Unconventional geometric design in an intersection in the city of Lima

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***Abstract* — Several intersections in Lima have traffic congestion. This is due to the fact that the road capacity has been exceeded and the design has not been modified to improve it. In this paper, a traffic study of an intersection will be carried out in order to identify the current conditions and propose an unconventional intersection as a response to the problem. This study will be supported by microsimulation, considering the geometric and operational design of the alternative. This resulted in a decrease in delay, queue length and number of stops per vehicle.**

Keywords— Simulation, Calibration, Geometric design, Operational design, Congestion.

I. INTRODUCCIÓN

Several large cities in countries around the world have traffic problems in many of their avenues and intersections, due to the different types of travel attractors, such as shopping malls, offices, restaurants, nightclubs, among others. This causes that the vehicles of different modes of transportation, mostly private, register delays in their travel times, due to the different stops that may exist or movements that these have; which generates conflicts with others. For this reason, different solutions are used, such as:

implementing coordinated traffic light systems to help organize traffic and/or making a change in the geometric design as a response.

This is the case of Taha & Abdelfatah [1], where having conflicts due to left-turn movements in their study intersection, they decided to make a change in the geometric design in order to redirect the movements that generated conflicts and delays, these designs are known as Median U-turns (MUT). These were compared with the Direct Left Turn (DLT) as well as the location of these U-turns obtaining results through simulations on the delays of the alternatives. As a result, MUTs are effective considering their location compared to DLTs, which generate much longer delays.

For Tao Hu and Jingsheng Chen [2], they sought a solution to the various left and right turns generated at an intersection which presents delay problems due to these movements. A new geometric design was made which consisted of redirecting these movements (channeling them) to a lane which would connect with the secondary avenue where, before arriving, they could decide the movements they would make. This alternative was simulated considering traffic controls and without them, comparing them and obtaining as a result a total improvement in the total average delay with respect to the current situation.

What the authors have in common is that the proposal of a new geometric design is validated by microscopic traffic simulation. Therefore, we propose the design of unconventional intersections to reduce congestion in the study area. These intersections are unusual in the planning of the city of Lima, so it was decided to test it to see its effectiveness.

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II. METODOLOGIA Y HERRAMIENTAS

Geometric design goes hand in hand with operational design because a physical change in a road network directly affects traffic signals. In other words, a physical change will lead to an operational change.

A. Tools

1) Vissim 9

Microscopic simulation models are applied to vehicles, pedestrians, cyclists and others in a given study area. They are called microscopic because they simulate in greater detail the individual behavior of everything within the scenario, for this we can find different programs, the one used for this research was Vissim. This software is a tool for multimodal traffic models where different scenarios can be tested in a realistic and detailed way, so it is useful for the evaluation of urban road infrastructure [3].

2) Synchro

An important part of operational change is traffic signal coordination. Traffic signal synchronization potentially improves traffic operations by significantly reducing delays, as well as producing time and fuel savings. The software used in this study was Synchro, which allows the generation of timing plans. In other words, it optimizes cycle time, partial times and phase sequences to minimize stops and travel time. [4].

B. Methodology

1) Data Collection

The study began with the collection of information, which can be manual or automatic. It should indicate the number, type and movement of vehicles and pedestrians. It should also indicate the cycle and phases of the traffic lights.

2) Analysis of the current situation

The model must be built in the Vissim software and the values of the data collected in the field must be inserted. This model must be calibrated to verify that the simulation represents the real scenario, using the GEH indicator, shown in equation 1. This parameter compares the hourly volumes obtained in the simulation with those obtained in the field. It is considered optimal when its value is less than 5 and acceptable when it is between 5 and 10, both results are allowed in an investigation, since the simulation is representing the same amount of vehicles as those observed in the field.

$$GEH = \sqrt{\frac{2*(M-C)^2}{M+C}} \quad (1)$$

M= Number of vehicles simulated (Vissim)

C= Number of vehicles in the field

3) Analysis of Unconventional Alternatives

One of the unconventional models proposed in this research is known as the Median U turn (MUT) intersection. This is mostly used when there are conflicts of left turns in the middle of an intersection composed of a main road with a secondary road, especially if these do not have the corresponding traffic lights or if the number of vehicles making such turns is considerable.

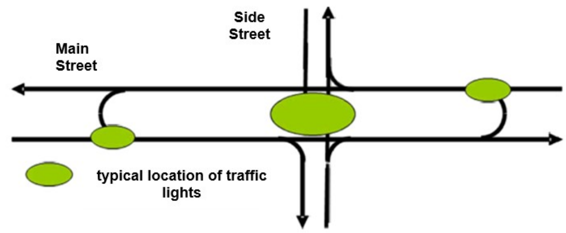

Figure 1: Location of signals at the MUT intersection/ Source: Adapted from FHWA, 2010 [5].

This unconventional intersection model consists of eliminating left turns and replacing them with U-turns followed by a right turn. With this, the green dots, shown in Figure 1, indicate where the traffic signalization should go for each of these. Consequently, the conflicts that were generated in the middle of the intersection by left turns by vehicles on the main road would decrease as they would be displaced and replaced by U-turns and corresponding traffic signals. [5]

The other unconventional intersection proposed in this research is known as the Restricted Crossing U Turn (RCUT) intersection. This considers all movements at the main avenue intersection, while at the secondary avenue it restricts the movements crossing the intersection. This is in order to have one traffic signal phase for both approaches and to be able to access the other side of the intersection by making the well-known U-turns. In this design, U-turns and direct left turns have protected phases for both cases, since by restricting certain movements the conflicts that were previously generated decrease, causing greater order in the intersection. Following is shown in Figure 2 the conflict points of the intersection with the RCUT design. [6]

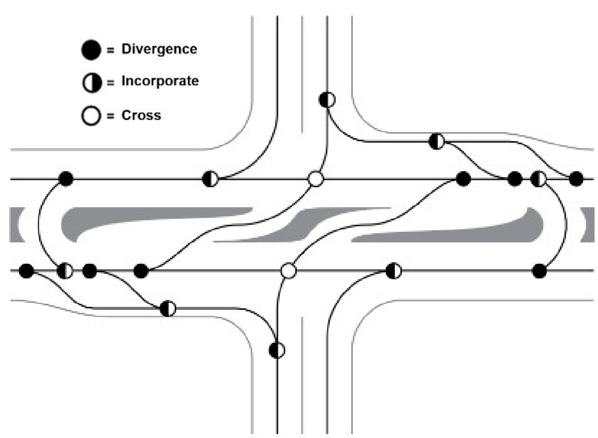

Figure 2: RCUT model with conflict points/ Source: VDOT adapted [6]

4) Design of alternatives

The alternatives are designed according to the parameters of the Ministry of Transportation and Communications (MTC) [7] and with the corresponding geometric design considerations by AASHTO [8]. Equation 2 shows the calculation of the length required for the transition from a main lane to an auxiliary lane, such as the left turn lane. Table 1 shows the distance required for the deceleration length with respect to the design speed. In addition, the light vehicle (LV) of 5.8 meters [7] is considered as the design vehicle. Once the necessary design parameters have been obtained, the following models are built.

$$L = \frac{(W*S)^2}{60}$$

(2)

W= Cone Section Length (ft)

S= Design Speed (mph)

W= Lane width considerado (ft)

Tabla 1:Desirable full deceleration lengths Source: Adapted from NCHRP [9]

Velocidad (km/h)	30	45	60	70	100	110
Distancia (m)	20	50	80	130	185	250

5) Results

Finally, the results are compared and it is concluded whether a non-conventional intersection shows an improvement in traffic flow in the city of Lima.

III. CASE STUDY

La Marina Avenue is one of the metropolitan thoroughfares with the greatest commercial movement, where one can find restaurants, discos, casinos, banks, movie theaters and more. All these elements work as generators or attractors of travel, since their activity generates a demand for traffic to the surrounding area [10]. Within this is the study area, which is the intersection of La Marina Avenue with Rafael Escardó Avenue, as shown in Figure 3.

As travel attractors we have one of the headquarters of the Universidad Peruana de Ciencias Aplicadas, an agency of the Banco de Crédito del Perú, the Hiraoka supermarket and the Repsol tap, all of these were appearing over time, so that the capacity of the road has been exceeded and can no longer meet the demand of users, as a result itgenerates a large traffic congestion. Also, the public transportation stops are located very close to the intersection, so they always interrupt the flow of traffic at turns, which generates a waiting queue. In addition, the traffic lights are not in optimal conditions, and there are conflicts in the movements, especially the left turn on the main road.

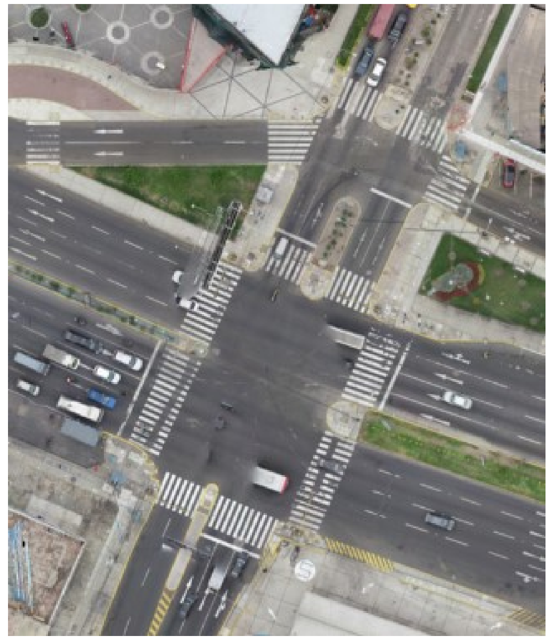

Figure 3: Intersection of study Av. La Marina with Av. Escardó / Source: Own elaboration

IV. RESULTS

A. Current Situation

For the current situation, the vehicle capacity was collected, which is summarized in Figure 4. In addition, information on the cycle and phases of the traffic lights was collected, which are shown in Table 2.

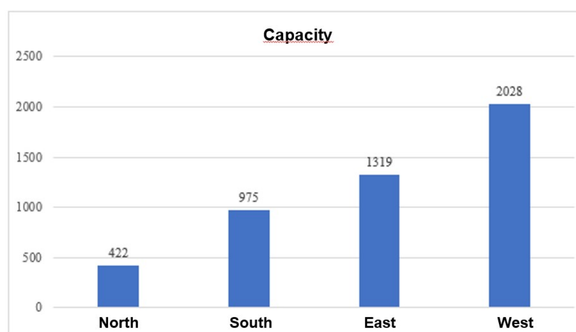

Figure 4: Vehicle capacity of the study intersection / Source: Own elaboration

Tabla 2: Traffic light cycle and phases / Source: Own elaboration

Av. La Marina - Av. Escardó					Cycle
Phase E-O	50	3	67		120
Phase N	57	30	3	30	120
Phase S	3	87	30		120

The pedestrian capacity was also collected for each intersection as shown in Figure 5.

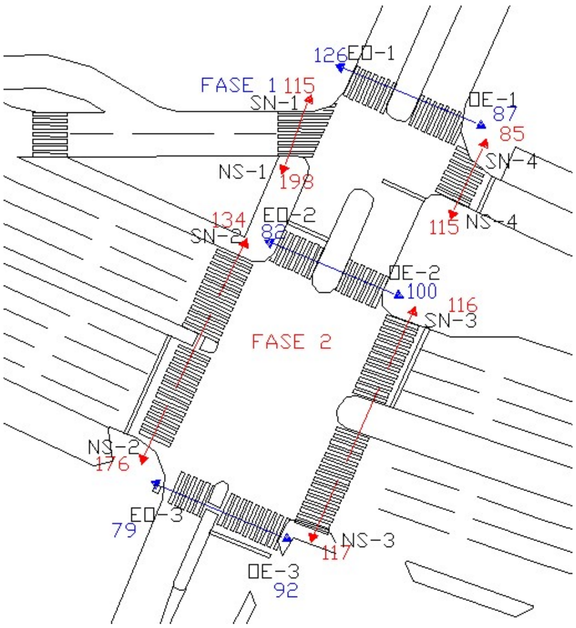

Figure 5: Capacity and pedestrian phases of the intersection / Source: Own elaboration

With all the data obtained in the field, the model was built and calibrated using the GEH indicator, the results of which are shown in Table 3.

Tabla 3: Resultados del parámetro GEH / Fuente: Elaboración Propia

Side	Capacity	GEH
Oeste	2028	2.591
Este	1319	4.165
Norte	422	1.01
Sur	975	6.618

Once it was verified that the model represented reality through calibration, the respective simulations were performed. Finally, the results of these simulations were obtained, which are shown in Table 4.

Tabla 4: Simulation results of the current situation / Source: Own elaboration in Vissim

Case	Average Queue (m)	Max Queue (m)	Delays (s)	Stops /veh
Current	132.85	299.49	167.83	4.98

The results showed an average queue is 132.85 meters, i.e. 23 design cars waiting approximately; the average delay during the intersection is 167.83 seconds, meaning that a vehicle takes that total time to cross the intersection, which is equivalent to a level of service F and the average number of stops is 4.98, in other words a vehicle stops 5 times before crossing the intersection.

B. Public transportation

The location of the bus stops along La Marina Avenue generates many conflicts, since they are located before the traffic lights without having a correct spacing, which generates congestion and problems for vehicles that would like to make any other movement on the road.

For this reason, within each alternative, it was considered that there should be no stops before the intersection, since these would create conflicts for vehicles that want to make right turns or waste time for those that follow in front of the intersection. Therefore, they will be located after the intersection and with a bay so that public transport vehicles can enter and not affect others.

Figure 6: Model of the RCUT alternative, showing the bays for public transport stops/ Source: Own elaboration in Vissim.

C. Unconventional alternative MUT

The design of the MUT alternative was performed using Equation 2 and these results are shown in Tables 5, 6 and Figure 7. In addition, an optimization was performed on the traffic signal with the Synchro program by changing the cycle to 150 seconds and adding phases for left turns and U-turns, as shown in Table 7.

Table 5: Interpolation according to speed and distance/ Source: Own elaboration.

Speed	Distance	L3+L2	L3+L2
50	45	72	75
60	71.67		
65	85		

Table 6: Interpolation according to speed and distance/ Source: Own elaboration

L	S	Nc	k	S	S	Length Total
12.7 cm	300 veh/hr	30 veh/hr	2	25 ft	0.635 m	85 m

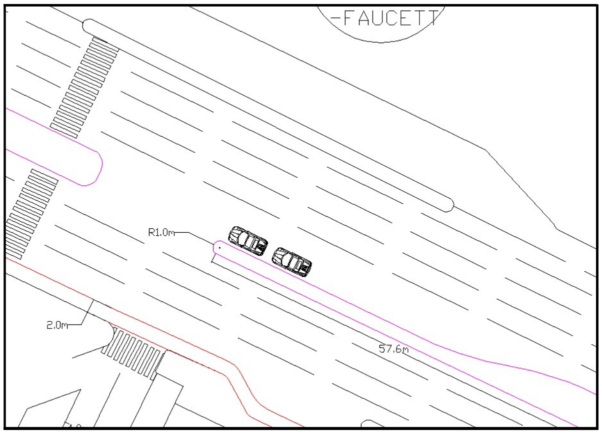

Figure 7: Diseño de Longitud de desaceleración/ Fuente: Elaboración Propia

Table 7: Traffic light phases for the main intersection for the MUT alternative/ Source: Own elaboration in Synchro

Av. La Marina - Av. Escardó					Cycle
Phase E-O	57	3	90		150
South Phase	60	60	3	27	150
North Phase	123	24	3		150
Turning Phase	3	70	77		150

With the calculations performed, the corresponding simulations were carried out, as shown in Figure 8, to finally obtain the results shown in Table 8.

Table 8: Calculation of the length for the MUT alternative / Source: Own elaboration.

Case	Average Queue (m)	Max Queue (m)	Delays (s)	Stops /veh
Alternative MUT	108.22	185.14	121.38	2.94

These results showed an average queue is 108.22 meters, or approximately 18 design vehicles waiting; the average delay is 121.38 seconds, which is equivalent to a level of service F. and the average number of stops is 2.94 per vehicle.

Figure 8: 3D model of the MUT alternative / Source: Own elaboration in Vissim.

D. Unconventional alternative RCUT

The same design parameters of the MUT alternative were used for the RCUT, since both have the same U-turns, these results are shown in tables 5 and 6. Also, an optimization of the traffic lights was performed with the Synchro program, changing the cycle to 150 seconds and adding phases for left and U-turns, as shown in table 9.

Table 9: Phases of the traffic light of the RCUT alternative/ Source: Own elaboration

Av. La Marina - Av. Escardó				Ciclo
Acceso E-O	70	3	77	150
Acceso E-O Clínica	55	3	92	150
Giros Izquierda	75	72	3	150
Acceso N-S	75	72	3	150
Giros U	58	89	3	150

With the calculations performed, the corresponding simulations were carried out, as shown in Figure 9, to finally obtain the results shown in Table 10.

Table 10: Simulation results of the RCUT Alternative/ Source: Own elaboration in Vissim

Case	Average Queue (m)	Max Queue (m)	Delays (s)	Stops /veh
Alternative RCUT	94.61	163.92	92.56	1.72

The results showed an average queue is 94.61 meters, or approximately 16 design vehicles waiting; the average delay during the intersection is 92.56 seconds, which is equivalent to a level of service F. and the average number of stops is 1.72 per vehicle.

Figure 9: Modelo de la alternativa RCUT y funcionamiento en 3D/ Fuente: Elaboración Propia en Vissim

E. *Compare Results*

For a better understanding of the research, Table 11 presents a summary of the alternatives.

Tabla 11: Summary of results of both study scenarios / Source: Own elaboration.

Case	Average Queue (m)	Max Queue (m)	Delays (s)	Stops /veh
Current	132.85	299.49	167.83	4.98
MUT	108.22	185.14	121.38	2.94
RCUT	94.61	163.92	92.56	1.72

The unconventional intersection alternatives show an improvement in efficiency measures. An average queue decreasing by 25 meters for the MUT and 38 meters for the RCUT, total delay decreasing by 47 seconds for the MUT and 75 seconds for the RCUT; and stops per vehicle decreasing from 4.98 to 2.94 for the MUT and 1.72 for the RCUT.

V. CONCLUSIONES

The main conflict points of the actual intersection situation were identified, especially those generated by left turns.

The simulation of the current situation was able to prove that the congestion problem exists, as it showed an average of approximately 133 meters of cars in queue, a travel time delay of 168 seconds to cross the intersection and 5 stops per vehicle during that time.

The optimization of the traffic signalization positively influenced the alternatives, since, by having a change in geometry, the movements and conflict points changed, so using optimized coordination significantly improved the performance of the intersection.

The simulation of the MUT alternative was able to show an improvement, the queue decreased by 25 meters, the delay was reduced by 47 seconds and the number of stops per vehicle decreased to 3 stops per vehicle.

The simulation of the RCUT alternative was able to show an improvement, the queue decreased by 38 meters, the delay was reduced by 75 seconds and the number of stops per vehicle decreased to 2 stops per vehicle.

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