Vehicular Conflict Assessment on a Road with Lane Reduction Using the SSAM Methodology

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Abstract*— In this article, an evaluation of the number of vehicular conflicts is carried out, in a section of road that is part of a traffic light intersection, with constant presence of traffic jams. In the trajectory of this section there is a reduction in lanes, variable lane widths and little uniformity, causing a bottleneck that produces different types of conflicts between vehicles. To carry out the evaluation, the VISSIM microsimulation software was used, here the real situation of the intersection is modeled and two new scenarios are proposed, in which geometric redesign proposals are made in the infrastructure of the section of road, in order to analyze variability in the number of vehicular conflicts. For the automatic counting of conflicts, the Surrogate Safety model (SSAM) is used. Vehicular conflicts are categorized according to their crossing collision angle (crossing), rear end collision angle (rear end) and lane change (lane change), and their severity levels in relation to the time before collision (TTC). The results indicate a count of 3916 conflicts in the microsimulation of the real situation. In the first proposed scenario, 2,231 conflicts were counted, which corresponds to a 43% reduction in relation to the current situation; while in the second scenario 3,835 conflicts were counted, a reduction of 2%. The TTCs ranged between 0.52 and 0.70, indicating a high risk of collision on the road.

***Keywords*—microsimulation, vehicular conflicts, VISSIM, SSAM, road safety.**

I. INTRODUCTION

Vehicular conflicts are the result of a not very fluid circulation of motorized vehicles due to deficiencies in the road infrastructure as well as the lack of driver education and erratic behavior of users at road intersections [1]. The improvement in the capacity and standardization of roads to improve road safety is an important task in a constantly growing city like Lima, Peru; where due to uncontrolled urban growth, deficiencies in the road infrastructure and traffic administration originated, which, added to the lack of urban planning, worsened over the years [2].

One of these deficiencies is the lack of uniformity in the geometry of the roads, this refers to the variability in the number of lanes, in the lane widths and in their route. A frequent phenomenon is the so-called bottlenecks; in terms of road geometry, these refer to the reduction in the number of lanes in the same section, forcing drivers to pass from one lane to another, affecting vehicular flow. In Lima, this commonly occurs on roads that pass from one district to another and intersect with other important roads. Its origin is in the lack of urban planning and coordination between the different municipalities of the city, resulting in the roads being designed according to the criteria of each district almost independently and not cooperatively while struggling with the exponential growth of the urban population [3]. Erratic user behavior is also considered a factor that increases the number of vehicular conflicts on non-uniform roads. Actions such as changing lanes, often unnecessarily, or waiting for public transport vehicles for passengers in the middle of the road are typical of the behavior of Lima drivers.

Usually, the measures used for the evaluation of road safety at intersections, such as the use of checklists, provide a shallow qualitative approach based on the history of traffic accidents in the area under study and certain characteristics of the infrastructure, which results in ineffective safety strategies that do not generate a greater impact in reducing vehicular conflicts. Likewise, these measures are not applicable to assess the safety of road designs not yet built or flow control strategies that have not yet been applied in the field [4]. Therefore, interest has grown in the use of tools that provide more quantitative and predictive methods for road safety assessment such as micro simulation and the surrogate safety model (SSAM) developed by Gettmann et al. (2008) for the Federal Highway Administration for the automated counting and analysis of conflicts in simulated vehicle trajectories. In this article, these tools will be the core of the research, testing their ability to evaluate and predict conflicts by modeling the real situation of the intersection in a microsimulation environment and later modeling two scenarios with redesigns in geometry and infrastructure in order to carry out an analysis of the variability of conflicts between each situation.

II. STATE OD THE ART

There are investigations that address the issue of road safety and the number of vehicular conflicts at intersections through the use of microsimulation and SSAM. These studies have given important precedents. A study performs a safety evaluation at signalized intersections, using a microsimulation model developed in VISSIM. Using the Surrogate Safety Model (SSAM), vehicular conflicts were categorized according to their severity in relation to their collision time (TTC), managing to identify the critical points where the greatest number of conflicts occur [5]. Additionally, research demonstrates the use of a microsimulation environment to predict vehicle-vehicle conflicts at signalized intersections in Doha, Qatar. A reasonable ability of the SSAM to predict possible accidents at specific points of the intersection is verified in the face of possible improvements in the geometry. [6]. In addition, the correlation between the conflicts between vehicles measured in the field and those simulated by microsimulation was investigated, giving a good correlation in the highest thresholds of the TTC [7].

From another approach, there are studies that used microsimulation for the implementation of improvements and optimization in the cycles and phases of traffic lights at intersections. In a study, a 14.6% reduction in the number of conflicts was achieved with the optimization of traffic light times at an intersection [8]. From another approach, there are

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studies that used microsimulation for the implementation of improvements and optimization in the cycles and phases of traffic lights at intersections. In a study, a 14.6% reduction in the number of conflicts was achieved with the optimization of traffic light times at an intersection [9]. Likewise, in another article the study of an intersection was carried out, in which a proposal for optimization in the waiting times of the traffic lights was raised. With the proposal, waiting times were reduced by up to 7 seconds and it was observed that while traffic light times are shorter, the average speed of vehicles increases, giving increases of up to 2 km/h. [10].

On the other hand, there are studies that use microsimulation to develop proposals for geometric redesign of roads. In a study, the Managed Lane – HSR strategy was implemented to improve traffic flow by adding an additional lane. Very good results were shown in terms of road safety, reducing traffic conflicts and yielding the best safety result at 90 km/h due to the reduced number and severity of conflicts. [11] On the other hand, there are studies that use microsimulation to develop proposals for geometric redesign of roads. In a study, the Managed Lane – HSR strategy was implemented to improve traffic flow by adding an additional lane. Very good results were shown in terms of road safety, reducing traffic conflicts and yielding the best safety result at 90 km/h due to the reduced number and severity of conflicts. [12].

III. METHODOLOGY

A. Flowchart

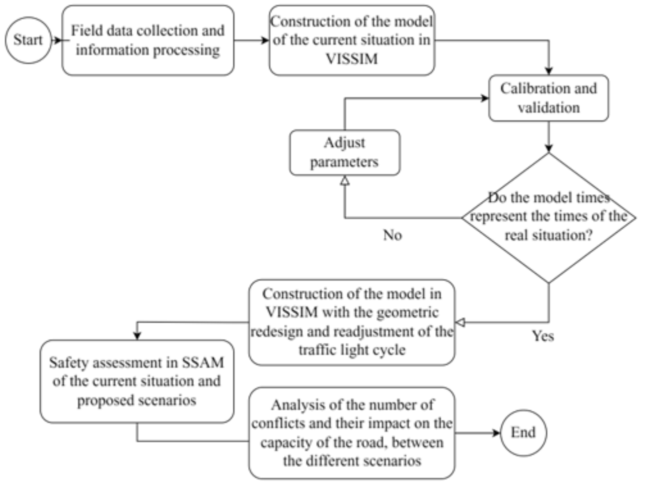

Fig. 1. Investigation process flowchart

B. Theoretical Framework

a. Vissim

VISSIM simulates the flow of traffic under the relationship "driver - vehicle - units" through the development of a model of the road network. This software is based on the psychophysical parameters of the vehicle tracking model proposed by Professor Rainer Wiedemann from the University of Karlsruhe in Germany. The function of VISSIM is the adequate representation of the behavior of vehicle driving in traffic. To achieve this, the dynamics followed by the different types of vehicles in interaction must be taken into account. It is internally composed of two functions: the traffic simulator and the signal state generator (SSG). The first of these allows the animation of the movement of vehicles; while the second internally generates output files with accumulated statistical data such as travel times and queue lengths. [13].

In this study, VISSIM was selected to model the scenarios due to its ability to simulate multimodal traffic flow, its flexibility to draw roads with complex geometries, and its dynamic and stochastic nature (random results), which resembles user behavior in Latin America [14]. In addition, the various parameters required in VISSIM can be calibrated by adjusting priority rules, conflict areas and vehicle characteristics to replicate real traffic conditions. [15]. The microsimulation of the project is represented by the road networks, the vehicles, the signaling and priority rules, the traffic light phases, and the vehicular tracking parameters. These items are recorded as input data in the software.

b. SSAM Surrogate Safety Model

SSAM is a surrogate road safety assessment model that combines microsimulation and automated conflict analysis, and assesses the frequency and character of possible collisions between vehicles to predictively assess the safety of traffic infrastructures [16]. A microsimulation environment is used as a traffic simulation tool for the vehicle trajectory output file (.trj file) which is compatible with the SSAM tool. This model is used as a processor to parse the batch of TRJ files. Manually entered data is time to collision (TTC), post-collision time (PET), and conflict angles. The TTC is the most common indicator and is also selected in this study to measure the severity of the conflict. Initially proposed by Hayward in 1972, it refers to the "travel time until a collision occurs between vehicles if they continue on their current course at their current speeds." [17]. Traffic conflicts are based on the TTC threshold of 1.5 seconds. Higher TTC values indicate less severity of traffic conflicts. SSAM uses the categorization of conflicts in relation to their collision angle proposed by the Federal Highway Administration (FHWA), conflicts with a collision angle less than or equal to 30° are considered rear (rear end), if the angle is between 30 ° - 85° is considered a lane change conflict, and if the approach angle is greater than 85° it is considered a crossing conflict [18].

C. Study Area

In this study, an intersection of two important roads (Av. Canada - Juan Pardo de Zela with Av. Paseo de la República) is chosen, located between two districts in the city of Lima, capital of Peru. The section under study corresponds to Canada Avenue in an east-west direction, in the Lima district of La Victoria, which is renamed Juan Pardo de Zela upon entering the Lince district. The road has 4 lanes in the section of Avenida Canada, later in the transition of districts is the Canada bridge, which has three lanes to finally reduce to two lanes in Juan Pardo de Zela. This transition between districts acts as a bottleneck forcing drivers to perform lane change maneuvers. Also, in this section there is a public transport stop just before the auxiliary lane for turning to the right. In fig. 2 there is a plan view of the intersection in which the reduction of lanes is visible.

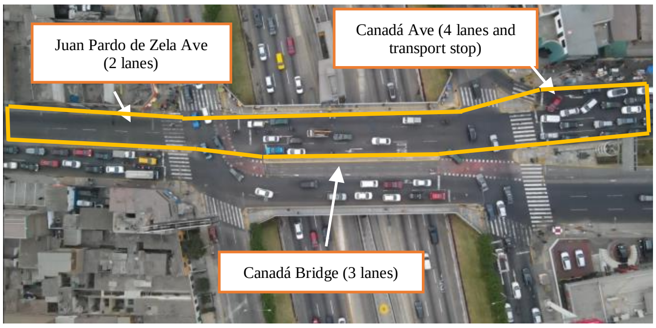

Fig. 2. Detail of the plan view of the section under study

At the intersection there are a total of 6 fixed-time traffic lights, which comply with four phases; likewise, the traffic light cycle has a total duration of 180 seconds. The intersection features exclusive left-turn lanes at the Canada Bridge and an auxiliary right-turn lane at the intersection of east-west Canada Avenue with Paseo de la República.

D. *Data collection*

To collect the field data, a drone was used to record the intersection at free flow times and at critical times, where the vehicular flow is highly discontinuous and the risk of traffic jams is such that traffic police are used to regulate the flow. The data collected in the field includes lane widths, traffic volume, measurement of traffic light phases, average vehicle speeds and travel times, these data are necessary for the construction of a micro simulation model. Vehicular capacity was determined by counting using video footage recorded at critical hours in the afternoon from 5:30 p.m. until 7:30 p.m. on a typical business day in May 2022. The routes that the different categories of vehicles follow at the intersection were defined. This intersection handled 8,278 vehicle movements per hour (see fig. 3), of which 1,736 vehicles traveled through the stretch of Canada Avenue from east to west (see fig. 4).

VEHICULAR COMPOSITION														
VEHICLE TYPE	NORTH-SOUTH			SOUTH-NORTH			EAST-WEST			WEST-EAST			TOTAL	%
	11	12	13	21	22	23	31	32	33	41	42	43		
Linear Motorcycle	0	29	250	6	9	80	19	501	36	7	297	8	1242	15.00%
Cars	32	378	1360	143	202	530	293	1441	354	62	1370	61	6226	75.21%
Bus	0	0	21	9	3	14	5	70	4	0	48	0	174	2.10%
Coaster	0	0	10	0	0	0	149	0	0	143	0	0	302	3.65%
Minibus	0	0	0	0	1	0	0	65	0	0	33	0	99	1.20%
Interprovincial Bus	0	0	2	0	1	4	3	7	0	0	14	1	32	0.39%
Truck	1	0	23	1	5	5	4	86	1	1	61	2	190	2.30%
Trailer	0	0	1	0	1	1	0	9	0	0	1	0	13	0.16%
	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
TOTAL VEHICLES	**33**	**407**	**1667**	**159**	**222**	**634**	**473**	**2179**	**395**	**213**	**1824**	**72**	**8278**	**100.00%**
U.C.P.	27	294	1203	121	178	466	251	1896	284	52	1616	57	6445	

Fig. 3. Summary of vehicular composition and capacity at critical hour.

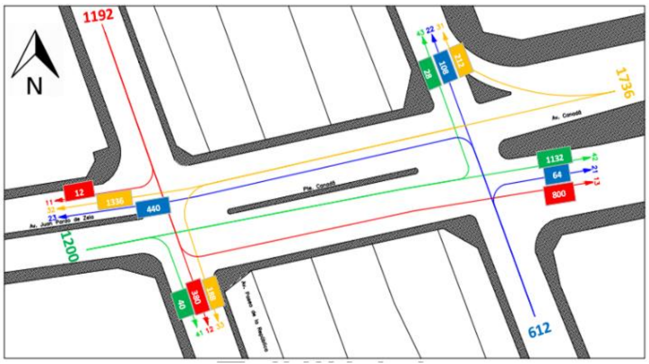

Fig. 4. Intersection flowchart with average traffic volume every 15 minutes and possible routes.

E. *Construction of the microsimulation model*

The modeling process begins with the drawing of the roads, for this the software allows the importation of satellite images called background, following the silhouette of the roads, the sections were modeled joining by means of connectors and assigning them their respective properties and characteristics measured in the field as widths of lanes, number of lanes and directions. Most of the vehicle behavior parameters were assigned using vehicular tracking parameters and entering data collected in the field from samples of vehicle speeds both in free flow and in interaction with other vehicles; At each entrance, a static route is assigned according to the intersection flowchart. A priority rule is established based on the principle of acceptance of the gap determined by the parameters of progress and time of the gap. In VISSIM, a conflict area is defined as the crossing between two links or connectors. Priority was given to vehicles going in an east-west direction and vice versa due to a greater volume of traffic. Finally, the cycle and traffic light phases are programmed using timed measurements in the study area.

Some remaining parameters, such as deceleration rates (1 m/s2) were assumed. All other parameters for the driving behavior of the vehicles were taken as default values in VISSIM. This study used the calculated mean value based on a simulation of 6 random seeds.

The efficiency parameter selected for the calibration process is the travel time for a selected interval whose average value was 4.62 seconds with a standard deviation of 0.84, the considered interval has a length of approximately 28 meters. Regarding the simulation, 30 iteration attempts of the Wiedemann 74 parameters were made. For each of the attempts, 15 runs were made [19].

The values of the parameters of average stopping distance (ax), additive part of the safety distance (bx add) and multiplicative part of the safety distance (bx mult) that achieved the closest sample mean to the average travel time measured in the field they were 0.50, 1.50 and 3.00 m, respectively; the average travel time was 4.65 and the standard deviation was 0.33. However, these parameters had to be verified through a statistical analysis in StatKey with a hypothesis test of 10,000 (ten thousand) samples in order to obtain sufficient data to allow plotting the statistical distribution. From the statistical analysis, a critical value of mean difference (-0.03) is obtained within the established range limits (-0.312 and 0.308), therefore, the hypothesis is correct.

For the final stage of modeling, it is necessary to validate what has been done through an analysis of the project simulation and compare it with a new set of field input data. To carry out the validation of the model, this new field data record was entered and it was verified that the results obtained for the selected efficiency parameter have a similarity between the simulated data and the field data. Finally, what was obtained in the field was an average of 4.51 s. and a standard deviation of 0.85 s. In the same way as the results obtained in the calibration, in this section it is also required to verify the results with a statistical test, obtaining a critical value of mean difference of -0.01, which is compared with the limit values of the range (-0.316 and 0.314) it is determined that the tabulated value is within the range and therefore the hypothesis is correct. Therefore, and considering that the parametric test also gave a positive result, the calibration and validation of the model is concluded.

F. *Construction of road redesign proposals*

Once the microsimulation model has been consolidated, the geometry and infrastructure of the section of the road is reconsidered in order to report the impact of these proposals on the behavior of the vehicles and later on road safety through the evaluation of the number of vehicular conflicts.

As the first redesign proposal, the standardization of the number of lanes in the transition from Canada Avenue to Juan Pardo de Zela was proposed. The last lane was converted into an auxiliary lane for the exclusive use of left-turning drivers, in this way, vehicles following a straight route have two lanes for the entire journey, thus eliminating the bottleneck and therefore the need to make lane change actions. The proposal for an auxiliary lane prevents drivers from interfering with the path of other users and gives exclusivity to users who turn left. This redesign proposal is based on the AASHTO (2011) basic lane number balance principles [20], the criteria of the DG Road Geometric Design Manual - 2018 [21] and the vehicular capacity measured in the field having a transition wedge of 25m and a lane length of 50m. In addition, the public transport stop was relocated one block before the intersection of the avenues, this to prevent public transport vehicles from invading the right-turn lane at the intersection to pick up passengers and then carry out lane change actions to continue with its route generating conflicts and delays. Finally, the readjustment of the traffic light phases with the help of the SYNCHRO 8.0 software and trial-error carrying out simulations, complements the redesign proposal.

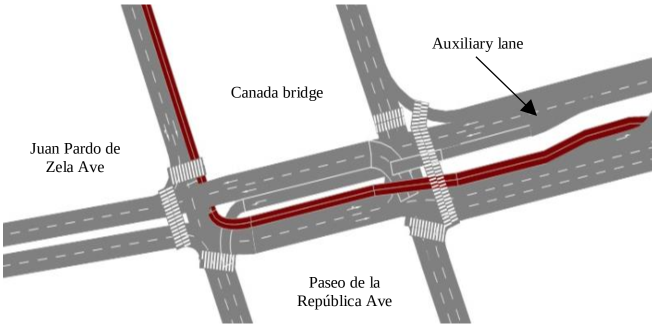

Fig. 5. First scenario

The second proposal consists of adding an additional lane, this with the purpose of evaluating the impact of a greater capacity of the road infrastructure on the number of vehicular conflicts. This proposal was designed by testing the predictive capacity of using microsimulation software. The additional lane compensates for irregularities in the route of the stage, providing straighter routes. As with the first proposed scenario, the traffic light phases were readjusted and the optimal cycle was determined using SYNCHRO 8.0 and the public transport stop was relocated.

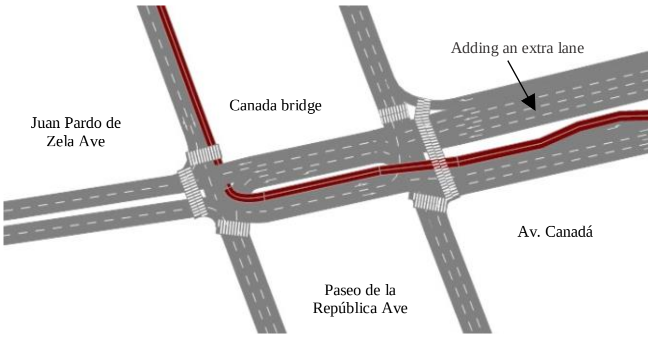

Fig. 6. Second scenario

G. *Evaluation of conflicts in SSAM*

The vehicular conflicts evaluation process is given as follows. When executing each microsimulation run in VISSIM for 3600 seconds (one hour), an output file of vehicle trajectories (.trj) is generated that is imported into the SSAM tool. SSAM is then used as a processor for analysis of the batch files. trj where it analyzes vehicle-to-vehicle interactions to identify conflict events and catalog them. The time to collision (TTC) and the minimum post-invasion time (PET) are entered manually to measure the severity of the conflict. According to Hayward's proposal, a threshold of 1.5 seconds is considered and the PET is assumed to be 5 seconds. In this way, the evaluation of each scenario is carried out, with times below said threshold being considered vehicular conflicts. Likewise, SSAM categorizes conflicts according to their angle of collision (crossing, rare end and lane change). Finally, the software provides a conflict map where the points where possible collisions occurred on the road and a summary of the count with the total number of conflicts are displayed.

IV. Results and Analysis

The microsimulation in VISSIM shows a user behavior similar to the real one. You can see in Fig. 7 the final result of the process of construction, calibration and validation of the model of the current situation of the intersection in a microsimulation environment.

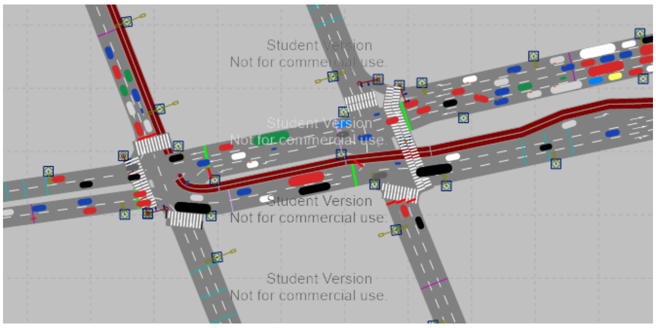

Fig. 7. Simulation of the current situation of the intersection.

The simulated conflicts in the real situation of the intersection in SSAM are shown in Figure 8a. The conflict map shows agglomerations of rear end type conflicts (yellow) along the entire section of Canada Avenue from east to west; Likewise, the largest number of conflict points due to lane changes (blue color) are shown at the bus stop between Canada and Paseo de la República and along the path of the Canada bridge. This occurs because public transport vehicles enter the right-turn lane to drop off and pick up passengers, then perform lane change maneuvers to continue their journey. On the bridge, as the reduction of lanes already appears, the vehicles in front and those that are going to make a left turn begin to change lanes to adapt to their routes and adapt to the final reduction of two lanes. Crossing conflicts occur at road junctions as can be seen in Figure 8a.

Once the conflict evaluation has been carried out in the first proposed scenario, the results are shown in figure 8b. A noticeable reduction in the number of rear end conflicts and lane changes can be seen. The relocation of the public transport stop one block earlier and giving exclusivity to the right turn lane reduced the need to carry out lane change maneuvers at the intersection with Paseo de la República.

Likewise, with the implementation of a left-turn lane, the behavior of vehicles seeking to make the turn is mostly to enter the auxiliary lane and continue the journey until making the turn. The second scenario shows an increase in conflicts due to lane changes in the crossing area between Canada and Paseo de la República (see Fig. 8c), in the simulation it is visualized how having added a lane accentuates the effect of bottleneck. However, on the Canada Bridge, the rear end and lane change conflict points decreased, which may indicate a more continuous flow. The simulation results showed that the total number of traffic conflicts for the two proposed scenarios is less than the total for the current situation, as shown in Table I.

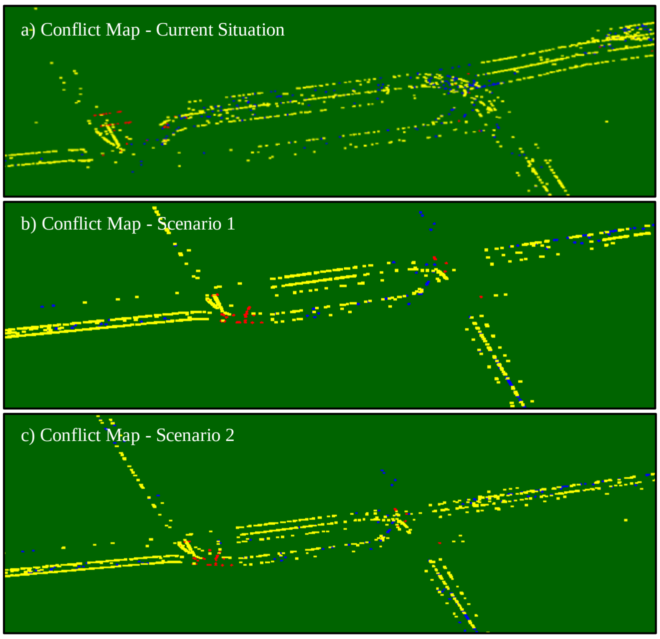

Fig. 8. Simulation of the current situation of the intersection.

TABLE I.
SUMMARY OF THE NUMBER OF VEHICULAR CONFLICTS

	Crossing	Rear End	Lane Change	Total
Current Situation	96	3059	761	3916
First redesign scenario	40	1868	413	2231
Second redesign scenario	106	2887	842	3835

The total number of vehicular conflicts recorded by the software in the simulation of the current situation is 3,916 conflicts. There were 96 crossing conflicts, 3059 rear end conflicts and 761 lane change conflicts. The mean value of the TTC is 0.55, which indicates a high risk of collisions. These results are now compared with the proposed scenarios. In the first proposal, the total conflicts were counted in 2231, a total reduction of conflicts of 43,028% is observed in relation to the real situation. Crossing conflicts decreased to 35, rear end conflicts to 1,712, and lane change conflicts to 484; they represent a reduction of 63.54%, 44.034% and 36.40%, respectively. The TTC in this case increased to 0.70, which indicates a slight reduction in the risk of collisions. On the other hand, in the second scenario the total conflicts are 3,835. The reduction in conflicts is only 2,068%. In this scenario, crossing conflicts increased by 10.42% (106), rear end conflicts decreased by 18.75% (2887) and lane change conflicts increased by 10.64% (842). Finally, the average value of TTC is 0.52, being at the limit denoting a high risk.

CONCLUSIONS

In this study, the SSAM surrogate safety model was used to assess the number of vehicular conflicts on a section of a road with reduced lanes and irregular geometry that is part of a signalized intersection with a high volume of motorized vehicles. Likewise, the microsimulation environment was used to evaluate the performance of two road redesign proposals in order to study the predictive capacity of the SSAM in the face of possible road management and road safety improvement projects, and to carry out an evaluation of the variability of conflicts between each situation.

The results of the study have shown a good predictive capacity of the SSAM to determine possible conflicts of different severities and the possible behavior of users in different scenarios. When evaluating the number of conflicts in the current situation of the road with the two proposed scenarios, a conflict reduction of 43% and 2%, respectively, was found, while the average thresholds of the TTC gave values between 0.52 and 0.70, which correspond to a high risk of collision. These results are reasonable for the intersection situation. Likewise, when carrying out a standardization in the number of lanes of the section, a notable reduction of conflicts is shown, which gives greater continuity to the vehicular flow; however, this proposal must be covered in more depth through a mesoscopic study that determines with certainty the feasibility of the proposal. Finally, the use of microsimulation with SSAM is a practical and fast way to examine the impact on road safety of possible solutions and proposals to a current problem in urban traffic. This study gives rise to future research on the use of microsimulation and SSAM, as reliable methods for the development of road safety assessments and road design proposals.

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