Pilot Simulation for Public Passenger Transport Energy Consumption

García-Cerrud Carmen Angelina[1], Hernández Rosales Manuel[2] and Flores-De la Mota Idalia[1]

[1] Facultad de Ingeniería, Universidad Nacional Autónoma de México, Mexico City 04510, Mexico

[2] Programa Universitario de Estudios sobre la Ciudad, Universidad Nacional Autónoma de México, Mexico City 06000, Mexico

ank271704ce@gmail.com

Abstract. The knowledge of the variables that impact energy consumption allows a better understanding of how to mitigate energy consumption and emissions production for public passenger transport.

The current operation of public passenger transport in a large city with unregulated types of public passenger transport like developing countries case, causes an increase in energy consumption and emissions generation. Therefore, this paper aims to propose a simulation that estimates energy consumption. Different spacing stops length configurations are used to compare the energy consumption estimates to acknowledge the impact. The performed simulation is an initial approach to how improvement measures impact energy consumption in public passenger transport, taking as a first measure stops establishment. The results indicate that stop spacings impact energy consumption, when there are non-established stops, meaning that the users take the buses where they want the consumption increases. However, after 500 meters of spacing, energy consumption does not vary significantly, therefore establishing stops considering a demand coverage approach is suitable.

Keywords: Public Passenger Transport, Energy Consumption, Simulation Spacing, Stops.

1 Introduction

Public passenger transport is important for a city's development since it helps the inhabitants to move from one place to another. However, it imposes a series of negative impacts that include high energy consumption and emissions production due to its operation. In large cities, it is the core of all m movements, but it still depends mainly on oil fuels, making it necessary to propose changes that impact energy consumption and emissions generation. To do so, before implementing the changes, simulation proves to be a reliable source of information to characterize the actual operation of the system and the impact the improvements may have on its energy consumption.

The simulation proposed in this paper is an initial approach to how improvement measures impact energy consumption in public passenger transport and the introduction of fine-grained variables used for energy consumption estimates. Stop spacing is the first improvement measure used as a test for energy consumption estimates. Even if stops planning is a basic concept in transport planning, there are countries with public passenger transport based on a man-truck system, and established stops are not respected by the users and the drivers.

This paper is divided as follows: section 2 presents the literature review regarding energy consumption models for public passenger transport and simulation of public transport to provide an overview. Section 3 shows the materials and methods used to develop the presented simulation. Section 4 presents the pilot simulation developed with an experiment and five scenarios regarding stop spacing and its impact on energy consumption. Finally, conclusions about how the stop spacing impact energy consumption is presented.

2 Literature Review

2.1 Public Passenger Transport

“Transportation is the lifeblood of cities and regions; since it provides the essential connection for its constantly moving population” (Vuchic, 1999).

City transport is responsible for a part of road transport energy consumption and emissions that causes air pollution in urban areas. The importance of public transport is increasing due to urbanization and the need for connections to work centers (Qin, 2008).

However, there is an increase on environmental pressure from road transports (CO emissions) due to its oil dependency (Sandalow, 2008). Public passenger transport depends on the amount of potential users in the area it serves (Lao & Liu, 2009) (Karathodorou, et al., 2010) (Karttunen, et al., 2010) and its importance also relies on the problems it produces, like congestion, environmental impact, and use of public space.

Therefore, the need to investigate the efficiency of public passenger transportation systems, particularly in larger cities, that are population concentration centers (Kenworthy, 2002) (Hu, et al., 2009).

Public transportation in cities has been studied from several points of view, such as the number of stop points, round-trip time, routes, and operating hours to plan the public transportation system operations (Lao & Liu, 2009) (Karttunen, et al., 2010).

However, it has not been studied with an energy consumption mitigation perspective but making changes may contribute substantially to reducing the negative impact on the environment.

2.2 Energy Consumption Models

Energy consumption for world transport has grown steadily in recent decades, with fuels produced from petroleum being most of the final energy consumption in the transport sector.

Road transport consumes approximately 70% of the energy used in the global transport system, of which road passenger transport alone represents 50% of this energy consumption (Ministerio Federal de Cooperación y Desarrollo, 2016).

Improvements in the public transportation system can induce a modal shift, leading to greater energy efficiency. A good public transport system is attractive, accessible, and reliable.

The World Bank (2018) indicates it is a priority not only to introduce new technologies but to adapt what already exists and reduce consumption.

Therefore, energy consumption models have been developed and contribute to organizing the information to provide a framework for testing the hypothesis.

The methods for calculating energy consumption and emissions depend on the pollutant, the mode of transport, and the type of vehicle. These methods are arranged into two groups (Hidalgo, 2005):

1. Top-down approach. - Offers a general volume of energy consumption or emissions for the entire transport activity or some of its modes; it is based on aggregated data or variables.
2. Bottom-up approach. - Directly calculates emissions and consumption from the source (the vehicle).

Energy consumption estimations use factors such as the type of vehicle and speed that enable energy savings in transportation and how policies can affect energy consumption identified as key factors: information and training programs, subsidies; prices and taxes; and administrative regulations (Geltner, 1985).

Also, Frey, et al. (2007) mention that the factors such as speed, acceleration, and altitude impact energy consumption directly (Frey, et al., 2007). Therefore, when simulating public passenger transport energy consumption, the inclusion of such factors must be considered.

2.3 Simulation of Passenger Transport

A system simulation requires the development of a model, to represent that model through a computer program that provides information about it (Abara , et al., 2017).

Passenger public transport simulation studies are divided into four groups according to the simulation method: discrete models, agent-based models, multilevel models, and hybrid and energy models.

Discrete models are used to link supply and demand (Li, et al., 2006), associate capacities (Castillo , et al., 2011), , to model vehicle arrivals and behavior when implementing the car tracking behavior (Bowman & Miller , 2016) and to find an acceptable solution for the volume of exhaust gases and noise pollution considering the individual characteristics of the vehicle (current mileage, type of engine, environmental safety class) (Makarovaa , et al., 2020) among other uses.

Agent-based models are used for assignment to optimize users' travel plans (Narayana, et al., 2017) ,vehicle-sharing operation modes (Hu, et al., 2017), passenger flow service indicators definition with behavior of potential passengers data (Tolujew , et al., 2018) among others.

Multilevel and dynamic models are used to integrate macroeconomic, energy supply and demand, and environmental modules (Schwefel & Schmitz , 1997), to predict traffic conditions (Hunter, et al., 2006), , for the incorporation of different relevant subsystems to categorize them (Halim , et al., 2012), and to support integrated transportation infrastructure and public space design (Yang, et al., 2020) among other uses.

Finally, hybrid and energy models are used to simulate demand-responsive transport systems and analyze their applicability (Dytckov, et al., 2018), to reduce the waiting time for buses (Pereira & Chwif , 2018), to provide dynamic operational feedback using network performance indexes (Saroj , et al., 2018) and to merge energy aspects with simulation (Poeting , et al., 2019), among other uses.

These studies are taken as a basis for the development the presented pilot simulation due to the applications they present.

3 Materials & Methods

The simulation is developed in Simulation of Urban Mobility (SUMO) software and shows a generic public passenger transport route. SUMO can integrate variables that impact energy consumption, such as the altitude of the road, the drives expertise, traffic lights, random stops, energy consumption estimations, emissions estimations, and traffic in the study area.

The equations to estimate energy consumption and emissions with information regarding the kinetic translational and rotational energy, the energy needed for a vehicle to overcome a slope, rolling resistance, and aerodynamic resistance energy are incorporated via Phyton. Through its immediate changes in the road, traffic lights, random stops, and demand configuration can be performed, making the simulation dynamic.

To develop the simulation, five conceptual abstractions (general, arches, nodes, stops, energy consumption models) of the system were developed to know and characterize how the system works.

The general conceptual model presents how the buses and passengers are incorporated into the simulation and its updates as the simulations performs (see Fig. 1)

Subsequently a conceptual model specific for the arches was developed, in which the arc length and travel speed in the arches are calculated (see Fig. 2). A node conceptual model considers two types of nodes (signalized and non-signalized) was developed to calculate the delay and time consumed in the nodes by the buses (see Fig. 3).

The stops conceptual model includes the number of stops (formal or informal) and its spacing, the passenger seats on them to calculate the delay in each stop (see Fig. 4). Finally, the energy consumption model in which the variables for energy consumption of the buses are introduced and the variables of arches, nodes and stops that impact energy consumption are actualized for every time step of the simulation (see Fig. 5). With these abstractions the pilot model was developed.

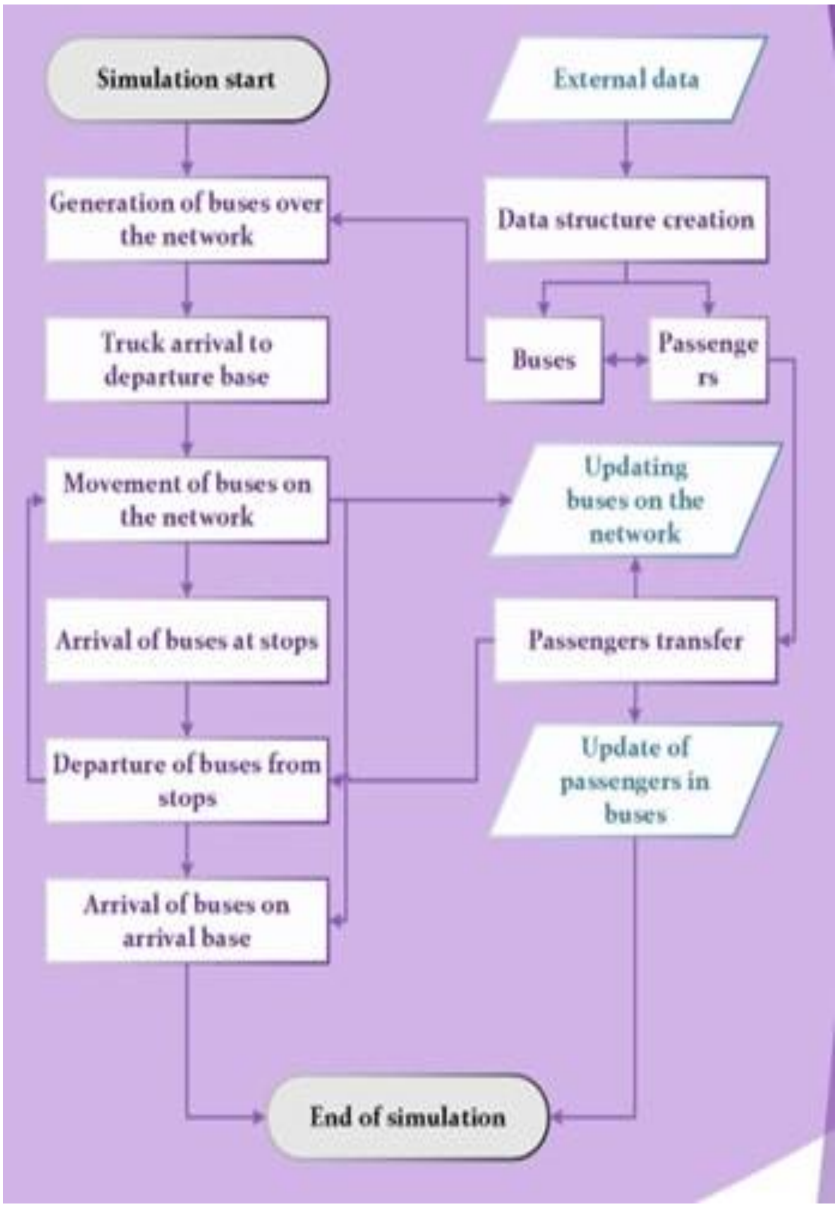

Fig. 1. General conceptual model.

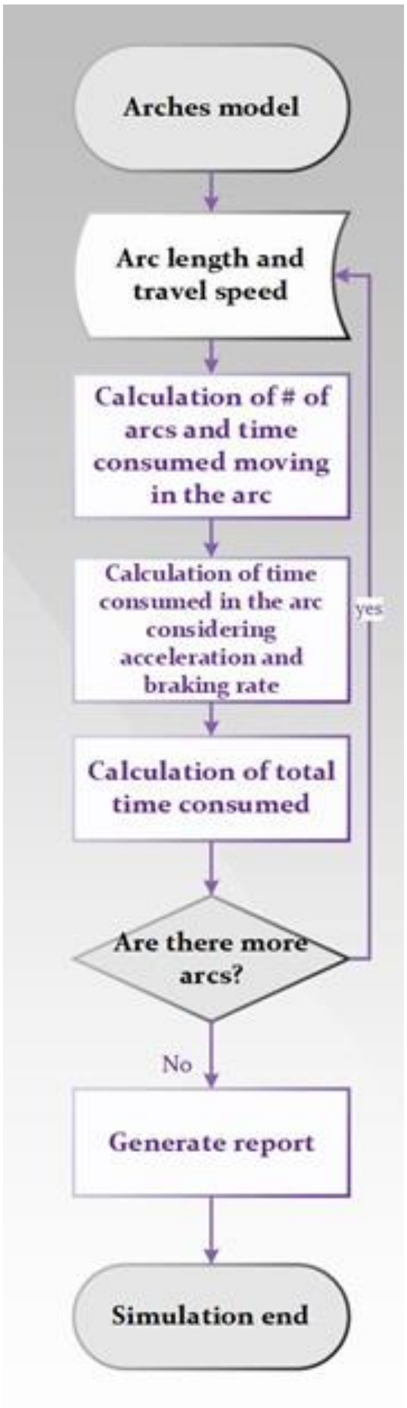

Fig. 2. Arches conceptual model.

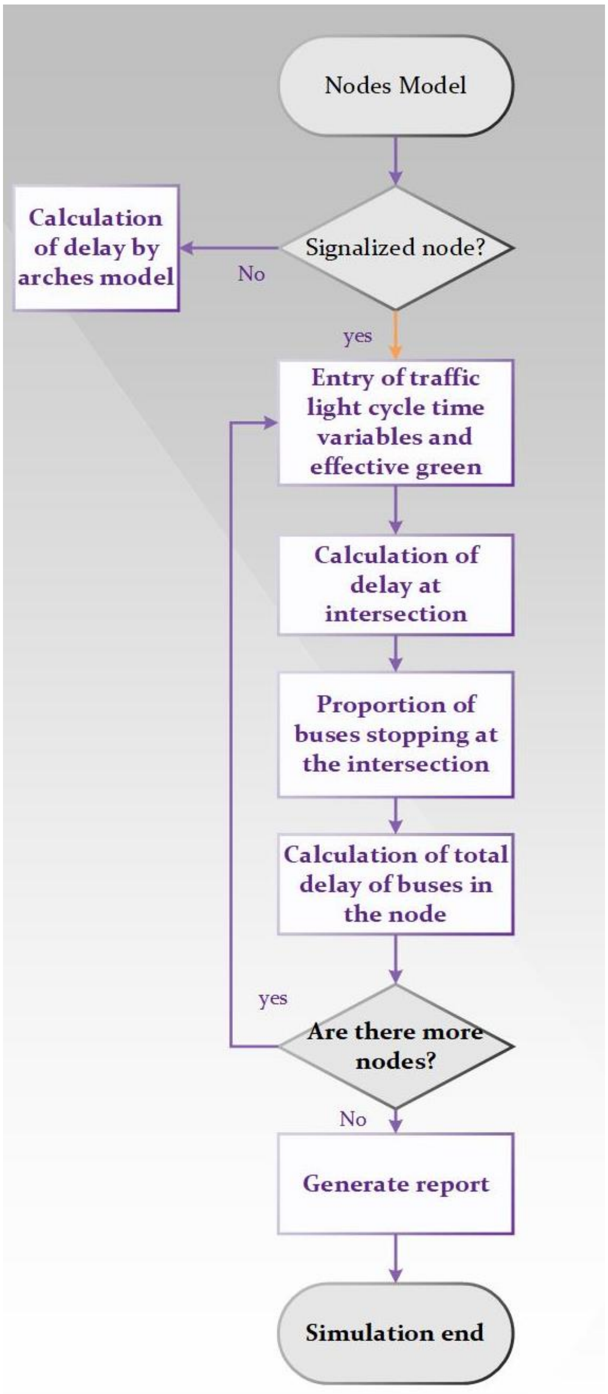

Fig. 3. Nodes conceptual model.

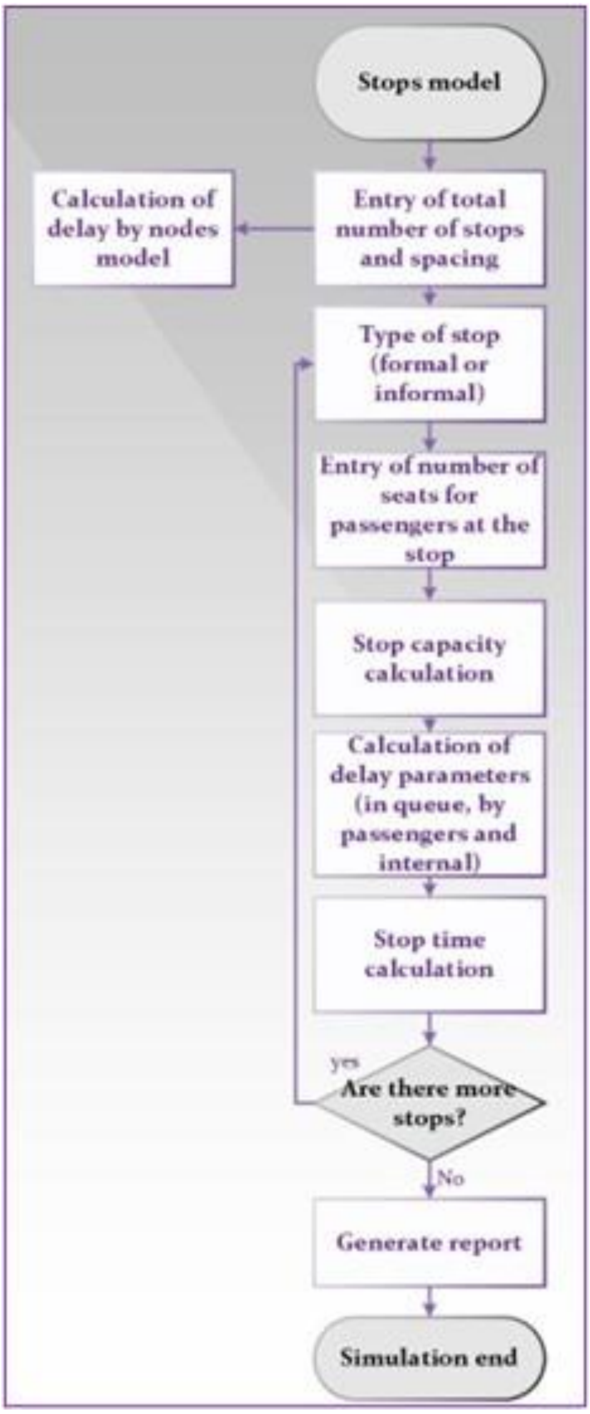

Fig. 4. Stops conceptual model.

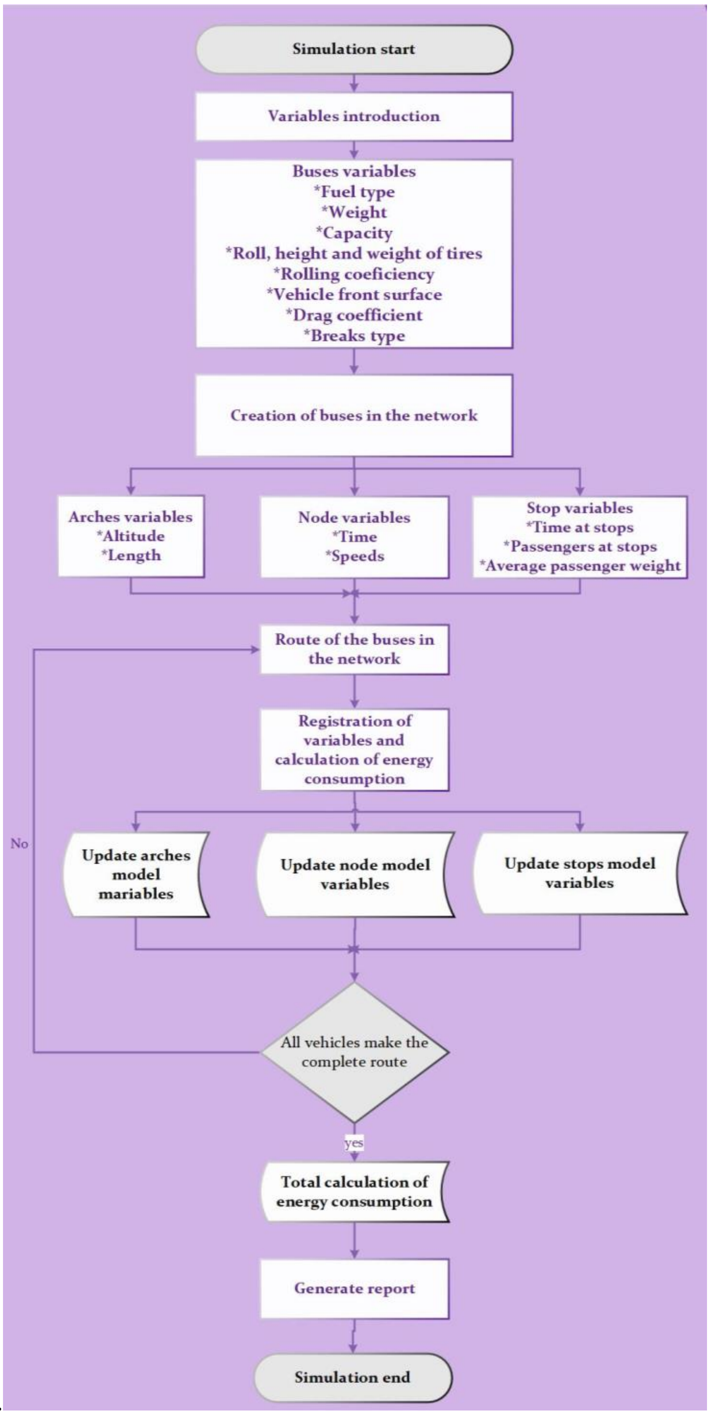

Fig. 5. Energy consumption conceptual model.

4 Pilot Simulation

The simulation presented in this paper is developed as a pilot since it is developed in a rectangular network (not with a current existing configuration within a city) and considers only the initial and final speed for the energy estimations. The simulation was developed as follows (see Fig. 6).

Through the SUMO-GUI interface, the network is created. The number and spacing of stops (formal or informal) and the pedestrians were created in an XML file using the Python idle.

Using SUMO via Command Prompt, the simulation is run. The results are obtained in an XML file and converted via Command Prompt into a CSV file for data preparation. Finally, the data is used in the Python interface on an energy consumption script to obtain the energy consumed by the trucks in the simulation. At this point, the energy consumption is estimated only using the initial and final speed in each simulation step to calculate the total energy consumed. The following assumptions were considered for the simulation: the data for these assumptions were obtained for the buses and stops through fieldwork. For the pedestrians and vehicles, the data was retrieved from (Instituto Nacional de Estadística y Geografía , 2017), (Instituto Nacional de Estadística y Geografía, 2020) respectively of an area with 22 kilometers of roads:

- Period: one hour
- Arches length: 22 kilometers each arch corresponds to 1km
- Pedestrian per hour:3061
- Buses per hour:35
- Vehicles per hour:4741

Stops duration: the first and last stops are taken as bases (250 and 150 seconds), the other stops last 30 seconds.

With these assumptions a simulation was developed in which the stops spacings are considered as an energy consumption factor. Five scenarios to acknowledge the spacing impact were developed and correspond to:

Simulation 1: Unestablished stops every 100 meters (see Fig. 7).

Simulation 2: Established stops every 1000 meters (see Fig. 8).

Simulation 3: Established stops every 500 meters since (Molinero, 1997) establishes that in urban areas the public passenger transport stops must be set between 400 and 600 meters (see Fig. 9).

Simulation 4: Established stops every 350 meters (see Fig. 10).

Simulation 5: Established stops every 250 meters (see Fig. 11).

After simulating the five scenarios, results show that the stop spacings do impact energy consumption (Table 1) (Figure 12). In experiment one case, in which there are no formal stops, the energy consumption is high with respect to the different established stops. If the stops are established, the difference in energy consumption varies from 60.4% to 67.9% when the unestablished stops are taken as a reference. However, the difference in energy consumption in the established stops does not increase significantly when the spacing varies.

If the literature-reported spacing is taken as a reference, the difference in consumption increases for the unestablished stops case and represents 184.5% of the increase in energy consumption.

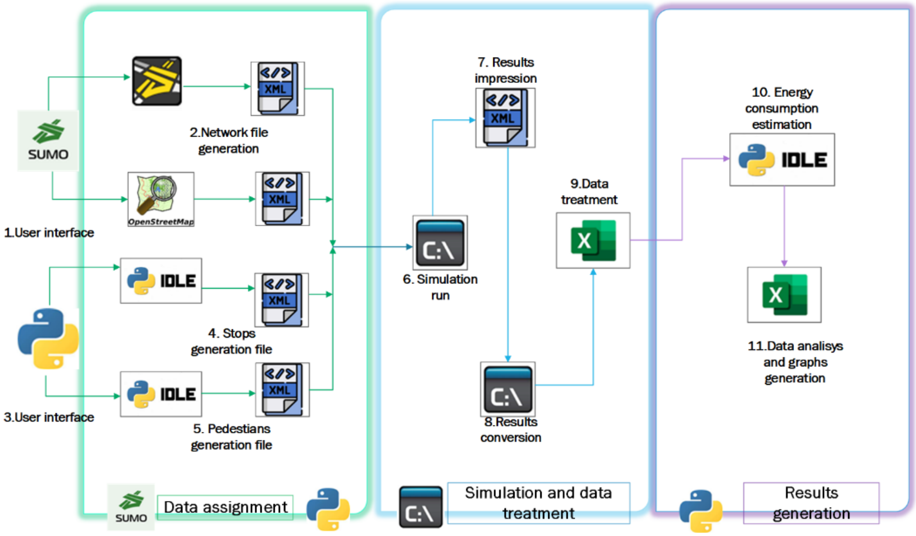

Fig. 6. Simulation development.

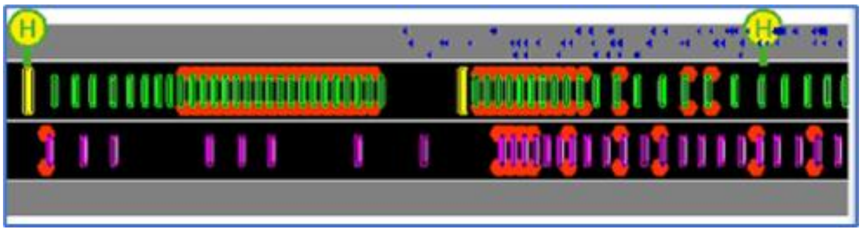

Fig. 7. Unestablished stops every 100 meters.

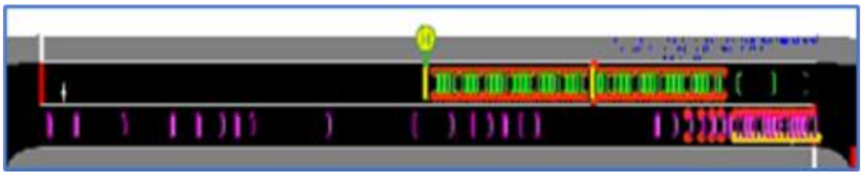

Fig. 8. Established stops every 1000 meters.

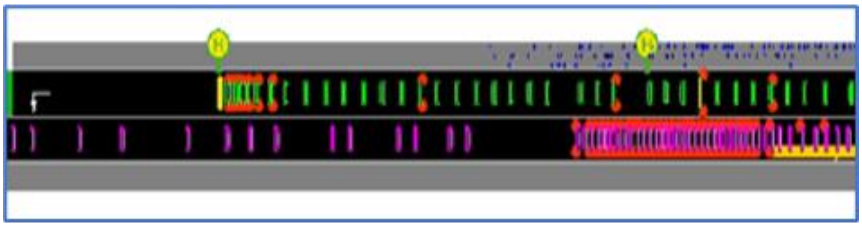

Fig. 9. Established stops every 500 meters.

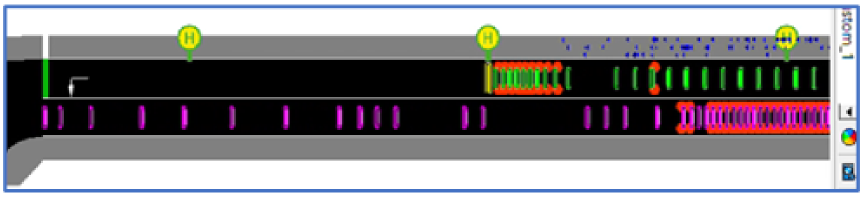

Fig. 10. Established stops every 350 meters.

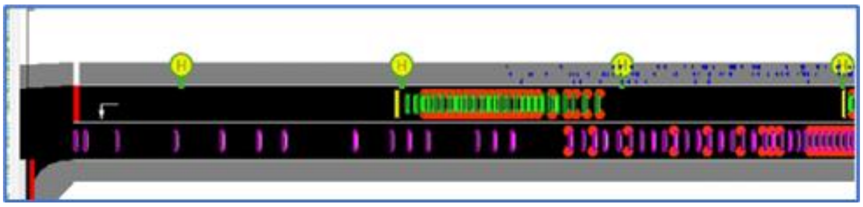

Fig. 11. Established stops every 250 meters.

Table 1. Energy consumption of the buses with different stops configuration comparison.

Stops /consumption	Energy consumption (Joules)	Difference respect to e/100	Difference respect to e/500
Unestablished stops every 100 meters	150,161,906	-------------	184.5%
Established stops every 250 meters.	59,402,134	60.4%	12.5%
Established stops every 350 meters	58,145,748	61.3%	10.1%
Established stops every 500 meters	52,789,456	64.8%	------------
Established stops every 1000 meters	48,246,387	67.9%	8.6%

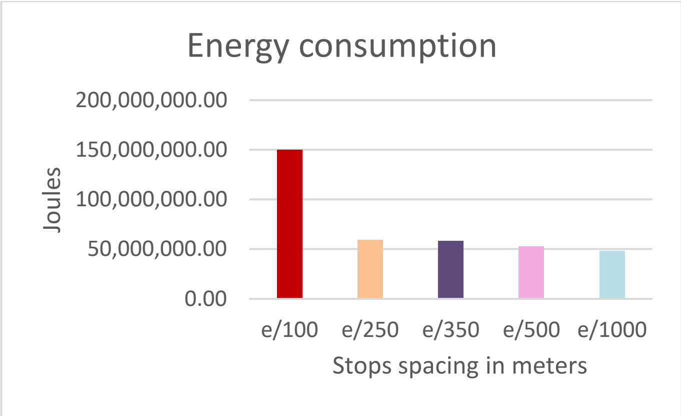

Fig. 12. Energy consumption of the buses with different stops configuration comparison.

5 Conclusions

The presented pilot simulation provides an insight on how the operation of public passenger transport impacts directly in energy consumption. The differences presented regarding the stops spacings are significant, so this factor must be considered when proposing improvement measures. It is important to notice that the energy consumption estimates presented in this paper only consider initial and final speeds. So it is expected to increase when the other variables are incorporated. Therefore, to test several improvement measures to reduce energy consumption and their combination should be proven.

For an energy consumption estimate using simulation the incorporation of several variables that impact it is needed to propose feasible solutions regarding public passenger transport energy consumption minimization.

Therefore, the energy consumption model incorporation will be performed in future work, together with an emission estimation script. Also, the simulation would include a distribution for time requirements at the stops and stops spacing using coverage areas by demand.

The simulation will be performed for a case study in Mexico, City.

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