Electric charging stations for electric vehicles in a traffic flow simulation model

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Abstract. This article substantiates the need to use simulation modeling in planning the location of parking lots equipped with charging stations for electric cars. Moscow is actively developing infrastructure for the use of electric cars for personal use, but there is a limited number of charging stations in the city districts. This increases the load on the transportation framework of the capital. Creating a simulation model of the transport system allows us to identify its "bottlenecks" related to the effective organization of road traffic and the creation of a sustainable environment. The use of methods of structural analysis, synthesis, groupings, information and simulation modeling allowed to establish all key objects of the problem area, their qualitative and quantitative characteristics necessary to create a simulation model. The created simulation model is based on the developed formal models of changes in the states of each class of objects, corresponding to the behavior in the real urban environment. To demonstrate the obtained results, a three-dimensional model corresponding to the simulation model is developed.

1 Introduction

The ecological state of the environment depends on many factors, one of which is the level of human use of motor transport. The combustion of fuel releases toxic substances that pollute the air and soil, while driving generates noise and dust clouds. The above factors affect the level of development of territories and the subsequent demand for electric cars.

Sales of new electric cars in Russia for 2023 increased 4.5 times (14,408 such vehicles were sold), 697 fast and 2163 slow electric charging stations were installed [Russia stimulates the transition to electric cars: https://avtocharge.ru/rossiya-stimuliruet-perexod-na-elektrokaryi-tempyi-ustanovki-elektrozaryadok-udvaivayutsya]. In Moscow, free charging stations and energy hubs for electric cars are being opened in city districts. The infrastructure is being actively adapted for this purpose: charging places are being equipped near business and shopping centers, and user interest is stimulated by organizing free parking for owners of such cars and adjusting the transport tax [Rossiyskaya Gazeta: https://rg.ru/2022/04/13/reg-cfo/v-moskve.otkryli-87-besplatnyh-zariadok-dlia-elektromobilej.html].

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In Moscow districts with an established architectural appearance for the installation of electronic charging stations the street is reconstructed to lay powerful cable networks [Official portal of the Mayor and Government of Moscow: https://www.mos.ru/city/projects/electro]. This allows for the comprehensive development of electric transport in the metropolis: travel by electric car, rent electric bicycles or electric scooters.

The implementation of the concept of active introduction of electric transport into the transport system of a megacity changes the appearance of traffic flows. This is due to the dependence of electric vehicles on the location, type and number of charging stations [1]. For example, there may be a station with only one charging place of long charging in the area of several kilometers. Based on this, the load on the road infrastructure of the neighborhood is increased. To identify such bottlenecks and to develop a comprehensive concept of the district's appearance requires the use of transportation simulation models that reflect qualitative and quantitative changes in traffic flows depending on a variety of parameters [2, 3].

Simulation models are a tool that allows using specialized software to perform experiments with a digital twin of real objects (processes or complex dynamic systems) to assess its changes over a given time interval [4, 5].

Thus, the aim of the study is to develop a simulation model of the transportation system of a city district taking into account the traffic of electric vehicles. This requires establishing the key aspects of the transportation system of the problem area, developing rules of interaction of the established objects and processes on the basis of the obtained results and formalizing such rules. All this refers to the main objectives of the study.

The object of the study is a section of the road transportation network in the Perovo area of the Eastern Administrative District of Moscow. The subject of the study is the transportation processes of the object of the study.

Theoretical significance lies in the systematization of heterogeneous objects that affect the transport system of the district, the creation of a set of qualitative and quantitative characteristics of objects and processes of the system, suitable for use in studies related to the sustainable development of urban areas, design and development of specialized software for the management of urban processes.

Practical significance lies in the creation of a software tool used in the development of concepts of urban development plans to assess the consequences at given time intervals and methodological recommendations for the operational management of transport system processes with minimizing the risks of accidents or losses.

2 Methods and Materials

The creation of a digital twin of any object requires the complex use of methods that allow to establish all key characteristics of the modeling object and formalize them [4, 6]. In studies related to the formalization of objects and processes the methods of structural analysis, synthesis, groupings and statistical analysis are used [2, 3]. Such an approach was implemented to the stated subject of the research. By decomposing it step by step, at each stage the significant elements influencing the changes in the states of traffic flows were identified and the links between such states were established.

In studies related to transport flows, methodologies typical for information and simulation modeling are used to formalize the established quantitative and qualitative characteristics of objects and processes and the links between them [7, 8]. For this purpose, we used the methodology of agent-based modeling, which allowed us to create diagrams of changes in the states of each category of elements with similar behavior within the study object.
3 Results

An analysis of the current state of parking space in the study area equipped with electric vehicle charging stations showed their low number. There is only one such station located within the neighborhood itself, while there are four such stations in nearby neighborhoods:

1. Aviamotornaya Street: a slow charging station (22kW) for two parking spaces (belongs to the Lefortovo district).
2. Enthusiastov Highway: a slow charging station (22kW) for two parking spaces (belongs to Ivanovskoye district).
3. Svobodny Prospekt: a slow charging station (22kW) for one parking space (refers to Novogireevo district).
4. Plekhanova Street: a slow charging station (22kW) for two parking spaces with one port (refers to the Perovo district).
5. Krasnokazarmennaya Street: a slow charging station (22kW) for two cars with one port (refers to Lefortovo district).

Fig. 1 shows an undirected weighted graph demonstrating the connectivity of the specified parking lots from the list (the number of vertices corresponds to the list position).

![Fig. 1. Connectivity graph of parking lots equipped with electric vehicle charging stations in the study area](image)

The specified weight of the graph edge corresponds to the distance between parking spaces (in km) that the car will need to travel. A slow charging station is able to charge an electric car for 6 hours up to 500 km of travel. On average, a city dweller travels no more than 100 km in a day. All this data is used to create a parametric model that determines the probability of an electric car appearing at a charging station and the workload of each station.

The location of charging stations affects the organization of traffic flows in the area, so the next stage of the study was to develop a model of the connectivity of such flows. Fig. 2 shows a fragment of the traffic flow model combined with a map of the neighborhood.
Fig. 2. Fragment of the traffic flow model of the study area

Fig. 2 shows a fragment of the model that formalizes the section of the street road network at the intersection of Zeleny Prospect and Novogireevskaya Street.

Traffic flows consist of flows of personal automobile and public transport. Their movement is carried out according to the rules of the road. When creating the model, exits to the intra-house territory are taken into account, as it allows modeling situations with the placement of charging stations near houses.

The density of traffic flows (or the probability of occurrence of any vehicle) is determined based on traffic congestion depending on the time of day, day of the week and seasonality. This is due to the fact that the neighborhood is pronounced traffic depending on the daily peak loads (morning interval is associated with traffic from home to workplace, evening interval - vice versa). Based on this, the load is formed depending on the day of the week: on weekdays (Monday - Friday) there is a high load on the transportation infrastructure, on weekends (Saturday - Sunday) - it decreases. Seasonal density is related to the vacation schedule, which falls in the summer period and, therefore, the pendulum migration of the population using personal motor transport for commuting is weakly expressed.

Based on this, a model of changing states of road transportation in the study area is created. Fig. 3 shows a fragment of the corresponding model.

Fig. 3. Fragment of the model of change of states during the movement of road transport of the study object
In the model presented in Fig. 3, any motor vehicle that moves in the area of the object of study is an agent. Such an agent is characterized by a set of certain states depending on its behavior (e.g., cars that move straight on Green Avenue or cars turning from Green Avenue to a parking lot or an internal house territory appear with a calculated probability). This behavior is true for all agents making a movement in a given direction. In this study, non-standard situations with agent behavior are irrelevant for the purpose of the study (e.g., one agent instance exceeding the speed limit). The use of the created diagram of changes in the agents' states allows analyzing the change in the agents' states when the probability of occurrence of any particular agent or the probability of occurrence of any event during the movement of any agents or their instances changes.

Based on the results obtained, a three-dimensional model of the research object has been developed, which simulates the processes of transportation flows of the research object, and is actually its digital twin. Figs. 4-6 show fragments of the corresponding model, which demonstrate the events in which the agent instances of transport flows are located.

**Fig. 4.** Fragment of a three-dimensional digital twin simulating the intersection of traffic flows at a cruciform intersection

**Fig. 5.** Fragment of a three-dimensional digital twin simulating the congestion of an electric vehicle charging parking lot located along a roadway

**Fig. 6.** Fragment of a 3D digital twin simulating the congestion of an electric vehicle charging parking lot located on an in-house lot

In order to increase the calculation performance and display the characteristics of the study object in the 3D model, the visualization of infrastructure objects (e.g. houses, trees),
cars, etc. has been simplified. All roads in the digital twin are highlighted by color (from green to red), demonstrating the level of traffic flow density on the corresponding road lane of the road.

4 Discussion

The developed simulation model is a digital copy of the research object reflecting the characteristics of the research subject. Conceptually comparing the obtained result with the results of other studies related to the modeling of transportation systems, we can conclude that they are valid when using the stated methodologies [5, 9, 10]. The researchers obtained models describing the changes in the states of each class of participants of traffic flows, affecting the overall behavior of the system. All this allows the evaluation of short-term or long-term changes in the system when modifying the parameters of the digital twin.

In addition, digital twins of such systems can be used in the educational process when training specialists in the field of state and municipal management, urbanism, road construction, environmental monitoring and management economics. In the works related to the development of methods and tools for effective management of the educational process, it is noted about the need for digital resources capable of simulating real processes for the formation of professional competencies [11, 12]. The developed model can be used as an electronic educational resource or digital simulator.

5 Conclusion

The infrastructure of Russian cities is currently not adapted for the active and large-scale use of electric vehicles for personal use. This is mainly due to the lack of charging stations or a small number of charging stations. Over the last five years, there has been a trend towards solving such problems, as they are related to the reduction of carbon dioxide emissions and the supply of environmentally friendly electricity.

The use of modern digital technologies in the development of concepts for the development of urban areas with a reduced environmental load is a priority. With their help, it is possible not only to create development concepts, but also to predict the results of changes in the short or long term.

References


