Simulation modeling as a means of integrating infrastructure for individual mobility in urban environments

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Abstract. The article presents the concept of sustainable development of the territory of the Moscow city district by introducing paths for individual mobility into the transport network. A simulation model of the street road network is created to substantiate the efficiency of implementation, traffic safety, and connectivity of street routes. The accuracy and validity of the obtained model is determined by the use of research methods, which provide a detailed description of the problem area, structured processes and objects, and also establish features of their interaction. To visualize the obtained results, a graph of conflicting and connecting flows in the transport network of the district and graphical models of their behavior are developed.

1 Introduction

Sustainable development of urban areas requires a comprehensive solution to problems of traffic congestion, development of public transportation, creation of convenient, comfortable, safe and barrier-free environment, reduction of environmental pollution, etc. One way to partially solve such problems is to create conditions for the active use of means of individual mobility (e.g., bicycles, scooters, etc.).

According to the 2022 data Russia ranks 86th in the list of the most favorable cities for the use of bicycles [1]. Moscow has little experience in this area and is gradually building bicycle lanes as part of the general roadway in some areas as part of the city’s programs of territory improvement. As Sanzhara notes in the study “230 km of bicycle lanes have been designed in Moscow, 90 km of which are placed on roads, and 140 km in park areas...” [1]. It should be taken into account that in Moscow a dedicated lane for public transportation is considered a bicycle lane [https://mos.bike/news/all/bus-lanes/].

In his study Senin notes that “bicycle infrastructure in Russia is often developed randomly, which is due to the uncertainty of the pattern of formation of bicycle flows, which does not allow an objective assessment of the potential effect of its development” [2]. From the state management of bicycle lanes construction point of view, methodological manuals and standards have been developed that determine the technical requirements for the objects of the corresponding infrastructure. At the same time, there are no recommendations to justify

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the choice of the bicycle routes location [3, 4]. This is due to the fact that territories with partially developed infrastructure are used for the introduction of bicycle routes therefore assessing the effectiveness of such introduction requires monitoring and evaluating a large array of indicators [2, 5].

The means to solve such an issue is the simulation modeling of the objects of the transport network of the districts that provide for the introduction of bicycle lanes. The simulation model is an exact copy of the research object, which fully reproduces its qualitative and quantitative characteristics, as well as all its processes at a given time interval. Thus, the simulation model can show the consequences of the results of the implementation and use of bicycle lanes in a given area.

Based on this, the purpose of the study is to create a simulation model of a section of the road network of a district of the city of Moscow to make the justifying the construction of a bicycle route possible.

Theoretical significance of the study is the possibility of obtaining qualitative and quantitative characteristics of traffic flows of the research object and the creation of its formal models.

Practical significance of the study is the possibility of forecasting changes in the parameters of the object of study at a given time interval to justify the development of concepts of urban areas, to improve urban space, to improve transport links between districts.

2 Materials and methods

The object of the study is Pervomayskaya Street, located in the Eastern Administrative District of Moscow and connecting the districts of Eastern Izmailovo and Izmailovo. The development of a bicycle route in the given area allows connect the dense urban development district with park areas (Izmailovo Estate, Izmailovo Park of Culture and Recreation), tourist sites (Izmailovo Kremlin), as well as with the objects of transport infrastructure (e.g., the station of the Moscow Central Ring), allowing access to bicycle routes or other park areas.

To conduct the research the authors used general scientific methods that allow obtaining the characteristics of the study object and creating its simulation model. The study of literature sources on relevant topics allowed the authors to determine the list of research methods that allow obtaining an accurate parametric description of the study object, necessary for creating a computer model of the object, reflecting its real behavior. Works of the following researchers studied in the course of the research should be highlighted: Altunina [6], Boikova [7], Logachev [8-10], Kulibaba [11], Mezentseva [12] and Di Mascio [13].

Comprehensive use of observation, analysis, synthesis and abstraction methods allowed the authors to establish the qualitative and quantitative characteristics of the study object. These methods were applied based on publicly available maps and schemes of the city districts where the study object is located, as well as based on its panoramic images. Onsite observations of objects (e.g., the organization of traffic at signal controlled intersections, phases of traffic lights, frequency of public transport) were carried out to establish individual characteristics and their dependencies. Such measures allow forming a set of characteristics to be used as input parameters for simulation modeling to carry out its initial setup, and also rules that define the basic behavior models of key subjects of the research object [6, 9, 10].

The graph theory method was used to visualize the rules of behavior. Such a method allowed establishing topological features of the study object. Thanks to its use, conflicting and adjacent traffic flows, accessibility of key actors were identified and a route network of agents included in the flows (e.g., public transport, personal vehicles, pedestrians) was developed.

The results obtained during the use of the above methods and the use of specialized software tools made it possible to create a simulation model of the study object. For this
purpose, agent-based modeling methods were used to reproduce the behavior of each agent at a given time interval under specified conditions.

3 Results

The use of the stated research methods made it possible to establish the characteristics of the object of study. Pervomayskaya Street connects two large districts of Moscow and has a length of 3.9 km. Along its entire length it consists of two lanes in both directions for motor vehicles and one lane in the center for trams. The lanes for trams are dedicated but not separated from other lanes. Drop-off and pick-up of passengers is carried out on the roadway, thereby restricting the movement of other traffic. There is also bus traffic, which predominantly lacks stop pockets for passenger pick-up and drop-off.

Due to its geographic location, Pervomayskaya Street has many intersections and adjacencies with other streets. All of this provides a large number of controlled T-shaped and quad intersections equipped with pedestrian crosswalks. Figure 1 shows some sections of Pervomayskaya Street demonstrating these features.

![Figure 1](https://yandex.ru/maps/-/CDUuIN9u)

**Fig. 1.** Panoramic image of Pervomayskaya Street in Moscow (source: Yandex-Panoramas https://yandex.ru/maps/-/CDUuIN9u).
A graph was developed to identify adjacent and conflicting flows (traffic and pedestrian). The graph for a separate section located within the study area is presented. Such a section is the section of Izmaylovskaya Square and Pervaya Parkovaya Street adjoining Pervomayskaya Street. The following designations of the resulting flows are introduced:

- $U_x$ – traffic flows along the Pervaya Parkovaya Street;
- $O_x$ – automobile flows (including public bus transportation) along Pervomayskaya Street;
- $W_x$ – trams flows;
- $N_x$ – traffic flows on Izmailovskaya Square;
- $P_x$ – pedestrian flows at signal controlled crosswalks;
- $T_x$ – pedestrian flows arising at pick-up and drop-off of trams passengers;
- $B_1$ – pedestrian flow arising at pick-up and drop-off of bus passengers.

Fig. 2 shows the location of the introduced designations on the panoramic image of the study area.

![Fig. 2. Marking of the graph vertices on the map of the study area (source of the background image: Yandex-panoramas https://yandex.ru/maps/-/CDUyAD7L).](image)

Fig. 3 shows the resulting graph of intersections and merges of traffic and pedestrian flows of the object shown in Fig. 2.

![Fig. 3. Model of merging and intersection of traffic and pedestrian flows on Izmailovskaya Square of the study object.](image)
According to the resulting model, all the key agents of processes that occur in the study object are identified. These include personal cars, public transport (trams and buses), pedestrians (moving on signal-controlled crosswalks, on sidewalks and entering the roadway during pick-up or drop-off from the tram), pedestrians moving on an individual mobility device (e.g., scooter, bicycle) on the sidewalk. Based on this, behavioral models are developed. Those are structured by agent types: trams (Fig. 4), cars moving along O3 and O4 directions (Fig. 5).

![Fig. 4. Fragment of the behavior model of “Tram” agents of the study object.](image)

![Fig. 5. Fragment of the behavior model of “Car” agents along Pervomayskaya Street.](image)

Fig. 6 presents a graphical interpretation of the entire behavior model for the section of the study object.

![Fig. 6. Two-dimensional model of agents’ behavior on Pervomayskaya Street in the area of Izmailovskaya Square.](image)

In the course of the study, the model of the entire object of study is developed. Based on the results, concepts have been developed to introduce bicycle lanes into the street road network (e.g., a lane in each direction of traffic at the corresponding sidewalk, combined two lanes as shown in Fig. 6, or zone delineation at the sidewalk).

4 Discussion

As a result of this research, qualitative and quantitative characteristics of the study object were obtained. The processes that occur between the subjects of the study object were
established and formalized. All this was used to create a simulation model of the transportation system of the city district. If the approach to obtaining such results is compared with the methods of conducting research by other scientists, the similarities can be found. In the works of other researchers on creating simulation models, methods are used to obtain an accurate description of the problem domain, synthesize them and formalize them using certain graphical notations [7, 8, 11, 14].

Conditions for the implementation of scenarios for predicting changes in the behavior of different subjects of the research object are created based on the obtained simulation model. This allows specialists to decide on the success of project decisions and on possible introduction of corrective actions to improve the planned results [6, 12, 15]. The obtained simulation model allows implementing different scenarios for behavioral changes not only in the flow of agents, but also in individual elements with unique behavior out of the general flow.

5 Conclusion

In the modern world, the relevance of bicycle transportation in the city limits is increasing. Along with this, comfort and convenience for appropriate trips are changing. Different countries realize environmental priorities in the transport network of urban areas and popularize new ways of transportation. Their active introduction and use require the development of routes that protect users of individual mobility devices from traffic and pedestrian flows, and speed up urban mobility. Such a concept is only possible with a proper approach to the bicycle route network design process.

The study presents an approach to such a design in terms of the use of simulation modeling tools. The results obtained allowed establishing all the dependencies occurring in the transportation network of the city districts in order to create an appropriate model. Such a model allows establishing not only the needs for safety and logical organization of traffic schemes with bicycle lanes, but also provides an opportunity to design the infrastructure necessary to stimulate the transition of city residents to more ecological ways of movement.

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References


15. M. Logachev, M. Zelenkov, BIO Web Conf. 107, 04023 (2024) https://doi.org/10.1051/bioconf/202410704023