Performance Evaluation of Urban Traffic Using Simulation: A Case Study in Brazil

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***Abstract*—As a result of a fast-growing population, an increasing number of vehicles on the road, and inadequate public policies, metropolitan areas in Latin America are dealing with significant traffic congestion problems. Most cities do not have real-time urban traffic control systems. Therefore, the use of simulation software is a cost-effective solution to evaluate and reduce congestion in metropolitan areas. This paper seeks to assess urban traffic performance using the Urban Mobility Simulator (SUMO) on Fernandes Lima Avenue, the most important thoroughfare in Maceió, Alagoas, Brazil, which features distinctive characteristics such as a dedicated lane for public transportation and three segments with pedestrian traffic lights. Comparing the real observations with the simulation results, it was confirmed that the model provided accurate estimates, with errors of less than 5% for vehicle traffic volume and 10% for total travel time. After conducting experimental studies on four different scenarios, including the current state (1), no blue lane (2), no pedestrian traffic lights (3), and no blue lane and no pedestrian traffic lights (4), it was found that significant improvements in efficiency indicators, such as travel time, waiting time, fuel consumption, and carbon dioxide emissions, could be achieved. Scenarios 2, 3, and 4 were particularly effective, resulting in volumetric increases of 9.95%, 7.88%, and 10.77%, respectively, in vehicle traffic.**

***Index Terms*—Urban Traffic, Simulation, Traffic-Lights, SUMO.**

I. Introduction

Large cities in Latin America have been facing significant challenges regarding urban traffic congestion, and Maceió, a Brazilian city and the capital of the state of Alagoas, is no exception. Population growth, the concentration of large residential and commercial buildings, as well as the increase in the number of motor vehicles on the streets, have contributed to worsening this situation, making urban mobility a major challenge for the expansion and development of the city.

According to data released by the 2022 Demographic Census[1] provided by the Brazilian Institute of Geography and Statistics (IBGE), Maceió encompasses an area of approximately 509 km² and has a population of 957,916 individuals. These figures indicate a 2.7% increase in population compared to the last Demographic Census[2] conducted in 2010, which had registered a population of 932,748 residents.

As the population grows, the number of vehicles in circulation significantly increases. According to data from the State Traffic Department of Alagoas(DETRAN/AL) [1], the number of vehicles in Maceió has climbed from 206,297 in 2010 to 376,815 in 2022, representing an increase of 82.66%. This increase may result in congestion on the main avenues during peak hours, affecting the mobility of people in their daily activities. To prevent this, authorities ought to implement measures that alleviate the problems caused by the excess of vehicles [2].

Fernandes Lima Avenue serves as the main thoroughfare in Maceió and gives priority to public transportation through the effective implementation of an exclusive lane, known as the blue lane [3]. Stretching approximately 4.6 kilometers, it is used daily by thousands of people for their daily activities. Given its significant importance to the city, it has been chosen as the subject of investigation for this work. Fig. 1 illustrates a congested section of Fernandes Lima Avenue, where the exclusive lane for public transportation is visible.

Fig. 1. Exclusive lane (Blue lane) for public transport on Fernandes Lima Avenue, Maceió/AL, Brazil, 2023.

Maceió is a city that features three important road axes connecting the high and low regions: the Farol Road Axis, formed by Durval de Góes Monteiro and Fernandes Lima avenues, the Bebedouro Road Axis, and the Serraria Road Axis. Due to the high volume of vehicles on these routes, they have a significant impact on the urban mobility of the city. In Fig. 2, it is possible to see that both the Bebedouro and Serraria road axes link the lower part of the city to the main axis, Farol. This connection further aggravates the congestion on Fernandes Lima Avenue, especially after a section of the Bebedouro Road Axis was interrupted due to geological processes in the region [4].

Among the main contributions of this proposed study, the following can be highlighted: 1. Development of a new open-source urban traffic simulation model, which was validated

[1] Brazilian Institute of Geography and Statistics. 2022 Demographic Census https://censo2022.ibge.gov.br/panorama/

[2] Brazilian Institute of Geography and Statistics. 2010 Demographic Census https://censo2010.ibge.gov.br/resultados.html

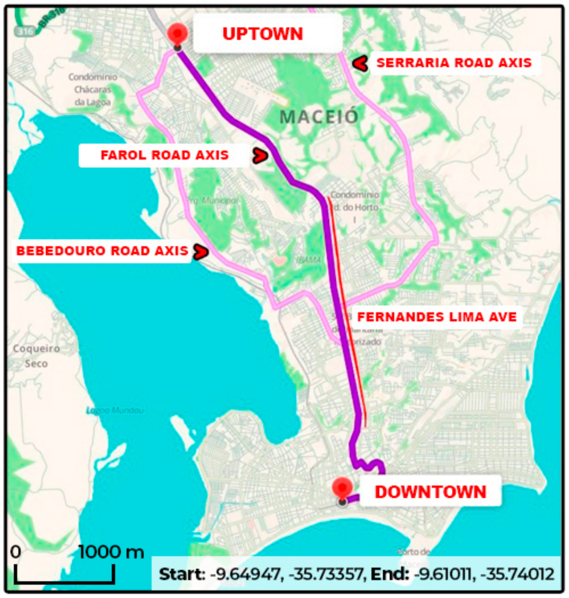

Fig. 2. Illustration of the three main road axes in Maceió collected on OpenStreetMap adapted from [5].

using real traffic data from Fernandes Lima Avenue, the main thoroughfare of the city of Maceió. This model can be used to model interventions designed to improve traffic flow for vehicles. 2. Comparison of the developed urban traffic simulation model and another one previously presented in the literature [6], where the proposed model demonstrated significantly higher accuracy, enabling the creation of projections and interventions for optimizing urban traffic with errors lower than 5% for vehicle volume and 10% for average travel time. 3. Conducting a case study that compares four scenarios that simulate different interventions for the purpose of assessing urban traffic performance. The study covered aspects such as traffic volume and vehicle efficiency indicators, including travel time, waiting time in congestion situations, fuel consumption, and carbon dioxide emissions. The results indicated that scenarios in which the exclusive lane for public transportation and pedestrian traffic lights were removed achieved the best outcomes. To achieve this goal, the Urban Mobility Simulator (SUMO) was employed, an open-source software widely used in the literature [7]–[9], which provides extensive documentation and an intuitive interface. SUMO enabled a detailed analysis of individual vehicle behavior, enabling the simulation of road interventions such as the removal of pedestrian signals and the blue lane on an avenue without real-time traffic control. The code used in this study is public and can be reached via the link https://github.com/flaviovasconcelos/simulation-urban-traffic-scenery-maceio.

II. Related Works

Over time, computer-based urban traffic simulation has proven cost-effective for modeling and evaluating urban mobility improvements. It simplifies reality, enabling the testing of different project elements without significant resource commitments [10]. This approach is increasingly vital for optimizing traffic management as researchers explore region-specific solutions using simulation tools.

In China [11], a traffic simulation was used to tackle recurring congestion in eight sections of Wuhan, accurately measuring in real time traffic conditions and predictions based on historical data, assisting in road planning and traffic signal optimization. In Spain [12], a heuristic approach was created to improve the modeling of traffic congestion, repeatedly using the DFROUTER module of SUMO to obtain an origin-destination matrix similar to the actual traffic distribution in the cities of Valencia (Spain), Cologne (Germany), and Bologna (Italy). In Brazil [6], the VISSIM urban traffic simulator was used to assess and compare the average speed of public transportation following the implementation of an exclusive lane on the Farol Road Axis, which includes Fernandes Lima and Durval de Góes Monteiro avenues in Maceió. In the United Arab Emirates [13], a detailed model of vehicle traffic microsimulation was developed using the VISSIM simulator to study a 3.5 km section of a major highway in Abu Dhabi, with the purpose of evaluating the effectiveness of expanding public transportation services in the city. In Morocco [14], due to the complexity of conducting real traffic control system studies, a model was built in SUMO capable of simulating incidents to recreate congestion and alleviate the resulting impacts. In Belgium [15], a traffic simulation model was suggested, which incorporates probabilistic elements to model realistic travel demand (origin-destination matrices), creating a valuable simulation environment for researchers and control organizations to test a variety of scenarios related to transportation planning.

It is evident that researchers around the world are using vehicle traffic simulation environments to understand congestion dynamics and propose measures to enhance traffic flow. Table I compares the main studies related to the proposed model. The first two columns represent, respectively, the studies identified in the literature and their countries of origin. From columns three to nine, respectively, it assesses whether the study incorporates interventions on the avenue (removal of pedestrian traffic lights), dedicated lanes for public transportation, uses real-world scenarios, real traffic signal cycle data, validation with real traffic data, availability of the simulation model code, and the type of simulator employed. As it can be observed, the studies found in the literature do not encompass all the listed items, unlike the proposed model, especially with regard to interventions on the avenue and the availability of the open-source code of the model.

Among the studies presented, the work of Silva [6] closely relates to the research proposed in this paper as it also focuses on Fernandes Lima Avenue. The study employs the VISSIM simulator to assess how the blue lane affects public transportation performance but confines the analysis to speed and travel time. Furthermore, it does not provide the simulation code or consider signal phase offset data, essential for signal synchronization. As it can be observed, none of the related studies conducted an urban traffic simulation considering all variables simultaneously, just as proposed in this work. This includes the implementation of scenarios and signage based on real data, the allocation of dedicated lanes for public

TABLE I
COMPARISON OF RELATED WORKS FOUND IN THE LITERATURE WITH THE PROPOSED MODEL

STUDIES FOUND IN THE LITERATURE	COUNTRY	INTERVENTION ON THE AVENUE	EXCLUSIVE LANE PUBLIC TRANSPORT	REAL TRAFFIC SCENARIO	REAL TRAFFIC SIGNAGE	VALIDATION WITH REAL TRAFFIC DATA	OPEN SOURCE CODE	SIMULATOR
Ma et al. (2021) [11]	China			✓	✓			SUMO
Zambrano-Martinez et al. (2017) [12]	Spain			✓	✓	✓	✓	SUMO
Silva et al. (2020) [6]	Brazil		✓	✓		✓		VISSIM
Hasan et al. (2023) [13]	United Arab Emirates		✓	✓	✓	✓		VISSIM
El Hatri e Boumhidi (2016) [14]	Morocco	✓						SUMO
Mehrabani et al. (2023) [15]	Belgium			✓	✓	✓	✓	SUMO
Proposed Model	Brazil	✓	✓	✓	✓	✓	✓	SUMO

transportation, the utilization of the open-source SUMO platform, and the incorporation of four case studies involving interventions on the avenue. This approach allows for the generation of more accurate projections, resulting in errors below 5% for vehicle volume and 10% for average travel time.

III. Methodology

The methodology used follows a simulation based on the process described by Banks [16]. The Fig. **??** illustrates the flowchart containing the stages of the dynamics adopted in the simulation process.

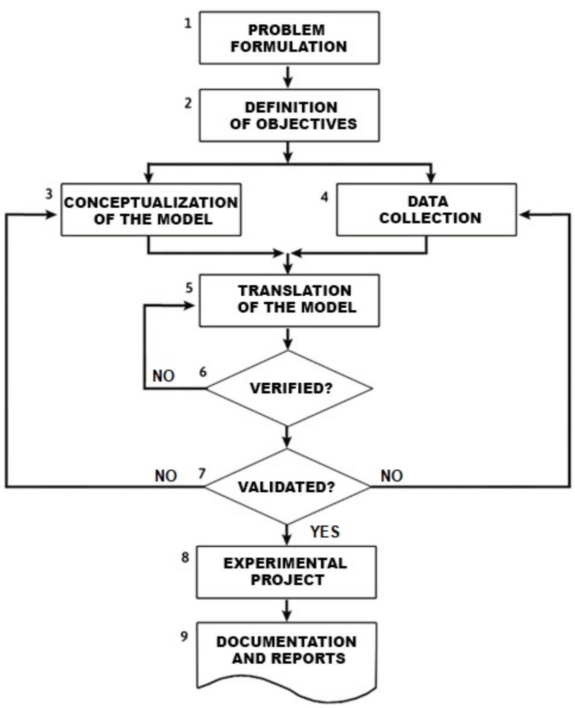

Fig. 3. Dynamic simulation model flowchart. Source: Adapted from Banks [16] apud [5].

1) **Problem Formulation:** Developing an effective urban traffic simulation model for situations where real-time control is not possible. Four different scenarios were assessed: current (scenario 1), without pedestrian traffic signals (scenario 2), without the blue lane (scenario 3), and without pedestrian traffic signals and the blue lane (scenario 4).
2) **Definition of Objectives:** Create a realistic urban traffic simulation model with the goal of implementing measures on the avenue to achieve enhancements in efficiency and vehicle flow indicators.
3) **Conceptualization of the model:** The existing system needs to be converted into a conceptual model. For this purpose, a map containing geometric data of the avenue was imported from open sources.
4) **Data Collection:** Regarding vehicular traffic data, we used the volumetric count from [6] and the traffic signal programming provided by the Municipal Superintendence of Transport and Traffic (SMTT) of the Maceió city government. Details of public transportation, including schedules and bus route information on Fernandes Lima Avenue and intersecting roads, were obtained from the SMTT website and validated through the Moovit[3] web application. The precise bus stop locations were determined through field research and observations using the Google Maps[4].
5) **Translation of the Model:** The developed model is implemented in the Urban Mobility Simulator (SUMO).
6) **Verified?** The operational model was examined in the traffic simulation environment, where vehicle input and output flows, traffic signal placement, signal configurations, blue lane positioning, bus stop locations, public transportation routes, and the implementation of the fourth lane at bus stops were observed.
7) **Validated?** The defined validation metric was the mean travel time of vehicles in the Uptown-Downtown direction. We utilized the relative error indicator, with a minimum acceptable rate of 10%, comparing the data with previous studies by Silva [6], as there are no other studies available in the literature. Additionally, a field survey was conducted to verify the traffic signal timings on the avenue.
8) **Experimental Project:** The simulation time was established as 90 minutes, with a total of 30 runs using different seeds for each scenario to generate random vehicle behavior. The first and last 15 minutes were excluded from the analysis, for environment initialization and avenue clearance, respectively.
9) **Documentation and Reports:** The methodology was concluded by documenting all the steps and actions performed, as well as preparing the corresponding reports.

IV. Proposed Model

In this section, the procedures for establishing the urban traffic simulation environment will be presented. The first step

[3]Urban mobility application with a focus on public transport and navigation information. Link: https://moovitapp.com/index/pt-br/transporte_p%C3%BAblico-Maceio-4466

[4]Service for searching and viewing maps and satellite images of the earth. Link: https://maps.google.com

TABLE II
VOLUME CALIBRATION OF VEHICLE TRAFFIC AT TRAFFIC LIGHT INTERSECTIONS (UPTOWN-DOWNTOWN) FROM 6:45 AM TO 7:45 AM.

INTERSECTIONS FERNANDES LIMA AVENUE	TRAFFIC VOLUME / HOUR SIMULATION (PROPOSED)	CI 95% (PROPOSED)	OBSERVED (LITERATURE) [6]	DIFFERENCE	RELATIVE ERROR (PROPOSED)	RELATIVE ERROR (LITERATURE) [6]
1- Camaragibe (FACIMA) Street	2455	(2433 - 2477)	2473	-18	0,7%	16,9%
4- Dr. Abelardo Pontes Lima Street	2353	(2327 - 2379)	2439	-86	3,5%	-
7- Tereza de Azevedo Street	1908	(1882 - 1934)	1939	-31	1,6%	-
8- Rotary Avenue	2968	(2936 - 3000)	2956	12	0,4%	10,5%
10- Miguel Palmeira Street	2825	(2790 - 2860)	2804	21	0,8%	3,2%
13- Desembargador Tenório Street	2892	(2869 - 2915)	2830	62	2,2%	4,6%
TOTAL	15401	-	15441	-40	1,5%	8,8%

involved defining the topology and geometry of Fernandes Lima Avenue, which mainly consists of three traffic lanes in both directions. Additionally, in certain areas, there is a fourth side lane designated for boarding and alighting of public transportation. A distinctive aspect of the avenue is the inclusion of a dedicated lane (blue lane) running along its entire right side, complemented by thirteen traffic signals, with three of them designated for pedestrians.

The OpenStreetMap [17] tool accurately incorporated the topological data of the avenue within the urban traffic simulation environment. This platform includes an open geographic database maintained by volunteers globally. It enables the export of a digital map with accurate geographic data and information about traffic signals, all incorporated using native scripts from SUMO [18] [19].

After importing the geometric data, editing was done using the Netedit tool to configure the flow of vehicles in the lanes of the avenue, including entry and exit points, as well as adding features such as the blue lane, lanes, and updated traffic signal data. These actions were crucial to make the model more realistic. Google Maps was another essential service used to observe the correct flow direction of vehicles, allowing for navigation through images and obtaining a precise understanding of public transportation stops.

In Fig. 4, SUMO can be seen performing a simulation in the scenario of Fernandes Lima Avenue, displaying the flow of different vehicles such as cars, taxis, buses, and trucks.

Fernandes Lima Avenue has four different signal programs, each with a specific operating schedule. The first is for the early morning, operating from 01:00 to 04:29; the second is for the morning, from 04:30 to 14:59; the third is for the afternoon, from 14:30 to 22:59; and the last one is for the night, from 23:00 to 00:59. For this study, the morning signal program was selected, as during this time there is a significant increase in traffic volume in the Uptdown-Downtown direction. Thus, based on the configuration of the selected signal program, the proposed model is suitable for simulating traffic during the period from 04:30 to 14:59, allowing it to be used in studies related to this specific time frame.

Fig. 5 depicts the Traffic Signal Cycle at the Intersection of Fernandes Lima and Rotary Avenues in the morning period. The total cycle length of the intersection is 170 seconds, with 90 seconds allocated to Phase 1 to allow the passage of vehicles traveling on Fernandes Lima Avenue. This is followed by a 5-second interval for the Yellow + Red phase, and then 70

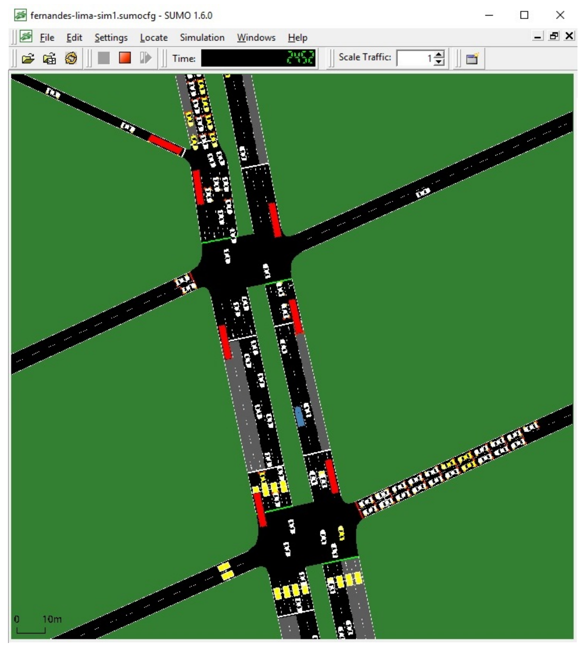

Fig. 4. Screen of the urban mobility simulator (SUMO) showing a section of Fernandes Lima Avenue. [5].

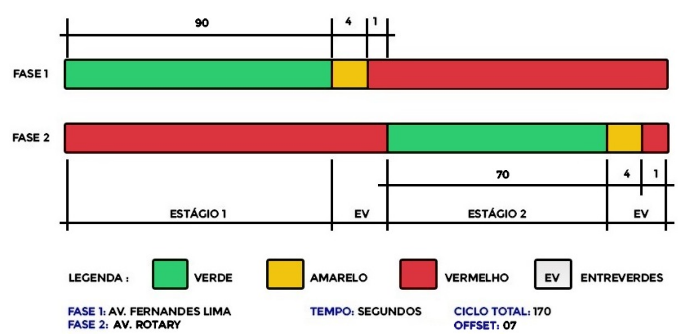

Fig. 5. Traffic signal cycle at the intersection of Fernandes Lima and Rotary Avenues from 4:30 to 14:59, [5].

seconds for Phase 2, which grants the right of way to vehicles on Rotary Avenue. Finally, there is another 5-second interval for the Yellow + Red phase, completing the cycle. The offset, which represents the time difference between the start of the cycle and the start of the signal timing plan, is 7 seconds.

Due to the lack of real traffic data, human and financial resources, unfortunately, it was not possible to conduct vehicular traffic flow studies in a broader area. For this reason, only Fernandes Lima Avenue was considered.

V. Experimental Results

In this section, the results of the computational experiments conducted will be presented, aiming to: (A) calibrate the model, (B) validate the model, and (C) analyze intervention scenarios on Fernandes Lima Avenue, such as the removal of the blue lane and pedestrian traffic lights.

A. Model Calibration

The objective of this stage is to fine-tune the simulation model in order to closely match the observed real values. In pursuit of satisfactory performance, three parameters have been configured to calibrate the traffic volume at signalized intersections: *carFollowModel*, *minGap*, and *speedFactor*.

The first adjusted variable pertains to the behavioral model of the driver, known as *carFollowModel*, where two models were tested: Krauss and Wiedemann. The Krauss model, which is the default model in SUMO, showed better volumetric results than the Wiedemann model used by Silva [6]. The latter exhibited lower performance than expected, resulting in a significant reduction in vehicle flow at signalized intersections. Therefore, for this study, the Krauss model was adopted.

The second adjusted variable was the *minGap*, which corresponds to the minimum distance, in meters, that a vehicle must maintain in relation to another when stopping on the avenue, considering the braking maneuver. The default values in SUMO for cars, buses, and trucks are 2m, 2.5m, and 2.5m, respectively. However, to obtain realistic results, the values were adjusted to 1.25m, 2.3m, and 2.3m, respectively.

The third adjusted variable is related to the speed factor, *speedFactor*, which allows the vehicle to exceed the maximum allowed speed by a certain percentage. On Fernandes Lima Avenue, the maximum speed limit is 60 km/h, but it is common for drivers not to adhere to this limit. To calibrate the model and find values closer to the observed ones, a value of 1.20 was established for the *speedFactor*, allowing the vehicle to exceed the maximum speed limit by up to 20%, which is 72 km/h. This is consistent with the conditions of the avenue, which is frequently congested and experiences acceleration and overtaking peaks, as observed in practice. The calibration step was completed using a trial-and-error approach, where several attempts were made to find an appropriate solution. Subsequently, the statistical indicator of relative error was employed to compare the observed traffic volume data at signalized intersections in the realistic and simulated scenarios. The analysis was conducted during peak hours, from 6:45 am to 7:45 am, and the minimum acceptable margin of error for the indicator was set at 5%, both positive and negative.

To create the origin-destination matrix, a native script of the urban mobility simulator (SUMO) called "randomTrips.py" was employed. The script was capable of generating a set of random trips for a specific network, selecting source and destination edges through a modified distribution simulating vehicle inflow and outflow, based on actual traffic volume data provided in the literature by [6].

The volumetric calibration of vehicles at signalized intersections is presented in Table II. The first column indicates the signalized intersection, while the second and third columns show the simulated traffic volume of vehicles and the 95% confidence interval simulated by the proposed model, respectively. In the fourth column, the traffic volume observed in the literature is indicated, obtained through field research conducted by Silva [6]. The fifth column presents the difference between the observed value in the literature and the simulated value by the proposed model, while the sixth and seventh columns indicate, respectively, the relative error achieved by the proposed model and the relative error of the model found in Silva study [6]. In general, the data calibrated by the proposed model demonstrated smaller errors compared to those obtained by Silva [6]. After conducting 30 simulations with different seeds, the relative error obtained in this study was only 1.5%, in contrast to the 8.8% found in the literature. Furthermore, when comparing the 95% confidence interval of the simulated traffic volume with the observed volume in the literature, it is observed that these values fall within the previously stipulated tolerance range. Another important piece of information to consider is that, according to Silva [6], intersections 4 and 7 were not considered in the analysis of vehicle traffic flow, despite jointly presenting a significant volume of traffic.

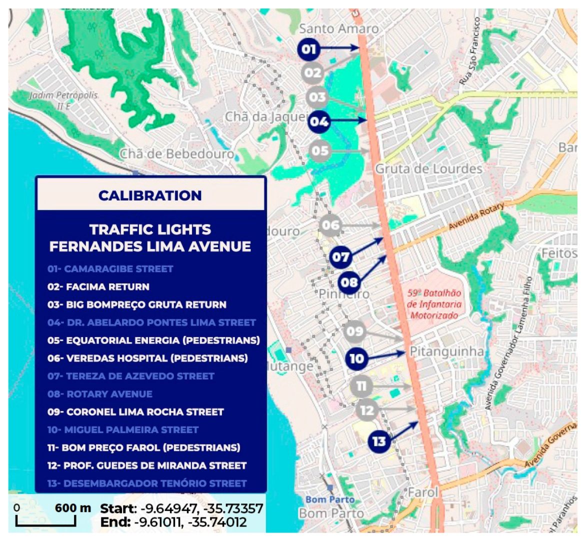

Fig. 6. Traffic light intersections for model calibration, OpenStreetMap, adapted from [5].

The Fig. 6 illustrates the location of the 13 traffic lights allocated on Fernandes Lima Avenue. Traffic lights 01, 04, 07, 08, 10, and 13 were strategically chosen to represent the entire avenue in the calibration process of the proposed model.

B. Model Validation

In this stage, the adopted validation measure was the average travel time of vehicles traveling on Fernandes Lima Avenue in the Uptdown-Downtown direction. For this, the model was executed 30 times with different seeds to generate random behaviors during a simulation period of 90 minutes. However, the first and last 15 minutes were excluded, which were used to initiate and unload the model, resulting in a total of 60 minutes of operation, representing the data collection period of traffic obtained by Silva [6], as data collection at other times was not possible due to the unavailability of human and financial resources to gather traffic volume from the high number of intersections. Therefore, assuming that this value is equal to 10% of the acceptable error rate, the relative error statistic is used to validate the model. However, the results published in Table III show the average of 30 executions.

TABLE III
VALIDATION THROUGH HARMONIC MEAN TRAVEL TIME ACROSS THE ENTIRE ROUTE OF FERNANDES LIMA AVENUE IN THE UPTOWN-DOWNTOWN DIRECTION

AVERAGE TOTAL TRAVEL TIME (m)	SIMULATION (PROPOSED)	OBSERVED (LITERATURE) [6]	RELATIVE ERROR	CI 95%
CAR	18,75	20,60	9,87%	(18,50-19,00)
BUS	16,11	15,90	1,32%	(15,94-16,28)

In Table III, the comparison of the harmonic average travel time for the car and bus modes along the entire length of Fernandes Lima Avenue is presented. The first column lists the vehicle type, while the second and third columns indicate the average simulated time and the average time observed in the literature by Silva [6], respectively. The fourth column shows the relative error rate, and the fifth column presents the 95% confidence interval for the simulated total travel time. In summary, the table compares the results of the proposed model with the data obtained from field research by Silva [6], which included both public transportation and private cars. The goal was to record the travel time and obtain an average over two consecutive days during the period from 6:45 AM to 7:15 AM. The average real travel time recorded in the literature for the Car and Bus modes were 20.6 minutes and 15.90 minutes, respectively. Whereas for the proposed simulation model, they were 18.75 minutes and 16.11 minutes, respectively. Thus, both the Car and Bus modes fell within the proposed range, with a relative error of 9.87% and 1.32%, respectively, demonstrating significant agreement with the collected real-world data. Finally, to determine the range of values that contains the true total average travel time simulated with a 95% probability, the statistical method of Confidence Interval was used. The results confirmed that the values are within the established margin of error, indicating good agreement between the obtained results and reality.

C. Case Studies

Interventions were performed on the avenue for each of the 4 proposed scenarios (current, without blue lane, without pedestrian traffic lights, and without both pedestrian traffic lights and blue lane) to analyze the behavior of vehicle traffic volume at signalized intersections, as well as efficiency indicators such as travel time, congestion waiting time, fuel consumption, and carbon dioxide emissions. The results were obtained after running 30 simulations for each scenario.

The current scenario represents the current conditions of Fernandes Lima Avenue, while the subsequent scenarios depict the same situation with specific interventions. The second scenario proposes the removal of the restriction on the blue lane, allowing vehicles from other modes of transport to travel in all lanes along with buses. The third scenario suggests the removal of three pedestrian traffic lights. Finally, the fourth scenario combines the interventions proposed in scenarios two and three, meaning it suggests the removal of the blue lane and the three pedestrian traffic lights.

Table IV presents the results of the simulations conducted for each of the 4 developed scenarios. The first column indicates the vehicle type, while the second column refers to the evaluated indicator (Travel Time, Waiting Time, CO2 Emissions, and Fuel Consumption). The remaining columns display the results obtained for each proposed scenario in relation to the evaluated indicator, namely: Scenario 1 (Current), Scenario 2 (Without Blue Lane), Scenario 3 (Without Pedestrian Traffic Lights), and Scenario 4 (Without Blue Lane and Pedestrian Traffic Lights). In summary, the results were obtained by averaging the simulations conducted, with a particular emphasis on Scenario 4, which suggests the elimination of the blue lane and the three pedestrian traffic lights. This scenario showed a 9.75% reduction in bus travel time, from 16.11 to 14.54 minutes. For cars, there was an even more significant decrease in average travel time, with a reduction of 59.25%, from 18.75 to 7.64 minutes.

Table V presents the results regarding the volume of vehicle traffic at the signalized intersections. Compared to Scenario 1 (Current), Scenario 2 (Without Blue Lane) provided a traffic volume gain of 9.95%, while Scenario 3 (Without Pedestrian Traffic Lights) offered a gain of 7.88%. Scenario 4 (Without Blue Lane and Pedestrian Traffic Lights) had the highest gain, with an increase of 10.77%. It is therefore concluded that the removal of the blue lane and pedestrian traffic lights can result in significant improvements in vehicle traffic. In fact, the removal of pedestrian traffic lights alone can help restore the traffic volume lost with the implementation of the exclusive lane for public transportation. In parallel, in order to support the removal of pedestrian traffic lights, regulatory agencies should focus on conducting studies to enable the implementation of pedestrian bridges in the three regions where pedestrian traffic lights are currently present.

VI. CONCLUSIONS

The proposed study offers a valuable contribution to urban traffic simulation by introducing a new open-source model that has been verified using real data from Fernandes Lima Avenue in Maceió. This model incorporates peculiarities such as the dedicated lane for public transportation and pedestrian traffic lights, which enable the simulation of interventions to optimize traffic flow. Furthermore, it distinguishes itself with superior accuracy, exceeding the performance of previous models in the literature. Additionally, four distinct scenarios were examined using various interventions, enabling a comprehensive assessment of traffic performance, including critical factors like traffic volume and efficiency indicators such as travel time, congestion waiting times, fuel consumption, and carbon dioxide emissions. The results emphasize the importance of considering interventions on the avenue to enhance performance metrics. While focused on Fernandes Lima Avenue, this study provides applicable insights and approaches to similar

TABLE IV
COMPARATIVE RESULT OF VEHICLE EFFICIENCY INDICATORS (SCENARIOS 1, 2, 3 AND 4).

VEHICLE	INDICATOR	SCENARIO 1	CI 95%	SCENARIO 2	CI 95%	SCENARIO 3	CI 95%	SCENARIO 4	CI 95%
CAR	Travel Time (min)	18,75	± 0,25	10,19	± 0,09	12,47	± 0,17	7,64	± 0,02
	Wait Time (min)	7,74	± 0,13	2,80	± 0,03	4,39	± 0,10	2,01	± 0,01
	Emissions of CO_2 (g)	2649,71	± 25,49	1656,26	± 8,84	1947,32	± 18,77	1398.30	± 3,87
	Fuel Consumption (l)	1,14	± 0,01	0,71	± 0,01	0,84	± 0,01	0,60	± 0,01
BUS	Travel Time (min)	16,11	± 0,17	18,15	± 0,19	14,91	± 0,11	14,54	± 0,06
	Wait Time (min)	3,72	± 0,09	4,77	± 0,09	3,29	± 0,05	3,54	± 0,04
	Emissions of CO_2 (g)	11448,60	± 33,03	11792,90	± 34,34	10915,60	± 26,02	10036,49	± 21,55
	Fuel Consumption (l)	4,88	± 0,01	4,90	± 0,01	4,65	± 0,01	4,28	± 0,01

TABLE V
COMPARATIVE RESULT OF VEHICULAR TRAFFIC VOLUMETRIC (SCENARIOS 1, 2, 3 AND 4).

TRAFFIC VOLUME (UPTOWN-DOWNTOWN)	SCENARIO 1	CI 95%	SCENARIO 2	GAIN	%	CI 95%	SCENARIO 3	GAIN	%	CI 95%	SCENARIO 4	GAIN	%	CI 95%
1- Camaragibe Street (FACIMA)	2455	± 22,34	2641	186	7,58%	± 1,21	2647	192	7,82%	± 1,42	2639	184	7,49%	± 1,31
4- Dr. Abel. Pontes Lima Street	2353	± 25,79	2592	239	10,16%	± 1,17	2594	241	10,24%	± 3,32	2591	238	10,11%	± 1,95
7- Tereza De Azevedo Street	1908	± 25,89	2159	251	13,16%	± 1,17	2117	209	10,95%	± 8,09	2143	235	12,32%	± 1,32
8- Rotary Avenue	2968	± 32,18	3279	311	10,48%	± 4,28	3175	207	6,97%	± 8,20	3206	238	8,02%	± 3,35
10- Miguel Palmeira Street	2825	± 35,37	3159	334	11,82%	± 7,01	3031	206	7,29%	± 8,89	3212	387	13,70%	± 2,85
13- Des. Tenório Street	2892	± 23,16	3104	212	7,33%	± 5,18	3051	159	5,50%	± 7,61	3268	376	13,00%	± 3,53
TOTAL	**15401**	-	**16934**	**1533**	**9,95%**	-	**16615**	**1214**	**7,88%**	-	**17059**	**1658**	**10,77%**	-

urban areas. For future studies, two points are noteworthy: 1. Integration of a metaheuristic to optimize the traffic signal cycle and improve flow. 2. Expansion of the geographical study area to understand the regional impacts of proposed traffic flow changes.

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