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Forecasting water traffic of the north-south transport corridor on the territory of the Russian Federation using simulation modelling

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Abstract. The paper defines the structure and importance of the international North-South transport corridor. The types and points of routes that run through the territory of Russia have been identified. These routes include road, rail and water. The main water route and its branches have been identified. Examples of the content of water traffic along the Volga River have been given. A parametric model of vessel movement has been developed, being the basis for the simulation of water routes. As examples, fragments of diagrams of the state of ships movement in the section from Nizhny Novgorod to Kazan have been provided. Such diagrams are part of a simulation model that allows implementing different scenarios for the organization of navigation in particular areas.

1 Introduction

In 2000, India, the Russian Federation and Iran signed an agreement on the creation of the international North-South transport corridor. With the passage of time, the route has been modernized, with the accession of ten countries. The initial purpose of such a corridor was to ensure communication between the Baltic countries and India, and the territory of the Russian Federation was used for transit [1]. The total length of the route is 7.2 thousand km and it runs from the Indian port of Nhava Sheva (south of Mumbai) to St. Petersburg through the territory of Iran [2, 3]. For the delivery of goods along this route, sea, river (NSW), rail (NSR) and road transport (NSA) are used with various branches from the main routes [1].

In its report, the Eurasian Development Bank notes that the development of the transport corridor is hindered by barriers in the field of physical and soft infrastructure, combined in infrastructure, tariff, administrative and financial groups [4]. Currently, more than 100 projects with different priorities are being implemented, planned to be completed

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by 2030. The highest priority are projects aimed at removing physical barriers on existing routes (for example, the construction of missing and electrification of existing railway sections, city bypasses, bringing inland waterways and shipping channels to a standard state, development of logistics centers).

The main water route of the North-South transport corridor across the territory of the Russian Federation passes through the cities of St. Petersburg, Vytegra, Cherepovets, Nizhny Novgorod, Kazan, Volgograd and Astrakhan (NSW). There are branches that include the White Sea-Baltic Canal (NSW1), Cherepovets – Big Volga – Moscow Canal – Moscow (NSW2), Kazan – Perm – Solikamsk (NSW3) and Volgograd – Volga-Don Canal – Rostov-on-Don (NSW4). The basis of this route is the Volga River.

Oil, oil products, salt, gravel, coal, bread, cement, metal, vegetables are mainly supplied up the Volga, while down – timber, lumber, mineral construction materials and industrial materials are delivered. In addition to freight, there are high-speed passenger transportation and cruise routes [5]. All this increases the level of navigation and requires the development of routes, scheduling in such a way as to ensure an effective load on hydroelectric facilities and locks, port infrastructure and an increase in river traffic in certain sections of the river.

Thus, *the purpose of this study* is to create a simulation model of navigation on the Volga River.

To do this, it is required to identify all the quantitative and qualitative characteristics of the existing routes and the infrastructure corresponding to them; based on this, to create formal models that reflect all the key aspects of the problem area.

The theoretical significance of the study lies in obtaining the key objects and subjects of the processes of the problem area that affect the level of shipping in particular regions. Such results are the basis for conducting research in the field of sustainable development of territories and the preservation of their ecological well-being.

The practical significance of the study lies in obtaining an adequate model of the real world for use in strategic planning for the development of territories, assessing the level of performance of individual infrastructure facilities and creating scenarios for operational process management.

2 Materials and methods

The object of the study is a section of the Volga River with a length of 395 km between the cities of Nizhny Novgorod and Kazan.

To obtain relevant research results, it was necessary to use a set of general scientific methods.

In order to obtain a list of elements related to the processes of the object of study and affecting its state, *the structuring method* was used. Methodologies for using this method are presented in detail by Logachev [6-8], Krasnikov [9, 10] and Shakhnov [11]. The results obtained are necessary to create rules for the interaction between these elements, which form the basis of a parametric and simulation model of the study object. As the researchers note, such results are the basis for the study design and form a list of input parameters of formal models [12-14]. For this, it is necessary to use *the method of analysis and synthesis* in a complex way.

All results obtained using the methods of structuring, synthesis and analysis are the basis for a parametric and simulation model. To create them, *parametric and agent-based modeling methods* were used. The result of parametric modeling is a system of differential equations describing the movement of ships along the river, and agent-based modeling is a visualized model of the state diagram of each group of objects with similar behavior [6, 7, 15, 16].

3 Results

The use of the claimed methods enabled to obtain a detailed idea of the object of study and to form a list of key elements and links between them for the implementation of all processes associated with any type of shipping.

A parametric model (formula 1) has been developed for a simulation model that demonstrates the traffic of ships on a given section of the river.

$$\{(m + \lambda_x)\frac{dV_x}{dt} + (m + \lambda_y)V_y\omega =- R_x - P_{px} + P_e - A_x, (m + \lambda_y)\frac{dV_y}{dt} + (m + \lambda_x)V_x\omega =- R_y - P_{py} + A_y, I(1 + \lambda_3) = M_R + M_P + M_A,$$

where m – vessel mass,

λ_x, λ_y, λ_z – added mass when moving along the corresponding axes,

V_x, V_y – projection of vessel's speed on the corresponding axis,

ω – vessel angular velocity,

R_x, R_y – longitudinal and transverse hydrodynamic force on vessel's hull,

P_e – propeller thrust force,

I – vessel's moment of inertia about Z-axis,

P_x – longitudinal force of water pressure on the steering wheel,

P_y – lateral force of the steering wheel,

A_x, A_y – longitudinal and transverse aerodynamic force,

M_R – moment of hydrodynamic force on the hull,

M_P – rudder force moment,

M_A – moment of aerodynamic force.

In addition to the parametric model, the simulation model is based on the developed model for changing the states of key elements (Fig. 1).

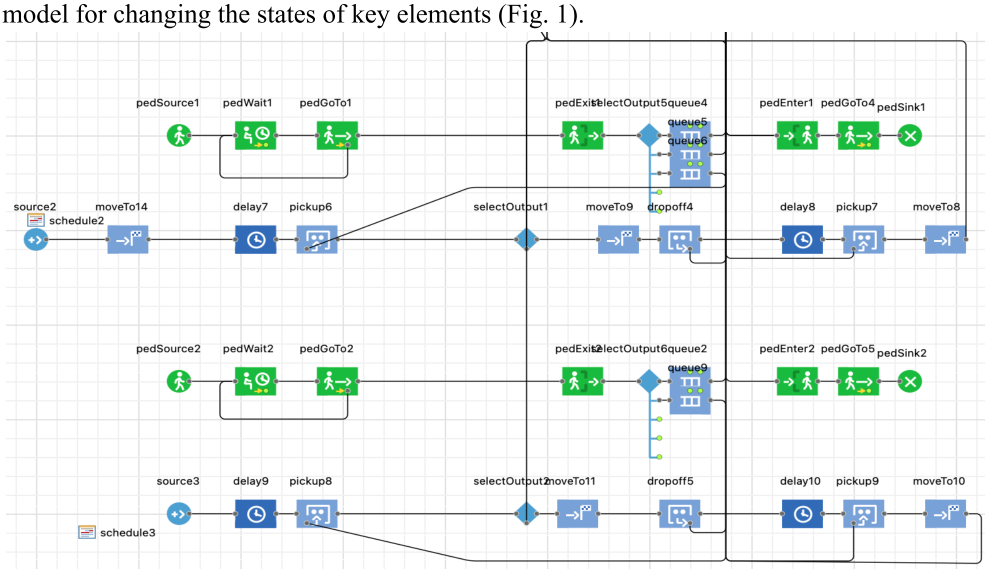

Fig. 1. Fragment of the general state diagram of the key elements of the study object.

The key elements in the study area are:

- passenger ships that carry out regular transportation within the region (traffic goes according to the established seasonal schedule, depending on the time of the working day and the day of the week);
- cruise ships that carry out seasonal tourist tours from one city to another (duration of movement and stop depends on the tourist program);
- cargo ships (schedule depending on the type of cargo and waypoints).

In particular, Fig. 1 shows the changes in the state of a vessel on the route depending on the passenger traffic, the number of stops along the route and the traffic in a given section.

Fig. 2 shows the general scheme of routes, matched with a geographical map. All this is the basis for a simulation model that clearly reflects all aspects of the problem area.

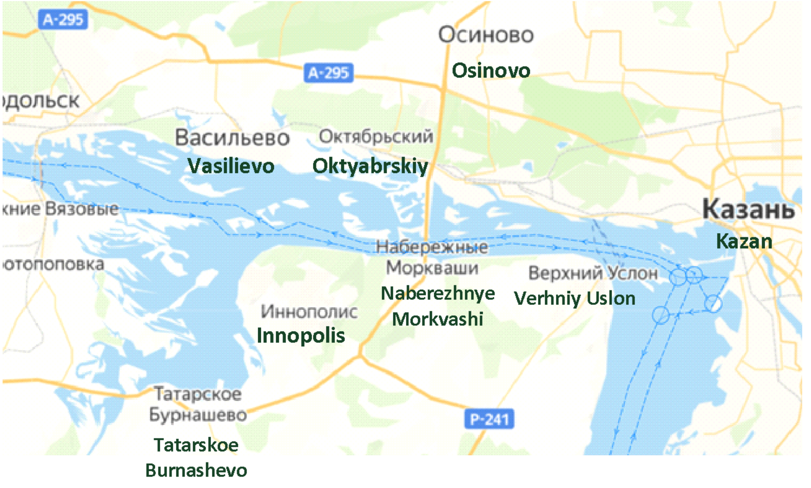

Fig. 2. Fragment of a navigation map in the area of the city of Kazan (Source: Yandex-Maps https://yandex.ru/maps/-/CCUNjMHC-A).

The blue dotted arrows mark the key routes along which the elements of the subject area selected as a result of structuring move. They are also a traffic marker, enabling to develop scenarios for operational traffic control.

4 Discussion

Simulation shows the behavior of any complexity object. The research environment has accumulated a unique experience that allows using it to predict and identify key risks in project management, assess the impact on objects, take into account the level of subjective facts in the implementation of processes, establish cause-and-effect relationships and the degree of their influence on objects in the problem area, etc. [6, 8, 12, 14].

The development of a simulation model of the shipping system of a given region allows evaluating design solutions and showing bottlenecks that affect the throughput of canals, ports and other facilities of the relevant infrastructure. The methods used enabled to obtain an adequate model of the problem area, taking into account all qualitative and quantitative characteristics. This is achieved through the standard use of general scientific methods. The characteristic of the obtained results in form coincides with what is presented in the research works of scholars on similar topics [13, 15-17].

5 Conclusion

The organization of traffic control for the movement of watercraft is the subject area in which it is virtually impossible to conduct full-scale experiments. The only tool for making any decisions in this area (on infrastructure modernization, traffic organization, etc.) is simulation modeling. The basis of such modeling is statistical data, mathematical methods and behavior models that allow establishing patterns, analyzing the processes in complex systems and repeatedly reproducing the objects or systems under study using specialized software in order to identify their optimal state.

The use of the obtained results is aimed at improving the efficiency of transportation and the quality of transport services, reducing the negative impact on the environment, ensuring sustainable development of the country's territories, developing domestic water tourism and passenger transportation by water.

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