Traffic simulation: an analytical review

Sergey Dorokhin¹, Alexander Artemov¹, Dmitry Likhachev¹, Alexey Novikov¹, Evgeniy Starkov¹
¹Voronezh State University of Forestry and Technologies named after G.F. Morozov, 8, Timiryazeva str., 394087, Voronezh, Russia

E-mail: kosta066@yandex.ru

Abstract. The constant increase in the number of cars in cities causes transportation problems that make it necessary to optimize the road network so as to satisfy the transport needs of the city. In this regard, modeling and optimal planning of the road network are of great importance. Motion modeling is a widely used method of traffic studies, modeling, planning and development of transport networks and systems. It represents the construction of a working model that reflects the similarity of properties or relations with the real problem under consideration. Modeling allows making possible to study the complex tasks of traffic not in real conditions, but in the laboratory. In a more general sense, modeling can be defined as a dynamic display of some part of the real world by building a computer model and moving it in time. Simulation models of traffic aimed at modeling real transport operations can be divided into three categories: microscopic, macroscopic and mesoscopic modeling. These methods of modeling traffic flows are designed to solve the most common transport problems. In most cases, models allow determining such parameters as traffic intensity, average speed, delays and time loss. This study is an analysis of existing traffic flow simulations in terms of their functions, limitations, and application by various criteria.

1. Introduction
The constant increase of vehicles on highways when no necessary level of development of transport infrastructure causes delays in the transportation process, which entails an increase in transport costs, reduced road safety and increased environmental pollution. Road transport is an important economic tool significantly effecting the pace of socio-economic growth of the society as a whole. The growth rate of the fleet, in addition to economic reasons, is also due to the high level of comfort in the operation of automobiles, which allows for the transportation of passengers and goods in the optimal time and on the shortest route [1].

Currently, there is a large number of studies to develop measures aimed at improving the organization of traffic [2-6]. One of the topical areas in the field of optimization of the transport process is the use of such a tool as modeling in the design of new and reconstruction of existing road infrastructure facilities [7, 8]. Traffic simulations are being increasingly utilized as transportation systems have become more complex and congested [9].

Traffic modeling is the process of creating a working model of traffic (transport simulation), corresponding to the real movement on highways. In simple words, the modeling of traffic flows is a dynamic computer system with virtual movement of cars on the road, which allows to track all the problems that arise and make decisions to solve them [10]. At the stage of preparing the design solution, the modeling of traffic flows involves a number of works aimed at studying the road situation...
with the allocation of problem sections of roads. Based on this study, a computer model of the traffic flow with a virtual projection of movement on the object is created. When compiling the mathematical model, it is necessary to take into account not only the real situation of the movement of vehicles over time intervals, but also the future workload with the prospect of developing related urban transport network projects and the development of the settlement. Modeling makes it possible to calculate the average speed on a complex site, while offering solutions to increase traffic intensity. Transport simulation includes modeling of transport processes and traffic systems on highways of both urban and federal types connecting different regions of the country into a single network. Motion simulation aims to accurately recreate the movement observed and measured on the street. Traffic modeling plays an important role in traffic design. It can be used to plan and control the traffic within a specific section of the road network, for example, to create smooth traffic at an intersection, etc. [11-13].

The basics of transport modeling include:
1. The purpose of transport planning is to optimize the use of resources in order to organize the effective functioning of the transport system.
2. Transport planning tasks include:
   • a forecast or receiving information about future transport processes;
   • an organizational and management task;
   • impact assessment;
   • applicability of design decisions;
   • a coordination task or implementation of planned activities.
3. Planning stages:
   • the stage of the analysis of problems: first goals are set and problems are identified, then the existing situation is analyzed;
   • the stage of the alternative analysis: the so-called cycle is underway - measures and scenarios are developed, consequences are calculated, the result obtained is evaluated;
   • the decision stage.
A model is a simplified representation of reality and / or processes taking place in it.
Modeling is essentially the construction of a working analogy. It represents the construction of a working model that reflects the similarity of properties or relations with the real problem under consideration. Modeling allows makes possible to study the complex tasks of traffic not in real conditions, but in the laboratory. In a more general sense, modeling can be defined as a dynamic display of some part of the real world by building a computer model and moving it in time.
Transport model is a visual display of complex transport processes with the possibility of predicting them depending on various conditions.

Stages of the system research using a model:
• goals and objectives setting;
• creation of a transport model;
• analysis of the resulting model;
• verification of the results;
• implementation of simulation results.
The transport model is:
• modeling of existing and projected passenger flows and intensities;
• a tool for optimizing the operation of passenger transport, including calculating the profitability of routes;
• analysis of passenger traffic;
• preparation of transport forecasts.
Basically, simulation models focus on three output values for solving transport problems. Firstly, these are traffic flows. Alternative routes can be determined depending on the number of vehicles. Using a simulation model, a specialist in the field of modeling can plan in advance activities aimed at reducing the level of congestion of certain sections of roads. Second, it is a network element in traffic modeling that consists of links, merging, intersecting links and other road elements [14]. This is due to
the geometric location of the road. Using appropriate modeling software, one can make adjustments to the geometric design of the road and see how these changes will affect the current traffic situation. Third, it is the category of perception. A simulation model allows to evaluate the time and cost of the trip. This is especially important in cases where it is necessary to determine the economic assessment of the traffic improvement. A specialist planning the transport work can conduct a comparative assessment of various options for traffic routes without significant material and time costs. Smart city projects, infrastructure planning, and traffic engineering are some of the applications where traffic simulations are playing an increasingly important role [15].

The second part of the article presents an analytical review of the simulation of traffic flows.

2. Classification of traffic simulation models
Motion simulation is an important tool for modeling the operations of dynamic traffic systems. Simulation models are usually classified according to the four most common criteria:

- the type of the computer used;
- the user interaction;
- a system time management method (system time mechanism);
- the method of organizing quasi-parallelism (formalization scheme of the simulated system).

Traffic simulation models are formed according to their application areas and these are microscopic modeling, macroscopic modeling and mesoscopic modeling (Figure 1). Macroscopic models (macro) are usually traffic patterns in a continuous stream. Mesoscopic (meso) models are models of individual vehicles. Microscopic (micro) models are models that capture the behavior of vehicles and drivers in detail, including interactions among cars, changing lanes, responding to incidents and behaving when merging items. Microscopic models are suitable for evaluating ITS at the operational level, since the presentation of many dynamic traffic control systems requires such a fine-grained simulation of the movement process.

![Figure 1. Classification of models of traffic flows.](image-url)
2.1. Microscopic modeling

The micromodel is characterized by a detailed description of the traffic flow and transport infrastructure. Microscopic modeling is based on the characteristics of various movements of vehicles, such as cars, buses, motorcycles and so on in the traffic flow. Microscopic models describe the behavior of each individual vehicle and options for interacting with other road users. Micromodels became popular after the advent of powerful computers, because they required a large amount of calculations. Such models are well suited for representing the traffic on a multi-lane road, because they can describe realistic vehicle trajectories. Microscopic modeling is aimed at collecting data parameters such as flow, density, speed, travel time and delay, long lines, stops, environmental pollution, fuel consumption and shock waves. Currently, the following modeling programs are widely used: Vissim, AIMSUN, SUMO, FRESIM, CORSIM, Paramics [16].

The objects of microscopic modeling are intersections, intersection groups, bridges, ramps, transport interchanges, terminals.

Tasks to be solved are choosing a traffic light control strategy, organizing the traffic at an intersection, choosing the optimal location for public transport stops, assessing the level of service, queue length, delay and a number of other parameters.

Input data are infrastructure parameters (number of lanes, lane width, road height, allowed speed), traffic flow structure, traffic flow intensity, priority rules, traffic lights, car acceleration and braking functions.

Output indicators are the queue length, delay time, service level, travel time for a particular segment of the path, average speed.

The negative aspects of the microscopic models include:
- large resources for microscopic models;
- a significant number of model runs are required to obtain reliable statistical information;
- a large amount of input data;
- the need for splitting the input data;
- calibration of a large number of parameters of the microscopic model;
- high sensitivity of the model to errors in the source data;
- the need to use expensive software [17].

2.2. Macroscopic modeling

Macroscopic modeling describes intersections with a low level of detail. In a macroscopic model, traffic flow is presented as a combination, measured in terms of characteristics such as speed, flow, and density. Flow, speed and density are the three main characteristics of movement. Investigations of the dependence of the flow velocity on density made it possible to develop its mathematical descriptions, which are used to develop a model of a continuous transport flow, which provides fairly accurate and efficient modeling. The macroscopic model is characterized by low detailing of transport infrastructure and traffic flows, which are presented in a generalized manner and are associated with a liquid (hydrodynamic model) or gas (gas-dynamic model). The main software products used in macroscopic modeling are Visum and Saturn [18].

The objects of macroscopic modeling are a city district, a city, a region, a country and a continent.

Problems to be solved during macroscopic modeling include the level of congestion throughout the city, traffic on roads, evaluation of the effectiveness of public transport routes, planning of public transport schedules, modeling of existing and predicted traffic flows.

Input data include the transport network (throughput and speed for each segment of the transport network), permitted directions of movement at network nodes, transport systems, information about the city’s transport zones and correspondence matrix.

Output indicators are the time of movement from zone to zone in free flow, time of movement in a loaded network from zone to zone, average speed of movement from zone to zone, load level of each road and traffic intensity on each road [19].

The disadvantages of macroscopic models include:
the resulting output characteristics are generalized;
the results are static;
to determine the number of input data, additional studies are required;
the need to use expensive software.

2.3. Mesoscopic modeling
Mesoscopic models occupy an intermediate position between macromodels of integrated characteristics of traffic flows and micromodels of movement of individual cars in a flow. A distinctive feature of mesomodels is the preservation of a sufficiently high level of detail in the description of the simulated street-road network and the simplified reproduction of the dynamics of the traffic flow, which allows to expand the scale of the simulated network while maintaining a high simulation speed. Mesoscopic models have been intensively developed in connection with the advent of integrated traffic modeling platforms that allow simultaneous modeling at meso and micro levels. Mesoscopic modeling describes the analyzed transport elements in small groups. Mesoscopic models are a combination of microscopic and macroscopic modeling. Mesoscopic models of traffic flows imply an assessment of macroscopic indicators at the micro level. Most scientists agree that mesoscopic models consider single vehicles, but describe their movement and interaction based on statistical, aggregated relationships. Структура таких моделей базируется на представлении сети в виде графа (узлы и дуги). These systems are designed to predict the parameters of certain routes. They are developed in order to determine the possibility of modeling and forecasting the traffic in real time and to provide this information. Another important task is modeling the dynamics of the automobile traffic. Currently, there are two main approaches to solving this problem. One approach is to divide the road section into two parts: the part along which cars move and the part on which the line of cars is formed. Accordingly, various models are used to describe the moving part of the flow and the line of vehicles. The speed on the part of the road on which the cars move is determined depending on the density, and the throughput on the section with the queue is limited by the traffic light control parameters and delays when passing cars from conflicting directions. Another approach to modeling at the mesoscale is based on dividing the road network into cells. The characteristics of traffic flows are determined by the presence of free and occupied cells, and in this case, the entire behavior of the traffic flow does not depend on individual drivers, but on the properties of a particular cell. The model output data are the average speed, average distance between vehicles, average queue length, travel time, average parameters of the incoming flow and average parameters of the outgoing flow [20]. The main programs for mesoscopic modeling are MEZZO, DYNAMIT, CONTRAM, DTASQ.

General requirements for input data of mesoscopic modeling are as follows:
1. Transport infrastructure:
   - nodes (permitted directions for further movement);
   - segments (speed, throughput, speed-density function).
2. Travel information:
   - OD matrix;
   - intensity of input streams.

Tasks to be solved include the level of road load, traffic on roads, performance indicators of individual elements of the transport infrastructure.

The disadvantages of mesoscopic modeling include the insufficient development of theory and software.

3. Conclusion
The use of simulation when solving problems of transport planning and optimizing the use of road infrastructure allows to evaluate the effectiveness of the implementation of an event even at the design stage. This is very important because errors made in the project may not allow to obtain the desired effect after its implementation and corrections at the operational stage require significant material and time costs.
An analytical study of the methods of simulating traffic flows allows to conclude about a wide variety of software products designed to solve problems associated with automobile traffic. The task of the simulation model is to present the real road situation in a dynamic model. There are three simulation models available for use in transport infrastructure, namely macroscopic, microscopic and mesoscopic ones. Unfortunately, at present, there is no ideal model to solve the whole complex of problems associated with traffic flows. Each simulation model allows to solve a certain range of transport problems, and therefore the use of a particular model depends on the purpose of the study. Summing up the analysis, it can be assumed that the selection of the right model in accordance with the objectives of the study is an important step towards solving transport problems.

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