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Simulation modeling of transport and socioeconomic development of megapolis districts (on the example of Moscow city)

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Abstract. The article substantiates the relevance of using software tools to manage the sustainable development of settlement territories. The main aspects that influence this development are established. These include, for example, socioeconomic indicators, environmental situation, and transportation accessibility. Using the methods of analysis, synthesis, systematization, quantitative and qualitative characteristics of such objects and processes that determine the content of the selected aspects are established. The obtained results are used to create formal models that demonstrate the changes in the system states necessary for agent-based modeling. Behavior of each agent, its internal states, peculiarities of the influence of the external environment or conditions on it form the overall behavior of the system. The model obtained allows for predicting changes in the system to control actions.

1 Introduction

Sustainable development of territories is influenced by many factors, which include socio-economic development of society, environmental and economic features of territories, transportation accessibility, development of economic activity sectors, etc. [1]. Such development is a purposeful process determined by one main goal or a system of goals structured by time, functional or sectoral characteristics [2]. Accordingly, to describe and manage such a multidimensional process requires the formation of a set of indicators that depends on the development of human potential, the dynamics of social and economic development of territories and transportation.

The functioning of the transport complex of the region or its individual territories is a full-fledged component of the territorial-production complex [2]. Transport provides the movement of goods and passengers, supporting the needs of the economy and population in organizing the activities of enterprises and organizations of different economic sectors, has political, cultural, sociological and scientific significance [2, 3].

Effective strategic planning and management of the above processes is one of the main conditions for the successful development of complex socio-economic systems of different levels [4, 5]. This requires the use of modern software tools that can process and analyze a

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large amount of data, develop recommended control actions depending on external conditions and assessment of predicted changes [6, 7]. Such tools are actively used in different branches of economic and production activities [8-10]. They are based on digital models of real objects and processes capable of predicting and reproducing their states depending on changes in different conditions [4].

Based on the above, the purpose of the study is to develop a simulation model of territories that allows forecasting of its sustainable development. The main objectives. of the study are to identify all the key objects and processes that affect the change of socio-economic, transport and environmental conditions of the territory, to establish their qualitative and quantitative characteristics, allowing to form a set of relations arising between objects during their interaction, rules and functional requirements for the implementation of processes, based on the obtained data to develop formal models of processes and objects to create a digital twin of the object studied

Theoretical significance of the study lies in the systematization of data describing the processes of socio-economic, transport and environmental development of urban areas, the development of formal models of processes necessary for use in related studies, providing the development and justification of concepts of comfortable and accessible urban environment and transport, the development of urban digital expert systems. The practical significance of the study lies in the use of the obtained results for digital validation of projects to change the urban environment.

2 Materials and Methods

The object of the study is the processes affecting the ecological condition of megapolis territories. The studied area is located in the North-Western Administrative District of Moscow in the territory shown in Fig. 1.

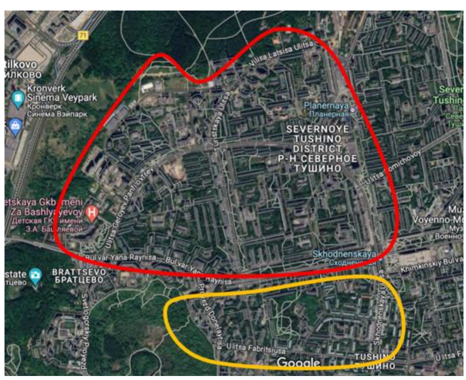

Fig. 1. Boundaries of the research object on the map of Moscow (map source: https://maps.app.goo.gl/EDFnbWb2pNjHHrdEA)

According to the administrative division, the selected areas belong to two different districts: red - Severnoe Tushino, yellow - Yuzhnoe Tushino).

To create a model that adequately reflects the objects and processes of the subject area, it is required to establish all aspects significantly affecting changes in their states. In the studies, in which the task of determining all elements of the subject area and their relations is defined, the methods of analysis, structurization, synthesis and generalizations are used [11, 12]. The results obtained from the stated methods became the input parameters and rules for the simulation model.

The agent-based modeling method was used to create the simulation model. As the researchers note in their works, the use of such a method allows to establish a uniform behavior for groups of objects (agents) united by similar characteristics, to establish links between them and the behavior of the environment [13, 14]. This is achieved due to the fact that agents act without direct control of others over their actions and internal state, agents interact with each other, are able to perceive and react to the environment, participating in purposeful behavior [4, 5, 15]. Thus, the global behavior of the whole system is formed based on the actions of each instance of objects.

3 Results

In order to create a model for the development of the territory of the object of study, it was analyzed in terms of population migration, accessibility of social and transport infrastructure, housing and employment. As noted, the object of the study consists of two Moscow districts located in the Northwestern Administrative District. We will present a fragment of the established characteristics, which became the basis for determining the input parameters of the simulation model and the rules of interaction:

1. Severnoe Tushino district. The territory is home to 165 thousand people (the district is among the 10 most populated districts of Moscow), is one of the three quietest districts of the megalopolis (Rockwool research), is on the second position of the rating of districts in terms of environmental safety (the report of experts Urban Awards and EcoStandard, based on the assessment of the area of landscaping, the number of potentially dangerous enterprises, the number of cars and traffic, air quality and soil quality), is considered one of the landscaped areas [source: Official Portal of the Mayor and Government of Moscow https://www.mos.ru]. On its territory there are educational organizations operating at all levels of education, cultural, health care, cultural and sports institutions, parks, there are organizations providing all kinds of services, developed transport accessibility. The population is characterized by pendular migration, associated with movement from the place of residence to places of work or study, either within the district or to other areas by personal or public transport (metro, bus, streetcar). Socially significant objects are connected by public transport routes: ground transport provides delivery of passengers to metro stations, places of residence, polyclinics, educational organizations, etc. Quarterly the metro station located in the district is used by 3.7 million passengers [source: Moscow Government Open Data Portal https://data.mos.ru].
2. Yuzhnoye Tushino district. The population is growing every year and as of 2023 amounted to 111,492 people. The development of the territory took place along the streets and boulevards, forming the appearance of the district. In addition to the secondary housing market, the primary housing market with internal infrastructure and landscaped adjacent territory is actively forming on the territory. There is a deficit of free territory, which affects the pace and volume of development. Transportation accessibility is provided by a complex combination of surface and underground transportation. Features of transport accessibility of infrastructure and transportation development are similar to those in Severny Tushino. On the territory of the district there are six significant cultural and historical objects, 95 organizations providing social services to the population, 490 organizations providing commercial organizations to the population [source: Official portal of the Mayor and Government of Moscow https://www.mos.ru/moi-raion/yuzhnoe-tushino]. Part of the district is occupied by the natural-historical park "Tushino", which favorably affects the environmental situation of the district.

Monitoring of the environmental situation of the research object is shown in Fig. 2.

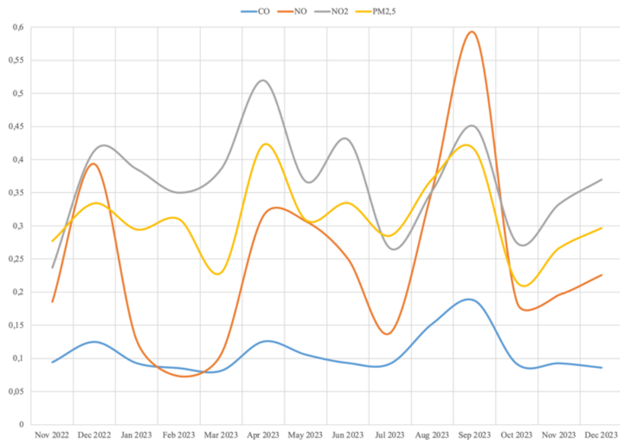

Fig. 2. Statistics of indicators polluting the environment of the research object (source: data of the measuring station Turistskaya MOSECOMONITORING https://mosecom.mos.ru/turistskaya).

When creating the agent model, the agent's behavior in relation to changes in the urban environment was taken into account: the location of permanent housing in relation to the place of work and social infrastructure facilities, available modes of transport, environmental conditions, as such indicators affect the indicators of accessibility and cost of housing and the development of the transport system.

The agent's behavior corresponds to the model presented in Fig. 3.

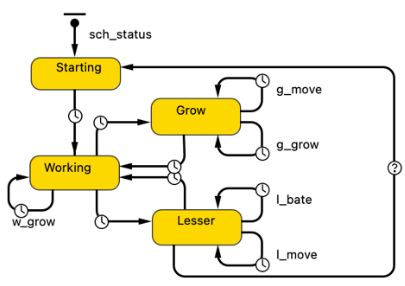

Fig. 3. Model of change of behavioral states of the district residents

A fragment of the transportation model corresponding to the agent's movement across the areas of the object of study is shown in Fig. 4.

Fig. 4. Model of transport flows most typical for the agents of the object of study

Fig. 4 shows the scheme of personal automobile (black lines) and ground public (red lines) transportation. These roads provide connectivity of intra-district infrastructure objects and access to highways connecting city districts.
The general behavior of the agent in the model is represented as a program model, a fragment of which is shown in Fig. 5.

```
initialDay = getDayOfMonth();
initialMonth = getMonth();

// init roads for private cars
for (int i = 0; i < networkPivot.size(); i++ ){
Object o = networkPivot.get(i);
// create node
if ( o instanceof ShapeRectangle ) {
Joint n = add_nodes();
n.node_rectangle = (ShapeRectangle) o;
n.node_name = n.node_rectangle.getName();
} else if ( o instanceof ShapePolyLine ) {

// create road
Road r = add_roads();
r.road_line = (ShapePolyLine) o;
}
}

// init references from nodes to connected roads
for ( Joint n : nodes ){
for ( Road r : roads ){
    if ( n.node_rectangle.contains( r.road_line.getX(), r.road_line.getY() ) ){
    n.entered_roads.add(r);
    r.beginning_node_of_road = n;
    }
    if (n.node_rectangle.contains( r.road_line.getX() + r.road_line.getPointDx( r.road_line.getNPoints()-1 ), r.road_line.getY() +
r.road_line.getPointDy( r.road_line.getNPoints()-1 ) ) ){
    n.entered_roads.add(r);
    r.end_node_of_road = n;
    }
}
}

initModelStructure();
selectZone( plz10 );
```

Fig. 5. Model of agents' behavior represented as Java code

Figs. 6-9 show fragments of models illustrating different aspects of the agent's behavior based on established aspects (behavior patterns, transport accessibility, availability of housing and social infrastructure facilities, changes in the environmental situation).

Fig. 6. Fragment of the model of wage formation per month in the organizations of the district

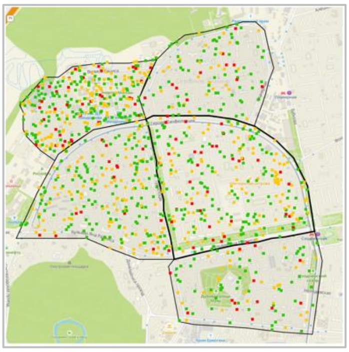

Fig. 7. Fragment of the model of population satisfaction by the main places of its concentration

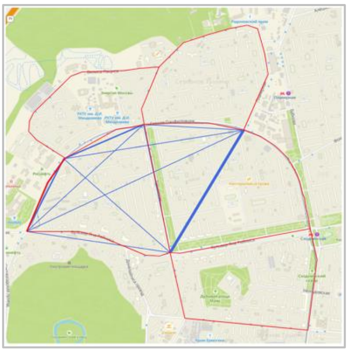

Fig. 8. Fragment of the model of traffic (red lines) and pedestrian (blue) flows

Fig. 9. Fragment of the generalized model

It should be noted that an agent can be in a state of "satisfaction" (■), positive change in condition (▲), "dissatisfaction" (■), negative dynamics (▼), "tolerable state" (■) without dynamics (▬).

4 Discussion

The developed simulation model is based on a set of indicators that include a set of constraints, requirements and conditions that determine the nature of the participant's influence on the development process and the impact of economic activity on the result of socio-economic development of the territory. The indicators used in the model correspond to the corresponding indicators in the assessment and forecasting of sustainable development of territories in the works of domestic and foreign researchers [1, 5, 9, 16, 17].

As a result of using the stated research methods, models of object behavior and process state transitions valid for the subject area are developed. In the studies related to simulation modeling, the authors obtained conceptually similar models reflecting all aspects of the object of study [9, 11, 13, 15].

5 Conclusions

Simulation modeling is actively used in economics to solve state strategic planning tasks for the purpose of forecasts for specific territories, taking into account their multidimensionality. When creating scenarios for the implementation of development concepts, it is necessary to make constant adjustments, accumulating information about possible changes in patterns, interrelationships, and supplementing it with new significant factors to qualitatively improve the system of forecast indicators.

The results obtained by such means become an additional tool for making a decision about the implementation of a particular development strategy. In addition, they can be used in the training of profile specialists in the sphere of state and municipal management to model practice-orientated tasks for the formation of professional and labor competencies.

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