Features of development of a digital twin of the transport system of an urban area using simulation modeling methods

Aleksandr Krasnikov¹,*, Vladimir Simonov², and Sergey Boykov³

¹Moscow Polytechnic University, Moscow, Russia
²Russian State Social University, Moscow, Russia
³Moscow Technical University of Communications and Informatics, Moscow, Russia

Abstract. The relevance of the study is justified by the growing share of urban population and their active use of personal automobile and public transportation. All this increases the mobility of the population and requires the development of transportation infrastructure in the established urban development. Solving such problems requires the development of models that simulate all aspects of the real object of the transportation system. With their help it is possible to conduct experiments on changing individual characteristics of the system in order to assess its response to control actions. The object of the study is Pervomayskaya Street at its intersection with the Tretya Parkovaya Street in the Izmailovo district of the Eastern Administrative District of Moscow. The article presents the stages of simulation model creation and their corresponding results in the form of models characterizing traffic flows, system objects and their behavior.

1 Introduction

The “Development of transport systems” state program is approved and implemented in the Russian Federation. It provides conditions for improving the quality of movement of the population, as well as for improving the infrastructure of the transport industry as a whole [1]. The growth of the vehicle fleet, the increase in traffic intensity and mobility lead to a high load on the established transportation system not only of a separate district, but of the whole city [2].

Systemic failures in road traffic lead to a sharp increase in transportation time costs, increased fuel consumption, increased number of traffic accidents and deterioration of the environmental situation [3]. The development strategy of any urban transport system provides for the increase of transport accessibility of territories, growth of economic efficiency, safety and environmental friendliness of transportation. In most cities, such measures should be implemented in areas with historically dense buildings, lack of parking spaces for personal motor vehicles, a large number of road crossings and lack of barrier-free, comfortable environment for pedestrians.
Many researchers use mathematical and simulation models [2, 4, 5] to develop concepts of sustainable development of urban areas and to introduce environmentally friendly modes of transportation. Such a model is essentially a digital twin of a real object, which is used to predict the response of the system to certain control actions [6]. This allows conducting experiments with complex objects in a specialized software environment without affecting the real transport systems.

Based on this, the purpose of the study is to create a digital twin of the transport system of the district for the effective organization of traffic flows.

Objectives of the study are to obtain a detailed description of the object corresponding to all aspects of the corresponding transport system, to create models of the behavior of the established objects, to visualize the obtained results and to develop scenarios simulating the change of individual parameters of the system.

Theoretical significance of the study lies in the creation of a formal model of a real-world object to investigate its behavior over a given time interval. All this is the basis for research in the field of sustainable development of transportation systems, creation of “smart cities” and other areas related to the development of urban environment.

Practical significance of the study lies in the possibility of using the results obtained in educational activities in the training of specialists in urban planning, traffic management, etc. It is possible to establish the effectiveness of plans to modernize road infrastructure and determine the vector of development of urban areas with the help of the created model.

2 Materials and methods

Object of the study is a section of the street road network, located in the Izmailovo district of the Eastern Administrative District of Moscow, and its processes related to the transportation network. The section is formed by the intersection of Pervomayskaya Street and Tretya Parkovaya Street, the image of which is presented in Fig. 1.

The authors used structural analysis technologies to create a model of the research object. Such technology is based on the principle of identifying the structure as a relatively stable set of relations between the elements of the system [4, 7]. System elements are system objects that perform one of the elementary functions related to its processes or phenomena [2, 8]. For this purpose, a step-by-step detailed review and investigation of the system was carried out, implying the division of the system into levels of abstraction with bounded and logically related elements, as well as a bounding context.

The results obtained during the application of the structural analysis method were transformed into the data necessary for the creation of the simulation model by means of systematization, synthesis, analysis and grouping techniques. A list of key elements and processes of the research object, their qualitative and quantitative characteristics necessary
Many researchers use mathematical and simulation models [2, 4, 5] to develop concepts of sustainable development of urban areas and to introduce environmentally friendly modes of transportation. Such a model is essentially a digital twin of a real object, which is used to predict the response of the system to certain control actions [6]. This allows conducting experiments with complex objects in a specialized software environment without affecting the real transport systems.

Based on this, the purpose of the study is to create a digital twin of the transport system of the district for the effective organization of traffic flows.

Objectives of the study are to obtain a detailed description of the object corresponding to all aspects of the corresponding transport system, to create models of the behavior of the established objects, to visualize the obtained results and to develop scenarios simulating the change of individual parameters of the system.

Theoretical significance of the study lies in the creation of a formal model of a real-world object to investigate its behavior over a given time interval. All this is the basis for research in the field of sustainable development of transportation systems, creation of “smart cities” and other areas related to the development of urban environment.

Practical significance of the study lies in the possibility of using the results obtained in educational activities in the training of specialists in urban planning, traffic management, etc. It is possible to establish the effectiveness of plans to modernize road infrastructure and determine the vector of development of urban areas with the help of the created model.

2 Materials and methods
Object of the study is a section of the street road network, located in the Izmailovo district of the Eastern Administrative District of Moscow, and its processes related to the transportation network. The section is formed by the intersection of Pervomayskaya Street and Tretya Parkovaya Street, the image of which is presented in Fig. 1.

Fig. 1. Study site top view (source: Yandex-Panoramas https://yandex.ru/maps/-/CDUfzNlI).

The authors used structural analysis technologies to create a model of the research object. Such technology is based on the principle of identifying the structure as a relatively stable set of relations between the elements of the system [4, 7]. System elements are system objects that perform one of the elementary functions related to its processes or phenomena [2, 8]. For this purpose, a step-by-step detailed review and investigation of the system was carried out, implying the division of the system into levels of abstraction with bounded and logically related elements, as well as a bounding context.

The results obtained during the application of the structural analysis method were transformed into the data necessary for the creation of the simulation model by means of systematization, synthesis, analysis and grouping techniques. A list of key elements and processes of the research object, their qualitative and quantitative characteristics necessary for creating a set of input parameters and parameters required for the simulation model customization [9, 10] were obtained as such data. In addition, the connections and relations of elements that form their basic states during the implementation of processes in the transportation system are established. This is necessary to create a set of rules for the formal model.

The use of the graphical method allowed visualizing the obtained results in the form of understandable models showing the behavior of each element of the system, dependencies during the implementation of processes, used resources, etc. [6, 8, 11].

The obtained results were transformed using simulation modeling methods to create an appropriate model of the research object.

3 Results
Information about the direction of traffic flows was obtained at the first stage of structuring. The corresponding scheme is presented in Fig. 2.

Fig. 2. Scheme of traffic flows of the study object.

Fig. 3. Scheme of public transport movement.
Pervomayskaya Street and Tretya Parkovaya Street form a cross-shaped intersection. The roadway of Pervomayskaya Street consists of two lanes in both directions for personal and public motor traffic. There are dedicated lanes for trams traffic in two directions in the center of the roadway. They are not physically separated from the other lanes.

At the second stage of structuring, public transport flows are allocated. The scheme of its movement is presented in Fig. 3.

The following designations are accepted in Fig. 3:
- $T1$ – tram stop (2 routes) on Pervomayskaya Street when moving from west to east;
- $T2$ – tram stop (3 routes) on Pervomayskaya Street when moving from east to west;
- $Pe1$ – bus stop (5 routes) on Tretya Parkovaya Street when moving to Izmailovskaya metro station;
- $Pa1$ – bus stop (5 routes, including one night route) on Pervomayskaya Street when part of the buses move from Izmailovskaya metro station and buses moving along Pervomayskaya Street from west to east;
- $Pa2$ – bus stop (2 routes, including one night route) on Pervomayskaya Street when moving from east to west;
- $Pe2$ – bus stop (2 routes) on Tretya Parkovaya Street when moving from Izmailovskaya metro station.

The bus routes are inter-district, providing transportation of passengers to social facilities and metro stations. The rolling stock includes medium, large and extra large capacity buses, trams only of extra large capacity.

At the third stage of structural analysis quantitative characteristics of transport flows were determined. The density distribution of public transportation flows by time of day in the study area is presented in Fig. 4.

The graph shows that the density of public transportation is high. This increases the “load” on the transportation network, which includes the study object.

At the fourth stage of the structural analysis, the dependencies of traffic congestion are established. Pervomayskaya Street lacks a dedicated bus lane, bus bays and isolated tram stops. This results in traffic congestion and increased travel times for passengers.
stops. Thus, when a bus stops at any of the bus stops, traffic in the respective lane is stopped or impeded. When a tram stops while moving in either direction, traffic in two lanes is stopped because passengers are dropped-off on the roadway.

Fig. 5 shows the pedestrian traffic pattern in the study area.

![Fig. 5. Pedestrian flows in the study area.](image)

The intersection is equipped with pedestrian crosswalks across all streets. Thus, when traffic flows along Pervomayskaya Street the following problematic areas arise:

1. those formed by a tram stop, a signal-controlled crossing and a bus stop in the right lane for two-way traffic (with the possibility to change lanes);
2. those formed by bus stops on Tretya Parkovaya Street when the bus stops, as the only lane is blocked for traffic;

Additional load on these sections is created by the flows of cars that make turns.

On the basis of the obtained results, a simulation model of the research object was made, which is based on the models of behavior of key objects: trams (Fig. 6), buses (fragments of the corresponding model in Fig. 7), personal cars (fragment of the corresponding model in Fig. 8).

![Fig. 6. Model of trams’ behavior in the simulation model.](image)

![Fig. 7. Fragment of the model of buses behavior in the simulation model.](image)
Fig. 8. Fragment of the model of personal cars behavior in the simulation model.

It should be noted that Fig. 7 presents the behavior models of unique bus routes. This means that those routes, which behavior coincides with those presented in the given section, are excluded for demonstration.

The resulting simulation model allows evaluating the implementation of concepts to modernize the street road network. For example, Fig. 9 shows the results of the scenario of creating bus stop pockets and moving tram stops out of the study area.

Fig. 9. The resulting simulation model allows evaluating the implementation of concepts to modernize the street road network.
Fig. 9 shows the changes in traffic congestion over time: traffic jam starts to form due to the phase of traffic lights and permitted left turns. At the same time, the traffic on the main road in the area of the bus bays is free. For example, Fig. 9 shows the results of the scenario of creating bus stop pockets and moving tram stops out of the study area.

4 Discussion

Simulation tools allow researching the study object in a systematic way and to establish all the facts of the behavior of the corresponding system. Based on this, it is possible to draw conclusions about the response of the system to various external influences and internal changes [4, 6, 7].

The results of related studies in the field of simulation modeling of transportation systems coincide with the obtained results. Researchers Logachev [5, 9, 10], Kozlov [8], Altunina [7] and Anda [12] in order to design a simulation model conduct a structural analysis of the subject area and obtain input parameters and rules of interaction of processes for it.

Formalization of the obtained results allowed obtaining a digital twin of the object of study to simulate different scenarios of its behavior. This approach coincides with the approach of other studies on the reproduction of processes, systems and objects [13-16].

5 Conclusion

The efficiency of the city’s transportation system determines the pace of development and the quality of the urban environment. The urban environment is a place of residence of a significant number of people who require comfortable and fast movement relative to the centers of business activity.

The accumulated experience and new technologies allow developing tools for the formation of transportation policy with many factors being considered. Assessment of consequences, cause-and-effect relationships between the decisions taken and potential indicators of changes in the transport sphere are the basis for the development of concepts and strategies for sustainable development of urban areas. The use of specialized tools based on the methods of simulation modeling allows creating a digital twin that reproduces its behavior without affecting the real object.

References


15. I. Krasnikova, Ya. Beresneva, E3S WoC **515**, 04006 (2024) https://doi.org/10.1051/e3sconf/202451504006