# SIMULATION MODELS FOR PUBLIC TRANSPORTATION

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## Abstract

This article presents a state-of-the-art review regarding transport simulation models currently developed. To identify the variables and types of models in transport simulation and how the operational characteristics and its associated energy consumption and emissions generation merge in a simulation that aids the decision-making process regarding energy consumption. Several simulation models are addressed and studied to propose a new simulation incorporating energy consumption and emission. In specific for public passenger transport, since it is the mean of movement in urban areas and improvements to its energy consumption and emission needs to be addressed to meet the sustainability goals by minimizing the externalities it produces.
Peer-review under responsibility of the scientific committee of the 4th International Conference on Industry 4.0 and Smart Manufacturing

*Keywords:* Models; simulation; public transport; energy consumption; emissions generation.

## 1. Introduction

Transport is the movement of people and goods through various modes and is considered an economic index.

Therefore, in search of its optimization, several investigations have been carried out; to acknowledge how transport policy changes affect its operation and impact its externalities. Issues related to sustainability, such as energy consumption, emissions, and the overall environmental impact of transportation, have become increasingly important factors in decision-making. Nevertheless, traditional support tools have not been enough since they focus on the operational aspects of industrial and service systems, such as efficiency, productivity, and cost, with little attention to environmental impact. Therefore, it is necessary to rely on tools such as simulation that allow the impact of changes observation without altering the real system.

Emerging needs in transportation network modeling and simulation generate new challenges for simulation-based optimization and vehicular behavior fidelity for accurate phenomena capture. The use of simulation aids in finding an acceptable solution for transport impact factors such as volume, road network configuration, characteristics, and operational modes, road infrastructure, allowing a better understanding of changes impact.

Using micro-modeling individual characteristics of the vehicles (current mileage, engine type, environmental safety class) are considered, which estimates fleet environmental impacts possible.

Therefore, to measure the probable effects of policies and projects application and evaluate them from a social, economic, financial, energetic, and environmental point of view, simulation models have been developed.

This literature review aims to provide insight into how the energy consumption and emissions problem for public passenger transport is tackled, in both a microscopic and macroscopic way, through simulation, to minimize the energy consumption by proposing operational, infrastructural, informational, and technological improvement measures. **2. Modeling and simulation principles**

### 2.1. Modelling

Modeling is a way of solving real-world problems when it is not possible to experiment with real objects since building, destroying, and making changes can be too expensive, dangerous, or simply impossible [1].
The term model refers to an abstract and simplified representation of a given reality, already existing or newly planned, and is defined to study and explain observed phenomena or to anticipate future phenomena [2]
A real system model is a representation in a modeling language and requires a process of abstraction, in which details to solve a problem are discarded or kept depending on its relevance; in some cases, the resulting model is always less complex than the original system [1].
A system is a collection of entities. For example, people or machines that interact, towards the achievement of some logical end. The state of a system is a collection of variables necessary to describe it at a particular moment. Systems are classified into two types, discrete and continuous. In a discrete system, the state variables change instantaneously at separate points in time. In a continuous system, the state variables change continuously in time [6]. A system can be studied in different ways (Fig. 1).

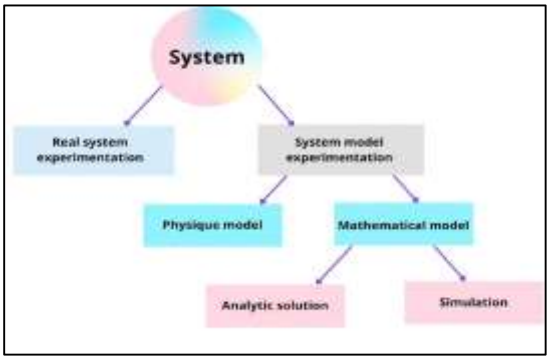


Fig. 1 Systems study.
Source: Own elaboration based on [6].

A model made for a simulation study; is a mathematical model developed with the support of software [7]. A simulation model refers to the computer algorithms, mathematical expressions, and equations that encapsulate the behavior and performance of a system in real-world scenarios. Building the model explores and understands the structure and behavior of the original system and tests how it will behave under various conditions and finding the solution sought [2].

### 2.2. Simulation

A simulation is a manifestation of a model, represented by a computer program that provides information about the system or application under investigation [2].
The term computer simulation means using a computational model to obtain additional information about the behavior of a complex system by visualizing the implications of modeling options. To evaluate designs and plans without making them a reality in the real world [4].
Simulation models have entities, input variables, performance measures, functional relationships, and output variables. The steps to develop and analyze a simulation model are [6]

- Problem formulation: The system boundaries, problem, and section to be studied are selected. The definition of performance measures is quantitative value, with which the different system configurations are compared.
- Collect and process data from the system: Collect data regarding system specifications, input variables, and system performance. It is important to identify the randomness of the system and select the appropriate probability distribution for each variable.

- Formulation and development of the model: Develop diagrams of the system, to translate them into an appropriate simulation language.
- Model validation: Comparison of the model under known conditions and the real system performance.
- Documentation: Document the objectives, assumptions, and input variables.
- Select the appropriate experimental design: Select the performance measures and input variables to influence.
- Establish the experimental conditions for the runs: Establish the warm-up period, decide the number of runs, and the starting conditions.
- Carry out the runs.
- Interpret and present results: Examine the system performance hypotheses, documenting the results and conclusions.
- Make recommendations

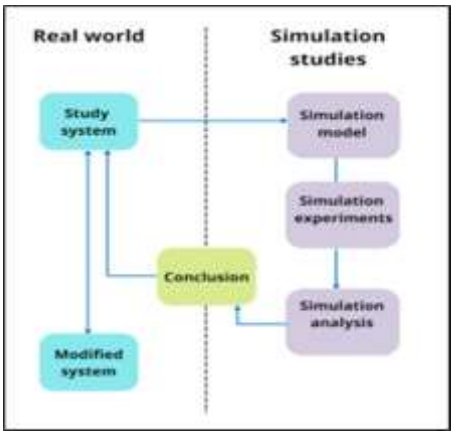


Fig. 2. Steps to develop and analyze a simulation model Source: Own elaboration based on [7].

The methods used in simulation modeling refer to how you map a real-world system to your model; the type of language or "terms and conditions" for the model construction. There are currently three methods. Depending on the modeled system, and its purpose, the method is chosen [1] [6]:

- System dynamics: is a method to study dynamic systems with an endogenous point of view. Modeling the system as a causally closed structure defines its behavior with feedback loops (circular causality). These feedback loops are at the heart of the system dynamics as they identify stocks (accumulations) and the flows that affect them. The system has system memory and sources of imbalance, so individual events and decisions are "surface phenomena that travel on an underlying tide of system structure and behavior" where events and decisions are blurred. Systems dynamics suggest abstracting from individual objects, thinking in terms of aggregates (stocks, flows), and feedback loops.
- Discrete events modeling: model the system as a process with a sequence of operations performed between entities, including delays, service by various resources, choice of the branch of the process, and division, among others. Discrete event modeling takes a process-oriented approach: the system dynamics are a sequence of operations performed on entities.
- Agent-based modeling: Based on the knowledge of the individual behavior of a system object. In an agent-based model, the modeler describes the system from an individual object's point of view, that can interact with each other and with the environment.

The three modeling methods are essentially the three different points of view that the modeler can take when mapping the real-world system in the modeling world, which depends on the available data, the system's nature, and the simulation project goals. Different problems may require different methods.

Often, the problem cannot fit within a modeling paradigm, so hybrid approaches, combining two or more methods are used [6]. Simulation is useful, although it also has advantages, disadvantages, and associated issues, as indicated by [9]:

- Advantages: Allows the performance estimation of an existing system with a series of projected operating conditions, provides a vision of the improvement options and which one best suits a specific requirement, and maintains better control of the experimental conditions than would generally be possible by experimenting with the system itself.
- Disadvantages: Requires several independent runs for each set of input parameters and it is expensive and timeconsuming to develop. If the model is not a valid representation of the system under study, the simulation results do not provide information about the system.
- Risks: Not having a set of well-defined objectives at the beginning of the simulation study causes an inappropriate detail level of the model.

## 3. Transport simulation models: state of the art

Simulation to study the effects of traffic or to obtain information on how certain traffic strategies can influence a specific situation is widely used. However, most of the studies address the consequences related to the appearance (or avoidance) of congestion or deal with aspects of the organization and configuration of road networks for optimizing travel times [10]. The state-of-the-art review presented in this paper is divided into four sections based on the simulation method: discrete models, agent-based models, multilevel models, and hybrid and energy models.

### 3.1. Discrete models

Regarding the use of discrete models, [11] uses discrete-event modeling techniques and parallel simulation methods through the SCATTER approach to design a simulator with memory and speed efficiency to achieve scalability through parallel execution and concludes that the efficient simulation of vehicular traffic in large spatial scenarios is an emerging need, being necessary a parallel simulation to better comply with the geographical scales and the realtime speeds
A simulation model of the passenger rail network to link supply and demand and thus evaluate the impact of differentiated prices on passenger travel behavior is performed by [12]. Using the overall network performance: financial and operationally are calculated; with two essential steps, demand modeling, and interaction simulation. This model represents the passengers choosing process over time, the route, and departure time choice under different pricing strategies.
[13 design and develop a set of sustainability tools for simulation, making the performance measures related to sustainability easy to model and collect as traditional performance measures based on productivity, through a simulation approach of discrete event systems
A methodology for analyzing the operation of exclusive bus corridors is presented by [14]. This methodology considers the capacities associated with different design alternatives, with which it is possible to make generic design recommendations for future investments considering their yields, using a microsimulation tool capable of incorporating several of the elements that could define the road supply, both in segregated corridors for public transport as well as modes of operation around stop zones.
A library for transport modeling is developed by [15], which seeks the parallelization of MATSim (multiple agent transport simulation) using a library called MASS (multi-agent spatial simulation library) for quantitative and qualitative analysis and demonstrates the portability and performance of library execution in practical transport simulations.
A method to model vehicle arrivals based on real data using regression techniques/time series introducing a new model to control the behavior of vehicles within the system, creating realistic

models for vehicle arrivals and behavior when implementing the car tracking behavior and free driving behavior is proposed by [16].
[17] use a simulation tool built on a statistical model to determine the effect of waterway disruptions on interconnected transportation systems by collecting data on extreme natural events that affect inland waterways and are used to predict potential occurrences of such events in the future with a Spatio-temporal statistical model and [18] simulate the implementation of electric vehicles in a national land transportation system to demonstrate the technical feasibility of electrification of the transportation sector and decoupling of petroleum derivatives; concluding that this substitution would imply a reduction in its consumption, as well as a decrease in its adverse effects.
Simulation models of an area of the street and highway network in a medium-sized city based on the discrete event approach by using a road traffic library to analyze problem areas of the network and thus suggest measures to modernize is performed by [19].
[20] use micro-modeling simulation to find an acceptable solution for the volume of exhaust gases and noise pollution. Using traffic flows theory, computer experiments, direct measurement methods of environmental emissions, and varying the parameters of the objects of the transport system to correctly estimate the degree of environmental impact, considering the individual characteristics of the vehicle (current mileage, type of engine, environmental safety class), which allows estimating the environmental impact of the fleet of vehicles operating in the area.

## 4. Conclusions

Transport is of great importance for a country's development, and public passenger transport is the core of movements in a city. Therefore, it is necessary to ensure that it generates the least number of externalities through energy consumption optimization and the consequent operational improvement.
A simulation is a tool to measure the impacts associated with the application of improvements before implementing the measures in the real system, thus supporting informed decision-making. If the implemented measures have no basis, unforeseen implications can emerge, but using simulation, prevention is feasible.
After reviewing the presented state of the art, a gap in research is recognized. Regardless of the method used for the simulations and scope, the operational aspect optimization is the most considered. Operational optimization is valuable since improving it helps lowering times and costs. However, energy consumption and emissions must be considered in further simulations. Thus, to meet sustainability goals and improve the lives of public transport users and the environment.
In this paper, the articles provide the basis to simulate public passenger transport considering all the variables incurred in its operation, energy consumption, and emissions.
Also, the state-of-the-art provides an opportunity for public passenger transport simulation to determine what measures are appropriate for implementation for its energy consumption and associated emissions minimization.
The combination of the different simulation approaches may generate a simulation with a complete and precise analysis of the implications of public passenger transport in terms of its operation, energy consumption, and associated emissions.
This analysis will be achieved by developing and obtaining realistic models and solutions that support decisionmaking regarding policy implementation to optimize energy consumption and mitigate the externalities caused by public passenger transport.

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