívar Ave.) has three lanes per direction with a 2 meters median, while the secondary road (Paso de los Andes Ave.) has two lanes per direction and a median of 7.70 meters on the side of the Clinic and of 10.70 meters on the side of the residential.

The main problem observed was that all right and left turns were allowed in the intersection; the intersection did not have any channeling in the center and it was observed that cars turning left could made up to 4 waiting lanes in the center of the intersection usually generating traffic congestions since traffic lights only worked in two phases and there were no protected phases. The 4 lanes formed in the center of the intersection were the most difficult when simulating the traffic micro-simulation model, as well as the order of priorities of crossing the center of the intersection.

In addition, the pedestrian number increases especially in the starting hours and end of schedules of the language institute lessons since at certain times all students enter and the students from previous lessons leave the building, since there are no protected phases, the pedestrian-vehicle conflict increases.

In addition, it was observed that many pedestrians do not use the crosswalk and they do it by the middle of the road reaching 11% of total pedestrians crossing the intersection. It was also observed that 16% of pedestrians crossed during red light. This improper movement of pedestrians impeded to calibrate the model that included them, which is why it was not considered in the current situation model, since calibration was already complicated, considering what occurred with vehicles in the intersection, due to the type of movements and maneuvers performed by drivers.

Other issue was the drivers' lack of respect for signposting, even during rush hour it was observed vehicles U-turning; over 4 vehicles per approach and in a number quite higher as where there was a "No U-turn" sign in approach coming from north which was of 8 vehicles.

Analysis and Results of Traffic Study

The saturation flow rates and degree of saturation were calculated in several ways: using HCM formulae, Synchro software and field measurements, four types of calculation are analyzed next, we shall call these "cases", in which different criteria were used.

1. Case 1: Saturation Flow Calculation without considering pedestrians in HCM formulae as if there were protected left turns; Table 1 shows calculations related to saturation flow.

Table 1 – Calculation of Saturation Flow and Degree of Saturation (Protected Left Turns).

Saturation Flow Base Rate per Lane			Sb = 1900		
		Approach 1	Approach 2	Approach 3	Approach 4
Demand (q)	veh/h/group	898	930	1144	1312
Saturation Flow	S =	2797	3350	3440	3407
Capacity (Q)	Q= S x veh/C	1293	1549	1461	1446
Degree of saturation	X=q/Q	0,69	0,60	0,78	0,91

2. Case 2: Saturation Flow Calculation without considering pedestrians in Synchro for protected left turns and permitted left turns;

   Table 2 shows the saturation flow of approaches obtained from Synchro 8 for the protected case and the HCM 2000, both without considering the pedestrian factor, in which little difference is observed.

Table 2 – Saturation flow calculations HCM vs. Synchro (Protected Left Turns).

	Approach 1	Approach 2	Approach 3	Approach 4
HCM 2000 Formulae	2797	3350	3440	3407
Synchro 8	2790	3366	3436	3386
Difference	7	-16	4	21

From the saturation flow obtained with the permitted left turn *Saturated Flow Rate* calculated by Synchro, it is obtained the degrees of saturation shown in Table 3, where it is observed that the capacity is strongly reduced when considering the left turn procedure, and which does not correspond to the reality observed, since in most approaches, queues cleared in the green, and no degrees of saturation over 0.85 existed. Also, it must be considered that pedestrians have not been included according to calculation methodology.

Table 3 – Degree of Saturation with Synchro considering permitted left turn phase.

Saturation Flow Base Rate per Lane			Sb = 1900		
		Approach 1	Approach 2	Approach 3	Approach 4
Saturation Flow Synchro *(perm)*	S =	1498	2070	2261	2244
Capacity (Q)	Q= S x veh/C	692	957	960	953
Degree of saturation	X=q/Q	1,30	0,97	1,19	1,38

If the permitted left turn was considered as a factor, as suggested by HCM, the degrees of saturation would be all saturated as shown in Table 3; for instance, for Approach 1 (Paso de los Andes Ave. N-S) goes from 0.69 to 1.3, which does not match reality. Therefore, as there are no protected left turns in the analyzed intersection, somehow the type of driving and total red (4 seconds) helps freeing the intersection in pending turns, so in this case the HCM procedure or the one used by Synchro that considers left turn factor does not match the reality observed.

3. Case 3: Saturation flow calculation considering the pedestrian circulation factor using Synchro with protected left turn.

   In Table 4 it is verified that when considering the pedestrian interaction, the degrees of saturation regarding Case 1 vary increasing in 4%; 3%; 4% y 2% for Approaches 1; 2; 3 and 4, respectively.

Table 4 – Calculation of Saturation Flow and Degree of Saturation with Synchro considering pedestrians

Saturation Flow Base Rate per Lane			Sb = 1900		
		Approach 1	Approach 2	Approach 3	Approach 4
Demand (q)	veh/h/group	898	930	1144	1312
Saturation Flow	S =	2657	3186	3284	3311
Capacity (Q)	Q= S x veh/C	1228	1473	1394	1406
Degree of saturation	X=q/Q	0,73	0,63	0,82	0,93

An important point to highlight is that when the simulation was ran in Synchro, it did not show similar behaviors to those observed in reality; for instance, vehicles do not stop in the middle of the intersection trying to turn. Even though these data are closer to reality it is not true that they are protected left turns. That is, if we consider what the HCM methodology proposes or do the same in the Synchro, high saturated degrees would be obtained and that do not occur in real situations.

4. Case 4: Saturation flow calculation considering the pedestrians circulation factor calculated in Synchro, protected left turn and lane factor equals to 1.

   Case 4 tried to gather all considerations of the field observations and considering the reality of traffic for a city like Lima for which factors considered as more appropriate for the saturation flow calculation were used, excepting that it is not a permitted turn but it was calculated as a protected one.

   As Saturation Flow Base Rate 2000 passenger cars per hour line (pc/h-ln) was used, since as studies performed by Gibson, *et al.* (1997) show pc/h-ln values in morning rush hour, according to the type of lane: right, central or left, have been estimated in 2055, 2292 and 2121 pc/h-ln; in addition, Fernández (2011) states that currently a Saturation Base Rate of up to 2000 pc/h-ln has been found.

Table 5 –Calculation of Saturation Flow and Degree of Saturation (Case 4).

Saturation Flow Base Rate per Lane			Sb = 2000		
		Approach 1	Approach 2	Approach 3	Approach 4
Saturation Flow	S =	2870	3287	3596	3638
Capacity (Q)	Q= S x veh/C	1327	1520	1526	1545
Degree of saturation	X=q/Q	0,68	0,61	0,75	0,85

In Table 5 contain the result of this case. The suppositions performed in Case 4 may be the ones that adjust better to field observations, since that all degrees of saturation are below 0.85; from which it is concluded that HCM and Synchro procedures do not adapt to reality since in order to obtain these values it was considered as if there were protected turns when they are actually not (in case 2 it was considered as permitted but values overcome reality). The fact that HCM and Synchro do not agree with reality, especially in an intersection like this, may be due to the type of driving in Peru, which is more aggressive that in other places, to the lack of respect for traffic rules and to a significant number of pedestrians who do the same and cross the street when lights are red or do it out of the pedestrian zone.

Traffic Micro-simulation Model

Pedestrian flows have been loaded in the micro-simulation model; however, their interaction with vehicles has not been considered, not even the difference if they crossed with red or green lights, or if they crossed out of the intersection. Pedestrians' representation is more visual than real at least for models of current situation, as it was verified that considering pedestrians with the behavior observed in the city of Lima would make difficult to calibrate the vehicle aspect. Nevertheless, for models proposed the interaction with pedestrians has been considered since measures proposed tend to correct bad habits (ex. Placement of pedestrian guardrails preventing people from crossing any place and out of the crosswalk, etc.).

In the real situation model the following Vissim parameters were used for calibration and model validation: “Average standstill distance” = 1.00m; “Additive part of safety distance” = 1.00m; y “Multiplic, part of safety distance” = 1.00m. In Table 6 queue lengths measured in field versus the averages obtained in different runs (each model run corresponds to a different seed number) are shown.

Table 6 – Field queue length and Current Situation Models

	Approach 1	Approach 2	Approach 3	Approach 4
Field Data for Calibration	22,4	19,3	15,6	27,6
Model with Calibration Data	21,8	15,7	19,6	27,8
Field Data for Validation	20,7	19,3	15,1	28,5
Model with Validation Data	21,3	16,0	19,7	25,3

Table 7 shows how the Proposed Models have longer queues but the benefits including the pedestrian security and the reduction of vehicle´s conflicts are more valuable. Likewise, when comparing the Average Delay Time per Vehicle of the Current Situation Model with the Model 1.2, which is 29.8 against 41.7 seconds of the Proposed Model 1.2; it has obtained an increase of 11.9 s in the average delay time but it was observe that queues cleared in the green, so it is prefer in this case to low the standard of traffic circulation in order to improve road safety.

Table 7 – Field queue length and Micro-simulation Models

	Approach 1	Approach 2	Approach 3	Approach 4
Field Data	22,4	19,3	15,6	27,6
Current Situation Model	21,8	15,7	19,6	27,8
Proposed Model 1.1 (Four phases)	42,5	42,3	50,0	50,4
Proposed Model 1.2 (Three phases)	37,1	44,1	34,4	44,2

In this case it is demonstrated that modeling and road safety audits can contribute to improve the system as a whole. Details included in the proposed model are discussed next in the Road Safety Proposals.

Road Safety Audit Proposals

Among the main proposals in the intersection were, generating protected phases for all approaches for the Model 1.1 and three phases for the Model 1.2 (with protected phases for approaches 1 and 2), in Model 1.2 left turns was prohibit for the approaches 3 and 4, partly because there is a possibility to do a U-turn no more than 100 meter out of the intersection over the approaches 1 and 2.

In both models the cycle length was increased to 120 s and it was suggest placing traffic lights for pedestrians and pedestrian guardrails to prevent pedestrians from crossing out of the crosswalk. In addition, it was proposed to implement vertical signs of No U-Turn in all approaches and no left turn sing for Model 1.2 that was preferred between both proposed models.

Model 1.2 was preferred to Model 1.1 because Model 1.1 has greater queues and more average delay time per vehicle reaching 58.2 s which almost double the actual situation.

Finally, it could be verified in the proposed model that these simple interventions would help to improve road safety despite of a lower vehicle traffic flow but in this case the degree of saturation was no the important issue.

Intersection 2: Túpac Amaru Ave. with Eduardo Habich Ave. (Rímac and San Martín de Porres Districts)

Characterization of Intersection

Intersection 2 and Intersection 3 were micro-simulated in one single model as part of one section of Túpac Amaru Ave. in the area surrounding the National University of Engineering (UNI), an important trip attraction center. Regarding the surrounding activities there is an important traffic generation point which is the National University of Engineering and recently there is the influence of the Metropolitano bus stations. Additionally, in front of the university there is a commercial surrounding that seeks to satisfy certain university student demands such as IT institutes, photocopy stands, bookstores, etc.; over Habich Ave. there is a commercial environment, also, there is a church and in the back street there is a school and three kindergartens.

Intersection of Túpac Amaru Ave. and Habich Ave., has 3 approaches (north, south and west) is a classic "T" intersection (See Figure N°2). Numbering of approaches for this traffic study is the one observed in Figure N° 3, Approach 1 has been denominated North Approach which actually would be the northeast approach (the same occurred with other approaches), therefore, Approach 2 corresponds to South Approach (or Northbound Approach) while Approach 4 to West Approach (or Eastbound Approach); in addition, the Metropolitano bus exclusive corridor lanes were denominated Approaches 1B and 2B. Intersection has traffic lights, 10 vehicle traffic lights and 8 pedestrian traffic lights, all of them acting in two phases. For north and south approaches the left turn is forbidden. Out of the intersection there is practically no chance of pedestrian crossing due to the pedestrian guardrails separating mixed vehicle lanes and Metropolitan buses.

The issue detected in the intersection was the vehicle queue length of the north approach (Approach 1) that may reach during the morning rush hour without police intervention to more than 500 meters, while the other approaches had queue lengths shorter than 30 m, that is queue lengths totally asymmetrical due to a poor distribution of phases time during rush hour; in addition a high pedestrian flow was observed with several pedestrian-vehicle conflicts, especially for pedestrians crossing between the south median (where the Metropolitan is located) and the west side of Túpac Amaru Ave., where it is very difficult to cross due to the high flow of vehicles coming from Habich Ave. and turn right when pedestrians have green light, which exposes them to such risks as those observed in recordings.

The great pedestrian flow in both intersections of the Túpac Amaru Ave. with Habich Ave. and Túpac Amaru Ave. with Honorio Delgado Ave. (approximately 3500 and 2300 pedestrians, respectively); the special geometry of intersection with Honorio Delgado Ave. (see Figure N° 4); geometry of the same Túpac Amaru Ave. which by the side of the north approach has 5 lanes (3 in the main road and 2 in the auxiliary one) and turns into a single 4-lane road and later is reduced to 3 lanes before reaching the intersection with Habich Ave., and by the side of the south approach starts with 4 lanes after the previous intersection to

Habich Ave. and turns into 3 lanes before crossing the intersection with Habich to later have 5 lanes (3 main road and 2 auxiliary ones) when reaching the Honorio Delgado Ave. All these configuration changes in the Túpac Amaru Ave. in less than 700 m, which also show two exclusive lanes per direction in the median of the avenue corresponding to the Metropolitan bus exclusive corridor; make suitable the studied section for micro-simulation usage.

Source: Google Earth
Figure N° 2 – Satellite image of Túpac Amaru Ave. with Eduardo Habich Ave. intersection

Figure N° 3 Picture of Túpac Amaru Ave. with Eduardo Habich Ave. intersection

Analysis and Results of the Traffic Study

In the approach analysis it was observed that the single approach showing traffic jams issues with large queue lengths is the north approach or Approach 1 (corresponding to the mixed vehicle flow), for which the saturation flow was measured in the field using the methodology proposed in Appendix H of Chapter 16 of the Highway Capacity Manual 2000 (TRB, 2000).

Table 8 – Result of the Saturation Flow Measurement in Approach 1 or North Approach (North-South Direction) of Túpac Amaru Ave. in the intersection with Habich Ave.

	LANE 1	LANE 2	LANE 3	LANE AVERAGE	APPROACH 1
[s/veh]	4.27	2.00	1.70	**2.66**	**7.98**
Saturation Flow	864	1867	2132	**1621**	**4863**

The field saturation flow results showed as observed in Table 8 that lane 1 (right lane) of the North Approach has a very low saturation flow of 864 vehicle per hour per lane (vphpl) compared with lanes 2 and 3. Lane 3 (left lane) processes a higher number of vehicles, followed by lane 2 (central lane) due to a higher number or right turns and heavy vehicles, as observed in Table 9. Lane 1 (right lane) has three times the number of vehicles turning right and twice heavy vehicles than lane 2, which should reduce in something more the capacity of lane 1; however, actually, this lane only processes 864 veh/h which is too low, the reason for this can be observed in Table 10 where blocking times in each lane appear.

Table 9 – Heavy Vehicles and Turns in the North Approach (Approach 1)

	LANE 1	LANE 2	LANE 3
Heavy Vehicles	69	32	17
Right Turn	76	22	1
Left Turn	0	0	0

Table 10: Blockages in North Approach (Approach 1)

	LANE 1		LANE 2		LANE 3	
Blockages	**Total [s]**	**Average [s]**	**Total [s]**	**Average [s]**	**Total [s]**	**Average [s]**
B=Bus	87	5.8	0	0	0	0
C=Van	65	4.3	0	0	0	0
T=Taxi	117	7.8	0	0	0	0
A=Car	26	1.7	0	0	0	0
P=Pedestrians	5	0.3	0	0	0	0
Total	**300**	**20**	**0**	**0**	**0**	**0**

In Table 10 it is observed that there are no blockage in lanes 2 (central lane) and 3 (left lane) but Lane 1 (right lane) has a total lost time of 300 seconds in the 15 analyzed cycles and an average loss time by blockings of 20 seconds per cycle which reduces significantly the capacity of this lane. It is observed that taxis are those blocking the intersection for more time, followed by buses, vans, cars and one pedestrian which is a newsboy interfering sometimes with traffic. The insightful point of the study was that the blocking time of taxis was higher than the blocking time of buses, due to the fact that there are no taximeters in Lima and to the negotiation process of the taxi service cost between the passenger and the taxi driver before taking the service.

According to the results, it was recommended to forbid the bus and vans stops, especially taxi stops in the north approach of up to 150 meters before the intersection in the north approach. This proposal is sustained by the fact that bus stops can be implemented after the intersection, on Habich Ave. (that does not receive any other flow than the right turn from Túpac Amaru Ave.); and on downstream Túpac Amaru Ave. (since after the intersection it increases to 3 to 4 lanes, that is reason why the right lane here may serve for bus stops).

Traffic Micro-simulation Models

It is necessary to remember that a single model was created for the intersection 2 and 3, separated almost 600 meters one from the other due to the relation between them. Next, a comparison is made between the micro-simulation model in Vissim reflecting the current situation (calibrated and validated model) named Current Model and the models with certain specific improvements of which the following should be mentioned:

1. Model 6.7: In which, unlike the Current Model, in the Habich Ave. it would be established that left lane (N°3) is left-turn only, the central one for two turns and right one (N°1) right-turn only remembering that in the current situation vehicles turn both right and left in the three lanes.
2. Model 6.8: This model, unlike the Current Model, establishes that in the Habich Ave., the left lane (N°3) turns may be both right and left, meanwhile, right and central lanes would only be used to turn right.
3. Model 6.9: Unlike the Current Model, in this model the Habich Ave. would simply close in the median allowing vehicle access (located 40 meters before the intersection) since every type of movements even U-turns occur in both sides of this part over Habich Ave.
4. Model 7.4: In this model it was forbidden that vehicles stopped in Túpac Amaru Ave. until 150 m before the intersection, measure guaranteed with the placement of pedestrian guardrails, also the bus stop was replaced after the intersection; the crosswalk of the south access was also relocated 7 meters south, a guardrails was placed to prevent pedestrians crossing outside crosswalks. Additionally, there is a phase for the pedestrian crossing the crosswalk of the south access between the Metropolitano and Habich Ave.; a lane was reduced in the Túpac Amaru Ave. after the intersection to the end of the crosswalk; also, it was decided that the crosswalk in Habich Ave. is made in two phases Similarly, Túpac Amaru Ave. obtained 5 seconds more of green light while the Habich Ave. 5 seconds less.
5. Model 7.5: Same as in Model 7.4 applying the same phase types than the Current Situation in Túpac Amaru Ave. and 5 seconds less in Habich Ave.
6. Model 7.6: Same as in Model 7.4, only that 2 more seconds of green light were given to the Túpac Amaru Ave. and 2 seconds less to Habich Ave., instead of the 5 seconds mentioned in Model 7.4.

In order to compare these models, the average delay time parameter per vehicle was used in a simulated network. Table 10 shows the seconds of the average delay time per vehicle in each model generated to assess proposals made.

Table 11: Average Delay Time per Vehicle in each Micro-simulation Model.

	CURRENT SITUATION	PROPOSALS					
Model:	Current Model	6.7	6.8	6.9	7.4	7.5	7.6
Average (s):	119.28	112.86	106.25	100.17	68.37	76.85	69.74

From all the micro-simulation models presented in Table 10, those with a shorter average delay time per vehicle are the ones having all the improvements included in the model, such as 7.4; 7.5 and 7.6. However, in spite of Model 7.4 having a shorter time equivalent to 68.37 seconds, the difference with Proposed Model 7.6 is one more second, but queues in the Habich Ave. would increase in more than 46 meters to their current situation, as seen in Table 11. Therefore, in order to prevent the deterioration in this queue and especially to protect pedestrians in their protected phase in the crosswalks widening and displaced, it was preferred Model 7.6 which also considers exclusive green light of pedestrians in the issue crosswalk, so the vehicles coming from Habich Ave. turning left on Túpac Amaru Ave. have to wait when pedestrians cross the crosswalk of the south approach in the section between the bus station and the side of Habich Ave. on Túpac Amaru Ave.

Table 12: Queue Length of Field Data vs. Queue Length of the Micro-simulation Models.

	Approach 1	Approach 2	Approach 4
Field Data	356.2	30.6	38.9
Model 6.8 (VISSIM 5.3)	367.4	30.0	26.5
Model 7.4 (VISSIM 5.3)	30.4	28.0	65.2
Model 7.5 (VISSIM 5.3)	153.6	31.6	35.2
Model 7.6 (VISSIM 5.3)	76.7	29.9	42.5

Road Safety Audit Proposals

Several proposals have been made regarding road safety audit, among them are the following. It has been recommended to add vertical signs to regulate traffic, give maintenance to the signs, as well as pavement markings, in some cases it was recommended to add or modify demarcation (like recommended by micro-simulation result). It was also suggested to remove or relocate several types of posts interfering with footpaths or that represent an increase in the risk of road users, as well as to improve the anchoring of traffic light posts so they do not represent a risk for pedestrians.

Mobility of all road users has been considered, which is why some proposals are integrated to improve traffic management, widening of sidewalks, relocation of street vendors, design of bus stops, implementation of pedestrian refuges, and the proposal of continuing the cycle track of Habich Ave. to the National University of Engineering, there are also proposals that should be implemented by the university in order to improve their pedestrian and vehicle accesses.

The need of enforcement was pointed out, both from the Peruvian National Police Force in order to enforce traffic regulations, as well as from municipal authorities to control sales vendors, tuk-tuks circulation and the urban transport service. In addition, people should become aware, especially the university students regarding respect for traffic regulations.

The remodeling in the intersection of Túpac Amaru Ave. and Eduardo Habich Ave. has been proposed, which includes: implementing a crosswalk and traffic lights on the left side of the cycle track in the North approach, move back the stop lines for vehicles coming in from north to south and give space to the crosswalk and cycle track; move the current south crosswalk to south and widen the crosswalk for having a flow higher than 1900 pedestrians/hour;

It has been also proposed to widen the west sidewalk of the Túpac Amaru Ave. after the cross with Habich Ave. taking the whole right lane for some meters, since as observed in the field, this lane is invaded by pedestrians that try to have some space to cross when traffic lights change, which is also little used by vehicles, it will provide more safety to the pedestrian when crossing, as it reduces the distance and therefore the crossing time, also, regarding the vehicle flow it will not have a significant impact since there are only 3 lanes before the cross for both Túpac Amaru Ave. and in Eduardo Habich Ave.; in this way, the uniformity of lanes in the intersection will be maintained; after some meters it is proposed to return to 4 lanes and take advantage of their starting points to be used as bus stops. With these improvements in the micro-simulation model it was observed a more organized and much safer cross without vehicle conflict.

40 meters from the intersection in Eduardo Habich Ave. it was recommended to close the median cross in front of La Rosa Street, suggested to reduce traffic conflicts in the area, in addition to move on U-turns made here through other route, to which an additional traffic light was added when returning to Habich Ave. Also, it is propose to give more green light time to the Túpac Amaru Ave. as modeled.

A two-phased cross was proposed for the crosswalk in Habich Ave., eliminating the conflict of vehicles coming from the north approach and turning right to the Habich Ave. with pedestrians crossing. These results and proposals were also micro-simulated helping in the reduction of queues in the North Approach (Approach 1) and to eliminate pedestrian conflict in the cross of the Habich Ave. intersection. All this proposals contribute to improve road safety for all the users which is the goal of RSA.

Intersection 3: Túpac Amaru Ave. with Honorio Delgado Ave. (Rímac and San Martín de Porres districts)

Characterization of the Intersection

The intersection of Túpac Amaru Ave. and Honorio Delgado Ave. has 4 approaches matching cardinal points. Denomination of each approach can be observed in the circles of Figure N° 4. Túpac Amaru Ave. is a 3-lane road in each direction in the main roads, 2 lanes per direction in auxiliary roads and in addition it has a Metropolitano bus corridor of 2 lanes per direction in the median. On the north approach there is a median where the

Metropolitano station is located (5 meters wide). On the south there is a median starting with a separation of 0,6m and widens progressively up to 4,3 m in the pedestrian platform in part of the intersection. There is a guardrail between the mixed vehicle lanes and those of the Metropolitano on both sides of the avenue.

Honorio Delgado Ave. is a 3-lane road per direction with a median of 6 meters wide; on this avenue is found Approach 4 in west-east direction, as observed in Figure N° 4. Approach 3 is in front of this avenue, which is the approach outside the UNI in the east-west direction with two lanes per direction; this approach comes from the vehicle access of the university. The whole intersection has traffic lights, 20 traffic lights for vehicles and 19 for pedestrians.

It was observed that this intersection corresponding to the cross of Túpac Amaru Ave. with Honorio Delgado Ave. had an important impact on the previously described intersection of Túpac Amaru Ave. with Eduardo Habich Ave., since there is an important volume of vehicles, especially public transportation, turning back, they come through the Túpac Amaru Ave. that first go in south-north direction and in the intersection go out through Approach 2A (auxiliary approach), then turn left through Approach 3 and enter later through right after Approach 1 in north-south direction, the number of vehicles following this route equals 42% of vehicles coming south-north direction (over 600 vehicles in the hour studied).

Source: Google Earth
Figure N° 4 – Satellite Image of Túpac Amaru Ave. with Honorio Delgado Ave. intersection

Source: Google Earth
Figure N° 5 – Picture of the Túpac Amaru Ave. with Honorio Delgado Ave. intersection

Among the main issues identified there are those vehicles coming from Approach 2A and turn left through Approach 3 that do not respect red light, and the observations during real situations is that there is an implicit priority type, in which if there are vehicles coming from Approach 4, those going out of Approach 2A that are going to turn respect the red light otherwise not; if the red light was respected as micro-simulated on the current model a long queue generates in Approach 2A; making difficult for pedestrians to cross so they seek any opportunity to cross by any possible place.

Other issue is the optimization of traffic lights (times and phases), they only work in two phases in spite of existing an important left turn of Approach 3 to the already described continuation of the Approach 1. There are no bus stops or infrastructure for mixed buses stopping to leave and board passengers in the main carriageways.

Analysis and Results of Traffic Study

The traffic study did not show significant traffic-related issues, not in the queue length, or traffic jams, with the exception on those related with road safety which occur in vehicle-vehicle or vehicle-pedestrian conflicts, as well as the non-compliance with traffic rules and inadequate crosswalks.

Intersection does not show either issues with saturated flows or the degrees of saturation. What is notorious is the great number of buses, coasters and vans of public transportation turning left from Approach 3 to Túpac Amarú Ave. in north-south direction, and that these public transport vehicles represent 78% of vehicles turning left.

Traffic Micro-simulation Model

Intersection 2 model was used for this intersection too. It was observed that if vehicles actually respected red light and stopped in the stop line of Approach 2A in Túpac Amaru Ave. and did not cross Approach 3 longer queues would be generated, affecting the entrance to this auxiliary road, the micro-simulation results were queues of up to 200 meters, which made the model respecting the red lights to not correspond the current situation, since when vehicles are stopped the turn through Approach 3 in north-south direction of Túpac Amaru Ave., also reduced the flow of vehicles crossing the intersection with Habich Ave.; for which the previously described model in Intersection 2 had to be micro-simulated making vehicles pass red light as they actually do.

Next, based on the model proposed in the Intersection 2, another model was created in which improvements described in the Road Safety Audit proposals were implemented, where vehicle flow could be observed, but mainly in which pedestrian do not have to perform risky actions due to vehicle conflicts. The vehicle-pedestrian conflict was eliminated in the west south corner of Túpac Amaru Ave., where pedestrians usually waited for a gap to be able to cross, since the traffic light displayed red light they could not cross due to the traffic conflict in

Túpac Amaru Ave., nor they could cross safely when green light was displayed due to the number of vehicles turning left from Approach 3; however, with the model proposed with a traffic light phase for these left turns of Approach 3, reinforced with the use of a traffic light with an arrow light indicating when is it possible to turn and when not, this pedestrian-vehicle and vehicle-vehicle conflict would be eliminated in this zone.

Road Safety Audit Proposals

A series of proposals were made from the road safety audits and micro-simulation regarding this intersection, among which it was recommended to implement bus stops in side medians where passengers are left and picked without proper spaces for that. In the case of the East side median of the South side, it is proposed to build a footpath from the bus stops to the existing path; in addition to avoid the jaywalking a guardrails must be placed to separate it from the side median in order to avoid pedestrians crossing by any side of Approach 2A.

It was proposed to consider crosswalk safety by generating pedestrian refuges, which due to the current design are not wide enough but will refuge pedestrians standing in the middle of the Metropolitano and mixed vehicle carriageways.

The optimization of the traffic light including three phases was proposed, that is, adding a protected phase for the left turn of vehicles coming from Approach 3 to the Túpac Amaru Ave. It was also recommended to add traffic and transport enforcement, as well as to make university students aware of traffic regulations, traffic, give maintenance to the signs and pavement markings, as well as adding some No Parking signs on the main carriageways.

CONCLUSIONS AND RECOMMENDATIONS

Traffic analysis results helped to better understand the road characteristics and traffic operation, as well as to identify better road safety issues. From such analysis a better knowledge of several elements contributing to improvement proposals was obtained, it also helped to clear out that results and methodologies developed in other realities such as the HCM or the Synchro software usage are not necessarily applicable, as such, to Peruvian reality and to certain geometrical characteristics of the urban surroundings, observation and analysis are required for its proper application when convenient.

Saturation flow field measurement served to observe the issue of low vehicle processing in the right lane of the north approach of Túpac Amaru Ave., where it was identified that taxis were those contributing to efficiency loss in the intersection, this led to propose improvements in traffic management and to point out one of the pending issues to be solved in the city of Lima regarding taxi service.

Vissim micro-simulation software was adequate for the analysis and assessment of selected intersections given the special characteristics of each of them. Several proposals could be assessed among the different micro-simulation models and in spite of obtaining better results for traffic in some micro-simulation models, they were not necessarily selected, but an alternative was chosen, with sufficiently good proposals for traffic but that would provide safety for pedestrians, trying to use the micro-simulation tool in order to improve road users' road safety.

It is shown the need of including vulnerable users as in the case of these assessed intersections, in which there is a high flow of pedestrians that lead to taking improvement measures a little different to those usually focused in vehicle flow. It was verified then that the use of several instruments and tools may contribute to having a wider view of the issue and that may lead to suggest measures that contribute to improve road infrastructure, urban mobility, as well as road safety for all road users.

It is recommended the usage of micro-simulation tools where both traffic management and safety audits or inspections improvement are required, especially in zones with special or complex characteristics and that all road users, road safety and mobility are considered.

It is suggested to perform other analysis in other developing countries with this integrating view, taking advantage of tools such as micro-simulation to support traffic improvement and road safety. In order to have more examples and which good practices can inspire people and engineers responsible for improving transport and road safety. Later, they maybe can be analyzed with other developing countries cases and differences between them appear, as well as the different needs with the purpose of obtaining a safe and efficient transport.

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