TRAFFIC SIMULATION WITH OPEN-SOURCE AND COMMERCIAL TRAFFIC MICROSIMULATORS: A CASE STUDY

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Resume
The analysis of traffic problems in large urban centers often requires the use of computational tools, which give the possibility to make a more detailed analysis of the issue, suggest solutions, predict behaviors and, above all, support efficient decision-making. Transport microsimulation software programs are a handy set of tools for this type of analysis. This research paper shows a case study where functions and limitations of Aimsun version 8.2.0, a commercial-like European software and Sumo version 1.3.1, a European open-source software, are presented. The input and output data are similar in both software and the interpretation of results is quite intuitive for both, as well. However, Aimsun's graphical interface interprets results more user-friendly, because Sumo is an open-access software presented as an effective alternative tool for transport modeling.

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1 Introduction

Planning, network development and management of vehicular traffic systems are a daily concern in every city all over the world. In this regard, it is quite clear that cities need their transport infrastructures to have capacity and synchronization in their operation for both current and future demands. The out of proportion increase in the number of vehicles affects large urban centers, especially during the rush hours, when the saturation of streets is more evident. Likewise, this phenomenon triggers other negative outcomes, such as the increase in accident rates, longer travel times and low circulation speeds, generating stress and irritability in road users, affecting them socially and economically, as well as reducing their quality of life [1-2].

Analyzing solutions to this type of problems requires, in many cases, the use of computational and simulation tools that describe, understand and predict the behavior of the studied vehicular phenomenon. These tools correspond to traffic simulators that offer different levels of detail for analysis: macroscopic, mesoscopic and microscopic. The main difference between the three approaches is that the macro simulators treat stationary and aggregated values, while the micro simulators study the temporal evolution of all the variables, as well as simulate in detail both user behaviors and their interaction with the traffic network. In addition to this, there is an intermediate level between the two previously-mentioned systems known as mesoscopic simulators [1].

The city level transportation decisions are supported by use of this type of tools which allow evaluating, in a controlled environment, the possible impacts that the solutions to be implemented would have. Hence, these simulation models seek to replicate the real-world conditions through a visual and mathematical representation that combine, in a single environment, the behavior and decisions of travelers with vehicles, as well as infrastructure. That is the reason why there is a lot of simulation tools on the market, some open-source and others with commercial value. An example of commercial software is Aimsun, whose license ranges from € 20,000 to € 25,000 [3] and in the case of open-source software, there is Sumo [4] - Simulation of Urban Mobility. These two tools can be used both at academic level and by decision makers when analyzing different transport-related problems [5].

This research objective was to build, calibrate and validate two simulation models in a specific sector of Bucaramanga, Colombia and, finally, to show a comparative analysis of the results of each traffic simulation packages. For that purpose, factors such as effectiveness, required information and validity of the obtained results were taken into account. Section 2 describes the literature review that determines the characteristics that represent each of the applications' functionality, the primary input data, the most relevant parameters that significantly impact the models and the most common output data requested in vehicular traffic microsimulation studies. Section 3 presents the study area considered for the scenario used as a real case application for the two simulators. Section 41 describes the construction of scenarios and Section 5 their calibration and validation. Section 6 shows the obtained results and Section 7 and Section 8 summarize the conclusions and future research.

2 Literature review

This section presents the results of the documentary research process that was conducted, which served as a starting point for the analysis carried out in this work [6]. This review allowed having a clearer vision of evolution of the microsimulation models in each of the computational tools used.

2.1 Bibliographic analysis

The bibliographic research was performed using BASE (Bielefeld Academic Search Engine). In addition, other databases, such as Scopus, Science Direct and ASCE were consulted; BASE yielded most of the positive results, which became the database used. The keywords for the search were defined as: Sumo, Aimsun, Traffic Microsimulation and Comparison. In addition, combinations were configured using Boolean operators to broaden and improve the search.

2.1.1 Bibliometrics

The current state of research status was analyzed in relation to the information on comparisons, characteristics, parameters and operation of microsimulation software, publications, authors, quotes and the development of research on simulation tools over time. This analysis made it possible to identify that the United States has the highest production in this area, followed by countries such as Italy, Germany and in the case of Latin America, Brazil stands out.

Moreover, these articles were grouped according to the year of publication and found that there was a greater number of publications related to transport microsimulation software between 2012 and 2013. These research studies include the revision of characteristics and performance analysis that enables to make the corresponding comparisons of the simulation tools.

2.2 Traffic microsimulation

Nowadays, the traffic microsimulation tools are regarded as an advanced mechanism of representation and analysis of vehicular flow on a transport network, which is suitable for development and evaluation of intelligent transport systems [7]. This is due to the fact that they allow modelling, in a flexible way, of any type of geometry and provide a more efficient representation of the behavior on a road network [8].

These tools also let professionals or authorities in charge of the transport system of a city to test and evaluate a set of traffic control and operation measures in different transport systems.

In addition to this, they give the possibility to predict behaviors according to the variety of results they provide [9].

These microsimulation tools are characterized by allowing a more detailed modeling of the behavior of drivers and vehicles individually. Nowadays, it is very common that research groups and traffic control and mobility organizations of cities around the world that work with traffic modeling topics have developed or adapted their own simulation package (e.g., MATsim at ETH Zurich and Sumo at Transport Research Institute of the German Aerospace Center (DLR)) [7]. They have done so mainly using algorithms based on vehicle tracking, lane changes and gap acceptance. All these, with the only purpose of obtaining more reliable results through the relationships between users, vehicles and elements that make up the network.

2.2.1 Aimsun

Aimsun is a commercially licensed transport modeling software developed and marketed by the Spanish company Transport Simulation Systems (TSS) [10]. It is currently considered as one of the most advanced simulators as it has three levels of detail (Micro, Meso and Macroscopic). Therefore, it has the capacity to deal with different traffic networks: urban networks, highways, arteries, intersections and combinations between them [11]. It has plenty of advantages over other applications on the market, chiefly because it is a hybrid simulator, which allows modelling large areas while examining other zones with a finer level of detail. Other advantages are its execution speed as it is very fast and its interface has around 6 languages [10-11]. However, having its license means investing a considerable amount of money, which not every professional or organization can afford [3].

Aimsun has been used in different countries all over the world at academic, research, business and

Table 1 *Examples of projects using Aimsun*

Year	Research and application projects
2017-2020	Sydney: M4 Smart Motorway project [11].
2019	Singapore: Technology trial for the real-time traffic simulation and prediction [11].
2015-2017	Leicester: Urban traffic management and Air Quality (uTRAQ) [11].
2016-2017	Gold Coast: Predictive Solutions Trial [11].

Table 2 *Examples of projects using Sumo*

Year	Research and application projects
2006	Soccer2006: Traffic prognosis during the FIFA-WorldCup 2006 [4].
2008	Veins - „Vehicles in Network Simulation“ [4].
2008	Analysis and simulation of linkability measures in pseudonymous mobile communication [4].
2011	ORINOKO: improvements on mobility in the city of Nurnberg [4].
2018	Bologna, Simulation of activity-based demand with Sumo [4].

Table 3 *Input Data*

Input Data	
Information for network creation	Network configuration
	Number of lanes
	Traffic signs
	Traffic control devices
	Lane width
Demand information	Modes of transport
	OD matrices
	Flow definitions and turn relationships

professional levels [11]. Table 1 shows examples of projects in which this software has been used.

2.2.2 Sumo

Sumo is a traffic simulation package created by the Transport Research Institute of the German Aerospace Center (DLR) in 2000 [10]. Basically, it is a highly portable open-source microscopic vehicular traffic. Since version 0.26.0, it has been possible also to model scenarios with a mesoscopic level of detail although it does not present the ideal functioning for this type of model [10].

It is made up of a series of applications, which help to prepare and perform the traffic simulation. One of these extensions, used for the development of this research, is SumoPy [8]. It is made with Python programming language [4] and is contained in a graphical user interface that provides tools with multiple functionalities: SumoPy allows to manage all the transportation data that can be simulated with Sumo [12] as well as deeply analyze the GPS traces [13-14]. A large number of research and application projects have been carried out with Sumo [4], in addition to projects that are responsible for the ongoing development of the tool thanks to the fact that it is open-source [4]. Table 2 shows some examples of projects developed with this software.

2.2.3 Data input in microsimulation models

The minimum input data required, established by the literature review that was conducted and which must be previously established to generate a scenario in microsimulation software, are listed in Table 3 [4-11, 15].

2.2.4 Characteristics

Based on the information and literature review obtained from the document of the US Federal Highway Administration [15] (FHWA), the characteristics considered relevant for the transport microsimulation applications were: License, Technical documentation, Source code availability, Maneuverability, Level of detail, Operative system, post-processing requirements, Integration with other Traffic Applications and Visualization (see Table 4).

Table 4 *Characteristics*

Caracteristics	Aimsun	Sumo
Licence	The license requires a permit, which is acquired at a capital cost. Therefore, it is commercial-type software [16].	The software and all its tools can be downloaded from the official website. No payment is required; therefore, it is opensource software under the terms of EPL V2 [4, 12-25].
Technical Documentation	The tool contains articles and reports on its implementation. It also provides a support feature that grants direct access from its interface [16].	It summarizes the information on its website. The information presented on the website is not sufficient to have a faster and easier implementation of the software [16].
Source code availability	Aimsun does not allow access, distribution of copies, or modification of the source code [16].	Sumo's source code is open, so it allows for on-going development by the community that implements it [4, 9-11, 16].
Maneuverability	It is generally easy to use. It contains an interface that has tools with intuitive functions. A user with programming skill is not required [4, 9-11, 16].	Sumo software requires prior knowledge of Python, C ++ or the command line, as well as manipulation of XML files [16]. It is equipped with an extension that offers a GUI interface, a network editor and a language that makes it user-friendly. For this reason, the main goal of SumoPy is trying to facilitate the use of Sumo's tools: it can be easily used for creating complex multimodal scenarios to be simulated with Sumo [4].
Level of Details	It allows making models with the three levels of details, Macroscopic, Microscopic,and Mesoscopic [16].	In addition to the Microscopic level, the Marouter tool allows calculating a Macroscopic assignment. As of Sumo 0.26.0, it is possible to model scenarios at a Mesoscopic level of detail [4, 12-26].
Operative System	Aimsun is compatible with Windows operating systems, Mac OS X and Linux systems [9].	Sumo is available on operating systems such as Windows, Mac OS X and Linux [5-9].
Post-processing Requirements	Aimsun produces the results in formats which do not require further processing. It has a report-only module with multiple options for the user to set up real-time graphical outputs of the results [4, 9-11, 16].	Directly from Sumo, it is necessary to enter the code and request the measures provided in different additional files. The SumoPy extension allows obtaining the results without a post-processing requirement, both from its interface and in additional files [4].
Integration with other Traffic Applications	It is compatible with the following software: Vissim, Visum, Paramics, Synchro, GIS, CONTRAM, SATURN and TRANSYT [11].	It is compatible with the following softwares: Vissim, Visum, OpenDRIVE, MATsim, ArcView and RoboCup [4].
Visualization	Visualization of the scenarios in Aimsun can be two-dimensional (2D) and three-dimensional (3D) [16].	The animation presented by Sumo is low-detailed compared to Aimsun, as it only allows for two-dimensional visualizations of the simulation procedure (2D) [4, 9-11, 16].

2.2.5 Parameters

Given the degree of sensitivity that some of them have, parameters play a vital role in model calibration and validation, as they have a direct impact on the results. [7]. All the microsimulation models involve three main elements, the vehicle, the road and the driver [7] and large number of parameters are associated with them. Based on the literature review, the most relevant parameters used for the validation and calibration process in microsimulation models were identified, both in Aimsun and Sumo; Sumo being an open-access software, uses the same parameters as commercial software, which offers the versatility of the software when creating the modeling scenarios.

Another requirement is the location of the study, which is the place that contains the details of the road network [16]. The representation of a road network is made by means of connections or nodes, which are joined together using linear elements that represent the lanes where each of the modes of transport will circulate.

These microsimulation tools have the ability to work together with geographic location applications, which makes it possible to import a road network with multiple details and this makes the procedure of creating the road network easier. In the process of generating the vehicle traffic demand, it is very common to find two ways to define it. The first one uses O/D matrices (Origin/Destination) and the second one directly assigns the traffic flows in each of the sections that make up the network.

Table 5 *Output Data*

Output Data	Aimsun	Sumo
Average Vehicle Queuing Length	Veh	Veh
Fuel Consumption	L	ml/s
Traffic Density	Veh/Km	Veh/Km
Total Vehicle Travel Distance	Km	m
Pollutant Emission	g/s	mg/s
Traffic Flow	Veh/h	Veh/h
Level of Service	A-F	--
Stop Time	h	s
Delay Time	sec/Km	s
Total	h	s
Total Vehicle Travel Time (Waiting outside)	h	s
Average Speed	Km/h	m/s

2.2.6 Output Data

This section analyzes into the ability of these tools to generate and produce different types of results in the areas of efficiency (performance and volume), dynamicity (speed and travel time), environment (emissions, fuel consumption) and productivity (cost-benefit) [18]. According to the document from the Federal Highway Administration (FHWA) on selection of the microsimulation tools [18] and the literature review that was carried out previously, the main output data were established, in order to draw conclusions on the most important results. Table 5 shows the main output data generated in the microsimulation models, their corresponding units according to the way in which they are obtained from the software and whether they are generated by each of these applications. As shown in Table 5, both Aimsun and Sumo are capable of generating the same amount of output data, except for the level of service, which is output data from Aimsun, but not from Sumo. The level of service, which is widely used for traffic studies, describes the operating conditions of the traffic flow. Another clear difference between the two applications is the units of delivery of results, as the output data highly differ when using one application or the other.

3 Characterization of the study area

In order to assess the benefits of each software, when applied in an urban microsimulation analysis, an urban area located in the city of Bucaramanga (Colombia) was identified. This city, which is located in the northeast of this country, is the capital of the department of Santander and is considered as one of the most prosperous cities in Latin America [19]. This area was chosen due to its previous operational characterization, which was carried out from records of the field data collection, as this allows for the identification of directions of vehicular traffic, traffic lights, vehicle volumes and horizontal and vertical signaling.

The information required as input data for the simulators was the following: the characterization of land use in the area, the geometry, horizontal and vertical signaling, traffic lights, vehicle capacity, cargo truck stockpiles, bus routes, location of bus stops and the matrices origin destination for each of the modes of transport [15]. Figure 1 sows the zone of influence.

3.1 Characterization of the road network

The zone of influence includes primary and tertiary urban connection roads. However, most of them belong to local level 1 and 2 networks that are characterized by penetrating residential sectors or main accesses to neighborhoods and channeling low-speed traffic flows to areas with higher activity [20]. Figure 2 shows the distribution of traffic networks.

Additionally, traffic light times were recorded at the intersections of the sector and the vertical and horizontal signals.

3.1.1 Vehicle count

The vehicle demand data collection for the validation process was carried out on a typical working day (weekdays), as well as on an atypical day (weekend), on the intersection located on Carrera 28 and Calle 41, which was the main intersection of study. This was made in order to determine the rush period. The corresponding vehicle counts to the typical day was made on Thursday, November 14, 2019, from 5:00 a.m. to 7:00 p.m., then the vehicle counts for the atypical day was made on Saturday, November 16, 2019 between 5:00 a.m. and 7:00 p.m.

The remaining vehicle counts, were made according to the hour of maximum demand, on Thursday, November 28, 2019, on three points that intervene in the behavior of the intersection. Figure 3 shows the arrangement of the information collection points.

3.2 In-field information processing

The coding of vehicle turns on the intersection was characterized according to the direction of origin and destination. This coding is in accordance with the planning and design manual for traffic and transport administration [21]. In the case of vehicles, a classification was made in order to define how they are regarded in Colombia. This classification was made in accordance with the provisions of the Ministry of Transportation.

With the aim of identifying the maximum flow amount and the peak time on the main road intersection of the study area, a conversion from mixed vehicles to equivalent vehicles was made.

Based on the analysis performed on the field information obtained, it was determined that the time of maximum demand on the road intersection was between 1:45 pm and 2:45 p.m. on the typical working day of the study. The maximum level of demand corresponds to the number of 1,355 mixed vehicles.

In the case of an atypical day, the demand decreases

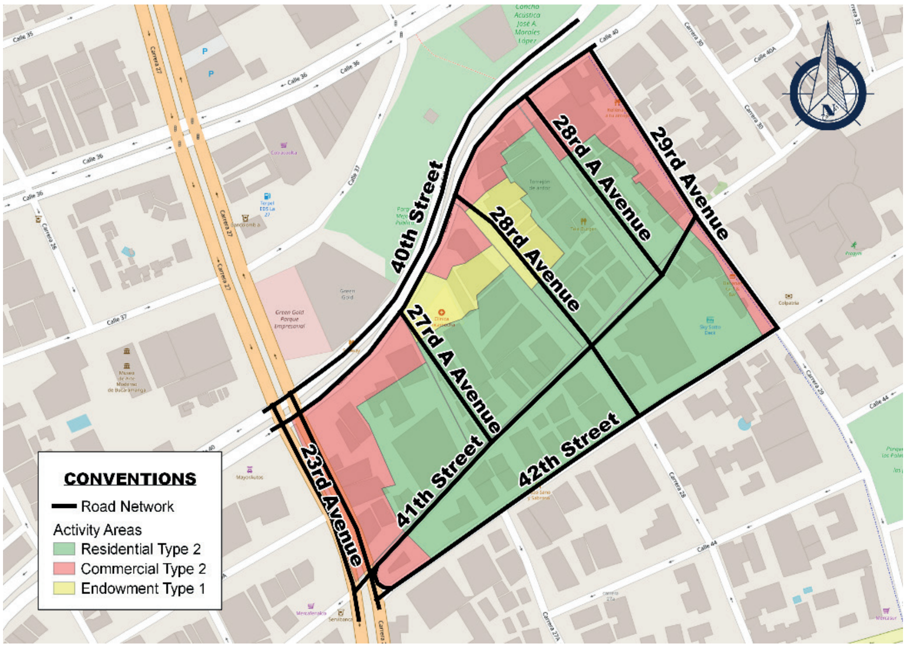

Figure 1 *Areas of Activity in the Zone of Influence Source: Adapted from POT Bucaramanga https://bit.ly/2FHvxmI*

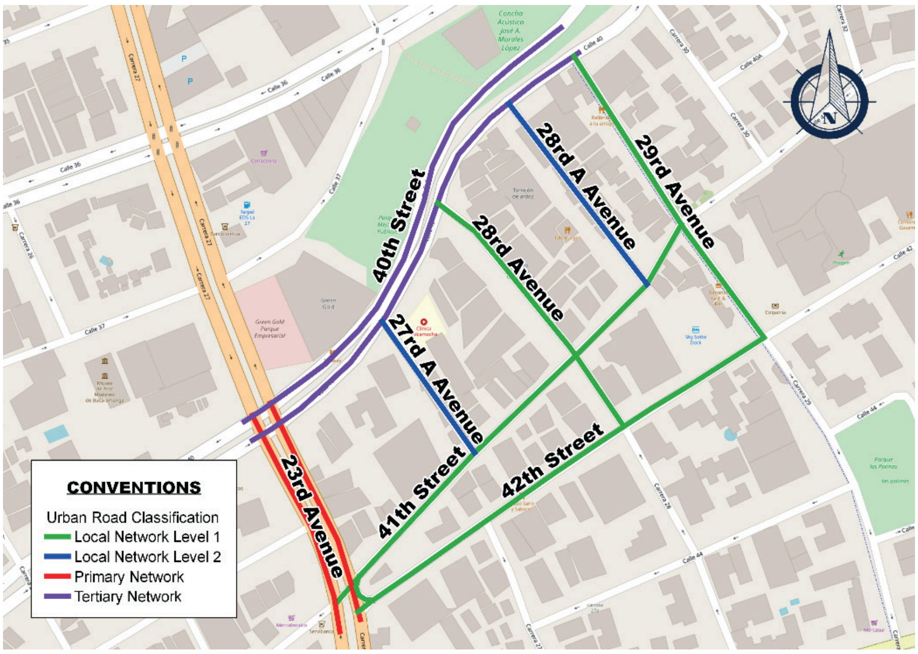

Figure 2 *Urban Road Classification. Source: Adapted from POT https://bit.ly/2FHvxmI*

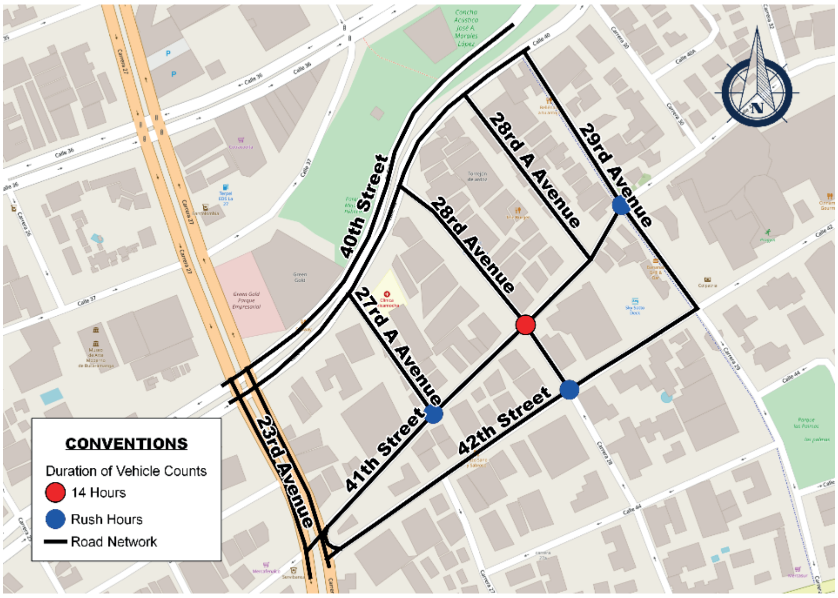

Figure 3 *Duration of vehicle counts*

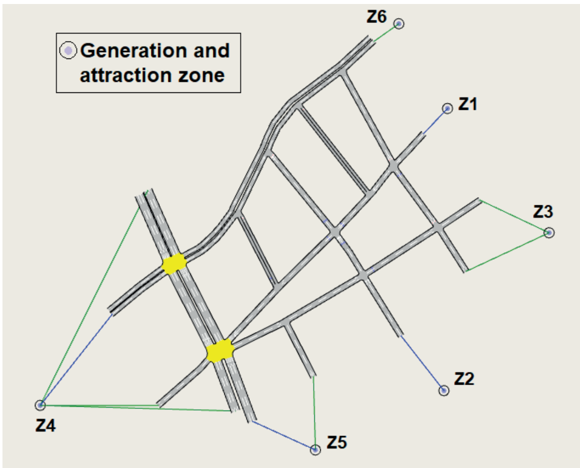

Figure 4 *Road Network and Centroids of generation and attraction on Aimsun*

in comparison to the demand of a typical day. This was expected due to the fact that the study area is made up of a residential zone in a higher percentage, which implies that most of the journeys take place in the morning and at the end of the afternoon. The maximum level of hourly demand corresponds to the total number of 1,038 mixed vehicles, between 9:45 am and 10:45 am.

It was also possible to determine the mode of transport distribution in the total rush period, for both the typical day and for the atypical day. The results showed that light vehicles such as taxis, cars and pickups are the ones with the highest presence, 57% of the total number of vehicles for both the typical day and the atypical day, followed by motorcycles with 40% for the typical day and 41% for the atypical day and a very small portion pertaining to bicycles and heavy vehicles such as buses, trucks and tractor units, corresponding to 3% for the typical day and 2% for the atypical day.

4 Construction and configuration of the simulation scenario

The process for the construction of a simulation scenario comprises four interdependent stages, the geometry and physical characteristics of the road network, signs and control equipment, vehicle demand and the products obtained [15]. In order to create geometry in each software, it was necessary to know its operation, as well as to identify the necessary data, which were determined in the literature review. The road network was imported from the Open Street Map tool; the modes of transport were classified as Light vehicles, motorcycles, buses, trucks and bicycles. Based on the information collected in the different capacities and their due mathematical processing; the OD matrices were defined for each of the modes of transport.

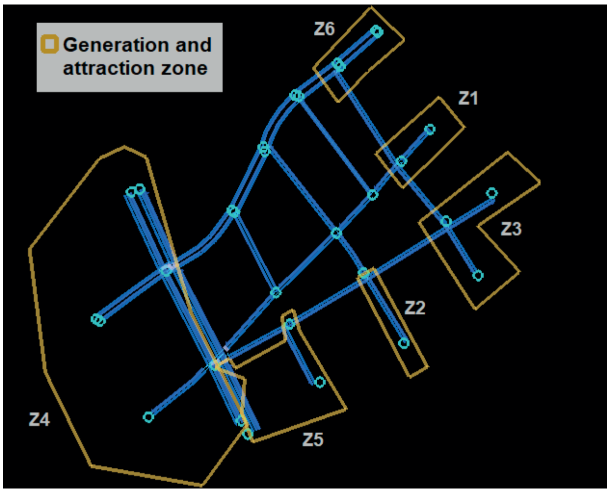

Figure 5 *Generation and attraction zones on SumoPy*

4.1 Aimsun

The license for the academic use of the Aimsun software (Version 8.2) used for the creation of the model was provided by the Geomatics, Management and System Optimization research group of the School of Civil Engineering of Industrial University of Santanderr. The process of the road network generation is relatively simple as Aimsun has an intuitive interface, which allowed the network to be adjusted according to the conditions taken in the field. The demand generation process was carried out using OD matrices, which made it necessary to identify vehicle generation and attraction areas. Altogether, 6 zones were identified, with 2 generation zones and 2 attraction ones, as well as 2 zones that perform both procedures (generation and attraction). The arrangement of these zones was made according to the directions of the trips observed in the field. Figure 4 shows the location of the centroids that represent these zones.

4.2 Sumo

The Sumo microsimulation software (Version 1.3.1) used to create the model was downloaded from the official website. Regarding the creation and generation of demand for the simulator, the SumoPy extension was used, which allowed this process to be carried out more easily and quickly owing to its interface. After importing the network through Open Street Map from SumoPy, with the help of the Netedit network editor, the network was adjusted according to the own characteristics of the network verified in the field. Exactly as in Aimsun, it was necessary to create the zones for generating and attracting vehicles (6 zones), this time by means of polygons that delimited these zones. The input data of vehicle flows and the OD matrices are entered disaggregated by vehicle type in both software. The graphical interface each software allows for creating tables with the origins in the rows and the destinations in the columns. Figure 5 shows the polygons that represent each zone.

5 Model calibration and validation

The calibration process of a microsimulation model is carried out adjusting the predetermined parameters contained in the software to local conditions [8]. The first step was to carry out the conditioning of the network adapting the lane width with the dimensions taken in the field, the number of lanes, the speed allowed in accordance with the provisions of the national traffic code and the regulatory signs that make up the influence zone. Subsequently, the parameters corresponding to the modes of transport are adjusted according to the types of vehicles shown in the Manual of Geometric Design of Highways in Colombia of the National Institute of Roads. It involves adjusting the length, width, maximum speed and the lane change model. Bicycles and motorcycles were left at their default values. The traffic allocation method chosen for this project was the stochastic method, which has a better representation of reality in the model. This method allows the road user to choose a route evaluating the fastest and cheapest way to reach their destination. In other words, the current state of the road is taken into account in the allocation method in relation to the vehicle flow. This influences the decision of each vehicle user, which is a very similar behavior in reality. According to the behavior during the course of the journey, from its departure, user can take a more effective route that allows them to get to their destination, avoiding queues of vehicles and low speeds that affect the travel time [17]. Successively, there are different methods to validate the obtained results, among these are: the GEH indicator in honor of Geoffrey E. Havers, the mean square error MSE and the correlation coefficient or coefficient of determination R2, among others [15]. Given that there are data taken

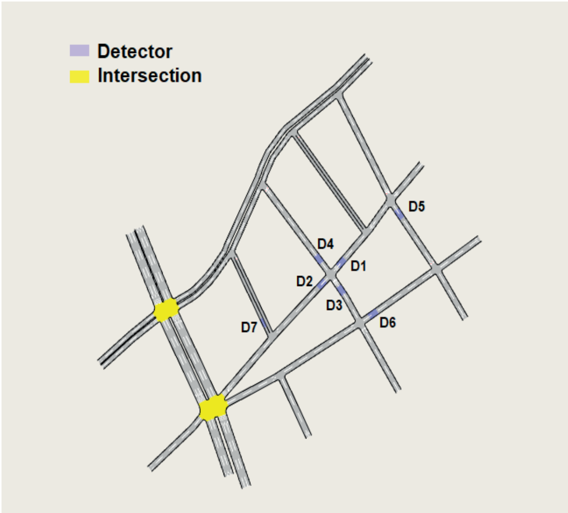

Figure 6 *Detectors Allocation on Aimsun*

from the field, the GEH indicator was used in this work, which demonstrates how easily adjustable the model is, which is given by the following equation:

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

where:
O = Traffic volume observed in the field,
M = Traffic volume passing in the model.

Based on [5], the criteria established for a traffic allocation model, to be calibrated according to the GEH statistical indicator, there must be at least 85% of the cases in which the GEH statistic has a value lower than 5.

A specific number of iterations is required to achieve the statistical validity of the models in the calibration stage or the evaluation stage of the project implementation scenarios. To determine the number of iterations, the guidelines defined by the FHWA, where a confidence level of 95% and a maximum standard deviation of 2 are sought.

5.1 Aimsun

The validation process in Aimsun was performed using detectors. The configuration of these detectors (blue bands in Figure 6) on the network was performed at the points where the vehicle capacity was carried out.

By means of these detectors, it was possible to obtain the number of vehicles, which passed on each of the lanes, according to equation of the GEH indicator. Moreover, verification of the model was made in order to find out whether it was correctly calibrated in accordance with the established conditions.

The validation was performed for each mode of transport; eight iterations were performed in Aimsun, as eight iterations are considered to be sufficient to obtain valid results from a traffic simulation model [12-14, 22-29]. For bicycles, trucks and buses (Table 6), the GEH statistical criteria validated the results, whereas for the light vehicles and motorcycles (Table 7), although validated, not all the criteria obtained 100% acceptance, they complied with what had been established by the indicator used.

Table 6 *Validation for Bicycles, Trucks and Buses on Aimsun*

Mode of Transport	Real Volume [Veh]	Model Volume [Veh]	Elements with GEH < 5 [%]
Bicycle	49	46	100
Truck	67	63	100
Bus	12	9	100

Table 7 *Validation for Light Vehicles and Motorcycles on Aimsun*

Mode of Transport	Real Volume [Veh]	Model Volume [Veh]	Elements with GEH < 5 [%]
Light Vehicles	2.791	2.578	90
Motorcycles	2.064	1.932	90

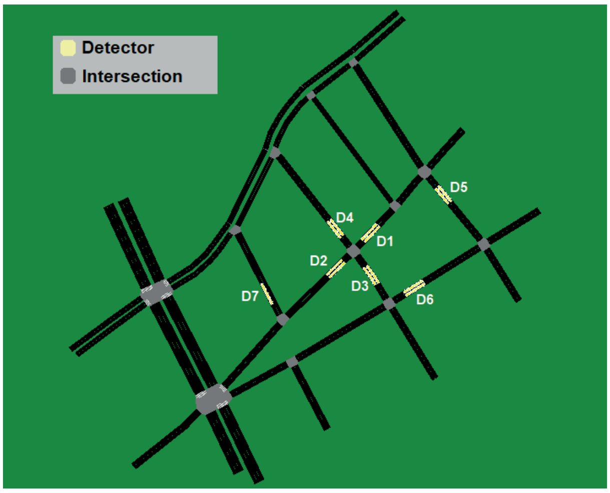

Figure 7 *Location of the Sumo Detectors*

5.2 Sumo

Regarding Sumo, the validation process was also carried out using detectors (yellow lines in Figure 7). These detectors were spatially located in the same position as they were located in the Aimsun model. In the same way, the number of vehicles was estimated and the corresponding calculations were performed in order to execute the validation process using the GEH indicator.

Validation was performed for each mode of transport. In Sumo, eight model replications were performed to obtain valid results [22]. Bicycles, trucks and buses (see Table 9) were fully validated, thus the results meet the criteria of the GEH indicator. Meanwhile, although validated, for light vehicles and motorcycles (Table 8) all the criteria did not obtain 100% acceptance, but they complied with the provisions of the indicator.

For bicycles, trucks and buses (Table 8), the GEH statistical criteria validated the results, whereas for the light vehicles and motorcycles (Table 9), although validated, not all the criteria obtained 100% acceptance, they complied with what had been established by the indicator used.

Table 8 *Validation for Bikes, Trucks and Buses on Sumo*

Mode of Transport	Real Volume [Veh]	Model Volume [Veh]	Elements with GEH < 5 [%]
Bicycle	49	44	100
Truck	67	65	100
Bus	12	12	100

Table 9 *Validation for Light Vehicles and Motorcycles on Sumo*

Mode of Transport	Real Volume [Veh]	Model Volume [Veh]	Elements with GEH < 5 [%]
Light Vehicles	2,791	2421	90
Motorcycles	2,064	1812	90

Table 10 *Test t to 95% confidence results by detector*

Detector	t Calculated		t Table
	Aimsun	Sumo	
D1	-2.057	-2.182	
D2	-1.371	-1.335	
D3	-1.387	-0.870	
D4	-2.126	-1.625	2.365
D5	-0.027	-1.416	
D6	-0.960	-0.754	
D7	0.082	-0.034	

** -t Table < t Calculated < t Table: Ok statistical significance to 95%*

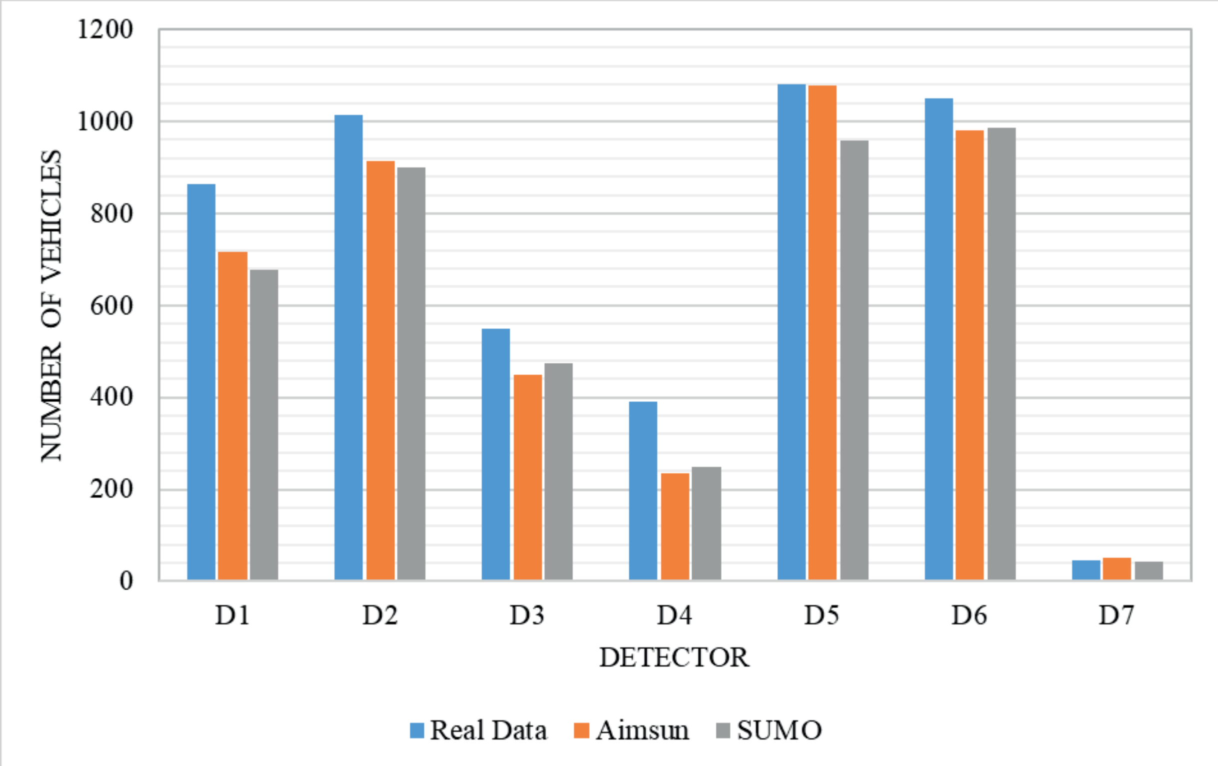

Figure 8 *Validation Comparison*

According to the results provided by the detectors in the validation process, it was observed that Aimsun and Sumo exhibit a similar behavior. These results come close to the data collected in the field. The data presented in Figure 8 correspond to the average of the eight iterations. Table 10 shows the result of the t-test applied to the 95% confidence to check the statistical significance of the results concerning the real mean values identified in each detector.

6 Results obtained

In accordance with the literature review, the most common output data, as well as the ones with the highest importance in the selection of a microsimulation tool, were chosen for a traffic study.

Moreover, it was verified that both tools implemented in this study can generate these results simultaneously to enable the comparison process. The indicators that were analyzed were: the average speed of vehicles during the simulation throughout the network; the total distance, which is the sum of the distance traveled by all the vehicles that entered the road network during the simulation period; the density, which is the number of vehicles per unit length; the total travel time, defined as the sum of the times the vehicles remained in the network during the entire simulation period and the number of vehicles that entered and exited the simulation. The simulation process corresponded to a 1-hour interval, which represented the hour of maximum demand on a typical day.

Taking into account the evaluation results in each of the applications, it was possible to determine that they are quite similar. Figure 9 shows the comparison of each of the results for both tools used in this study. The results with greater similarity when comparing Sumo and Aimsun are: vehicle density, which showed a difference of 0.68 Veh/Km between both software and the number of vehicles simulated or out of simulation, with a difference of 27 vehicles. Meanwhile, the total travel time is the result with the highest difference, as it had a value of 17.7 hours, which amounts to a difference of (13 %). A great similarity is observed between the results. Such similarity is caused by the relationship that exists between the operation of the microsimulation models deployed by the software, in accordance with what is indicated in the literature. It is also necessary to take into account the size of the study area, as it may be possible for the results to be more comprehensive. Table 11 shows the results of the t-test for the 95% confidence, revealing the statistical significance of the results obtained for each software concerning real data from the zone of study. Also, this table shows the results obtained from the subtraction between the Aimsun output data and the Sumo output data, as well as a percentage difference obtained using the following equation:

$$Dif_{\%} = \frac{D_{Sumo} - D_{Aimsun*100}}{D_{Aimsun}}, \quad (2)$$

where:

$Dif^{\%}$ = Percentage difference between micro simulators,

D_{Aimsun} = Data obtained on Aimsun,

D_{Sumo} = Data obtained on Sumo.

Table 11 *Difference and Percentage Difference of Results*

Result	Density	Speed	Total Travel Distance	Total Travel Time	Vehicles out of Simulation
Unit	Veh/Km	Km/h	Km	h	Veh
Test t (Aimsun)	1.897	2.056	NA	NA	-1.859
Test t (Sumo)	2.189	1.945	NA	NA	-2.146
Average Difference	0.71	1.26	78.9	18.2	31
% Average Difference	4	7	6	12	1

* *Test t for 95% confidence; t Table = 2.365*

** *NA: No real data to check*

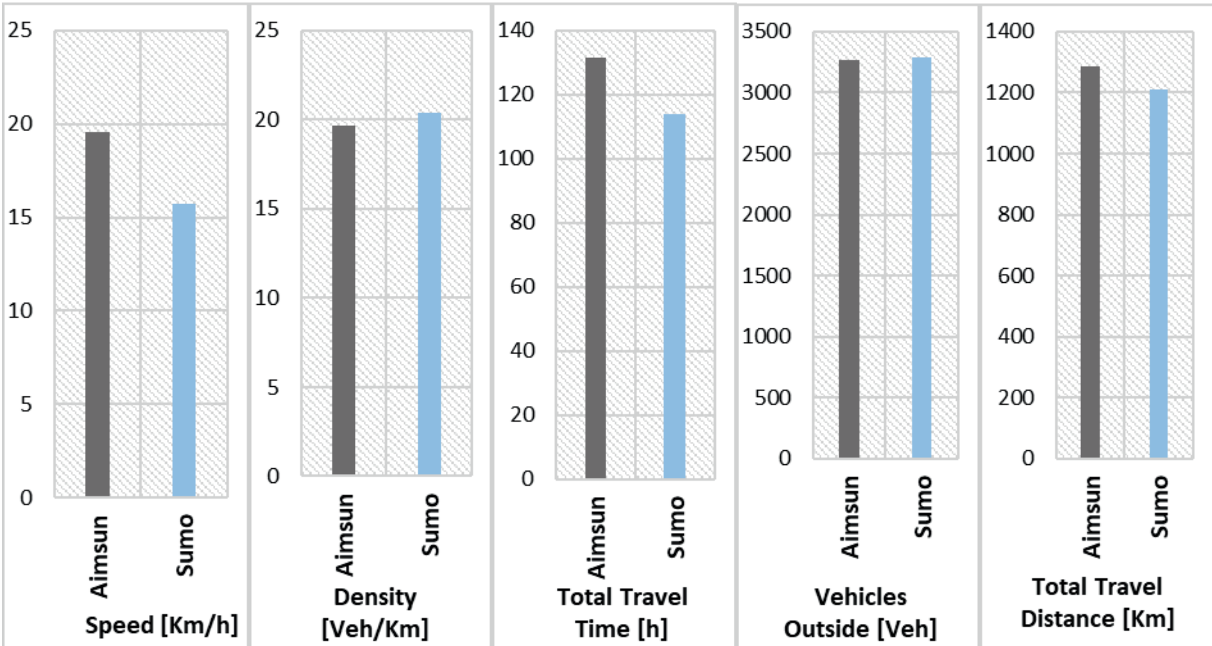

Figure 9 *Comparison of Results obtained with Sumo and Aimsun*

7 Conclusions

The literature review made it possible to conclude that both kinds of software, regardless of the way in which data is entered, require the same input: mainly a network or map and vehicle traffic demand in order to generate the microsimulation scenarios. Both software products have similarities in terms of output data characteristics and parameters. Aimsun has better options for building a network and requesting output data, while Sumo relies on external files or extensions for network creation and display of results and thus, it becomes more error-prone by the user who is entering data.

Due to the fact that it is relatively new software, Sumo has a higher level of complexity when it comes to creation of the model and execution of the simulation. In fact, the transport community became familiar with it only until a few years ago.

As described in the literature review, in Latin American countries research with this application is scarce and there is not yet much documentation available or with the appropriate level of detail. For all these reasons, the Sumo's extension SumoPy is developing to help users to manage all the data thanks to a user-friendly structure and graphical interface.

On the other hand, Aimsun allows the entire process to be carried out from its interface with efficient and intuitive user support, which can be accessed once a commercial license is acquired.

The results obtained in the validation process demonstrate that Aimsun shows a greater proximity than Sumo in 4 of the 7 detectors used, while Sumo shows a closer approximation than Aimsun in 3 of the 7 detectors. Although Sumo approximates in a lower percentage than the real data, it provides an acceptable level of reliability for this type of simulations, since as for the results taken into account for this study, differs by 13% compared to Aimsun, which is a software approved by a great deal of research. The microsimulation models used by both kinds of software are based on the safe speed and lane change; however, the main difference lies in the algorithm that represents it. In the case of Aimsun, it is the Gipps model and for Sumo, it is the KrauB model, which is a derivation of the Gipps model. The software applications under study use the classic transport model or four-stage model as a basis. Nonetheless, currently the generation/attraction, distribution and modal distribution stages basically function as procedures to generate input data in the final simulation. As for traffic assignment, which is considered the most important step, Aimsun has 5 model options, while Sumo has only 3 assignment model options.

Speed, density and total travel time are the most widely used output data to analyze the operation of a vehicle network. By means of these results, it was possible to determine that despite the fact that the tools operate with different micro simulation algorithms, the values obtained in the output data did not present significant differences between the two tools.

In short, it can be concluded that even though there are studies on these applications, there are still gaps to be filled regarding the operation of these tools, especially for open-source softwares like Sumo, which is in constant development and has very similar characteristics to commercial software such as Aimsun, when it comes to model microsimulation. Additionally, according to comparison of results carried out with respect to Aimsun, it could be determined that the implementation of Sumo was highly accepted and reliable for academic and technical purposes.

8 Discussion and future work

There are no absolute standards that must be met in the calibration of a model and this is due to the fact that the level of calibration obtained depends on the objectives of the modeling [23]. Although in the process of calibration and validation of a vehicle traffic simulation model, it is recommended to use 90% of all the vehicle capacity taken in the field for calibration purposes and 10% to carry out a more rigorous validation process [23], the purpose of this project is to verify the operation of the tools, but not to carry out a rigorous validation process that makes it possible to obtain reliable results to give a judgment on behavior of the road network under analysis [24]. As a way to continue with this work, it is suggested to analyze the behavior of the Sumo software with larger scale models. A further recommendation is to include analyses that allow for evaluation of the behavior of the software with other modes of transport, such as Massive Public Transport, simulation of pedestrians, bicycle routes or electric cars and its comparison with other types of software.

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