TRANSPORT PROBLEMS 2019 Volume 14 Issue 2
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2019.14.2.10

Keywords: transport processes; mathematical modeling; simulation; ferry network; cruise network

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FORECASTING OF THE ROUTE NETWORK OF FERRY AND CRUISE LINES BASED ON SIMULATION AND INTELLIGENT TRANSPORT SYSTEMS

Summary. According to statistics, the marine passenger transportation sectors (both cruise lines and ferry lines) show a significant increase of passenger traffic and the intensity of ship routes. But new features of the conditions for passenger traffic growth require the development of new methodological transport models for cruise and ferry networks and new practical forecasting methods. Changes are observed in the fleet composition, mostly in the direction of increased. New approach for forecasting has to be based on the interaction of such systems as «city–sea passenger port–cruise and ferry lines». This condition now determines new need to describe the principles and forms of organization of maritime ferry networks and changes under the influence of the external environment. The object of the research is the Baltic Sea region and the existing route networks of cruise and ferry lines. Exploring this system, the usage of new mathematical apparatus based on correspondence matrices and agent-based simulation was justified for estimating the workload on transport infrastructure around the passenger port and for the existing ferry or cruise route network. The practical results of new simulation model, on the one hand, justify the need for a comprehensive study of the conditions for the formation of ferry and cruise route networks in changing conditions. On the other hand, these new results could improve the quality of decision-making process in forecasting the route network on the basis of the research of passenger traffic between systems «city–sea terminal–cruise line or ferry line».

1. INTRODUCTION

One of the most dynamically developing segments of tourism is cruise shipment. Ferry transport is also very popular for both cargo and cruise shipments. From a theoretical point of view, a cruise industry (cruise and ferry business) is a complex system consisting of companies engaged in product promotion for the transportation of passengers and shipbuilding organizations, and companies organizing the supply chain, logistics and information services. It is necessary to note the influence of passenger ports and terminals on the formation of marine route networks. This transport industry is in the process of renovation, with the construction of new marine terminals and the modernization of existing terminals. In confirmation with this trend, the forecast data in fig.1show (presents) the potential of the ferry and cruise transportation market until 2022 [1-3].

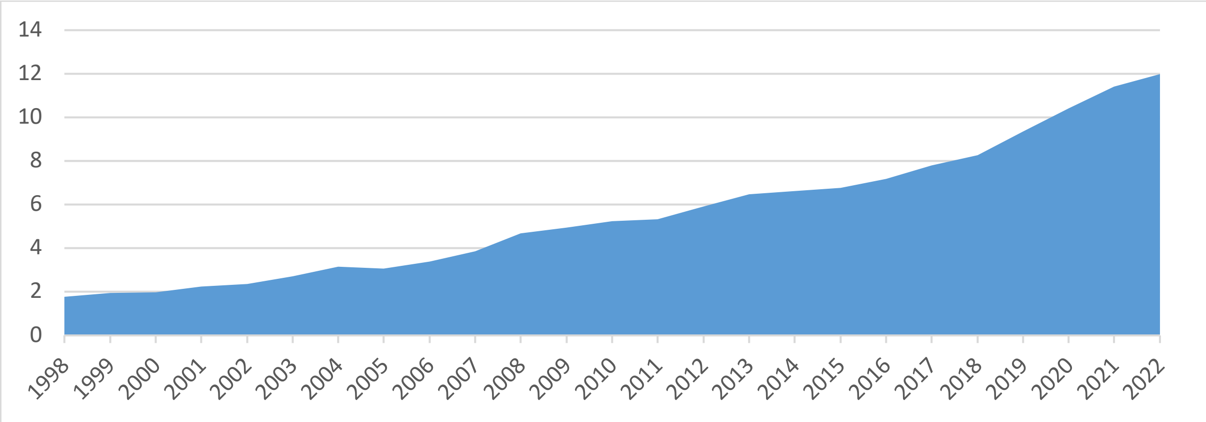

Fig. 1. Cruise market potential, mln. people (according to CINN 2018 EUROPE. European Cruise Lines)

There is a significant increase in the number of cruise lines of their fleets, which leads to an increase in the market, involving more and more regions as new sources of passengers and new cruise lines. According to statistics from Cruise Market Watch, over the past 15 years, the global number of tourists using cruise ships has been increased more than 3 times, and the popularity of cruise holidays continues to grow. Over the past three years, the annual percentage increase (average) of transported passengers was about 4% (more than half a million people per year). The total number of passengers transported by cruise lines in 2017 amounted to more than 25 million people. Analytical data of the industry, both for 2018 and forecast values, are presented in table 1.

Table 1

Analytical characteristics of CRUISE INDUSTRY (2018 and forecast)

Year	Number of Berth	Growth, %	Number of ships	Growth, %
2008	372	-	-	-
2013	443	1,19	-	-
2018	563	1,27	386	-
2023	746	1,32	459	1,18
2027	784	1,05	472	1,02

According to table 1, there is a significant increase in the number of ports and number of ships. A proportional increase of ports that are part of the cruise network requires the construction of new ships. The construction of new types of cruise ships with greater passenger capacity requires infrastructural changes in the passenger terminals. Increasing the route network and changing the role of ports and terminals make it necessary to use a systematic approach, together with the use of prediction methods based on artifical intelligence. For high-quality forecasting, it is not just enough to consider cruise ship routes [6,8], it is necessary to consider the interaction of such systems as «urban infrastructure (land transport networks)–sea passenger terminals–cruise network». To analyze the differences of these systems, it is necessary to solve the problem of selecting variables, based on which, it is possible to investigate and predict the operation of the entire system, to determine changes in route networks. Fig. 2 shows the main areas of interaction in systems «cruise line (shipping company)–passenger terminal–megalopolis (city)), which reflects the multicriteriality and difficulty of their tasks.

In fig. 2, F is a functional characterizing scale of the route network; W_n is a function of the number of berths that can simultaneously process the incoming intensity of cruise ships; T_{obr} is the function of the consistency of the terminal services for the processing of passenger traffic and cruise ships; and N is the number of berths in the passenger port.

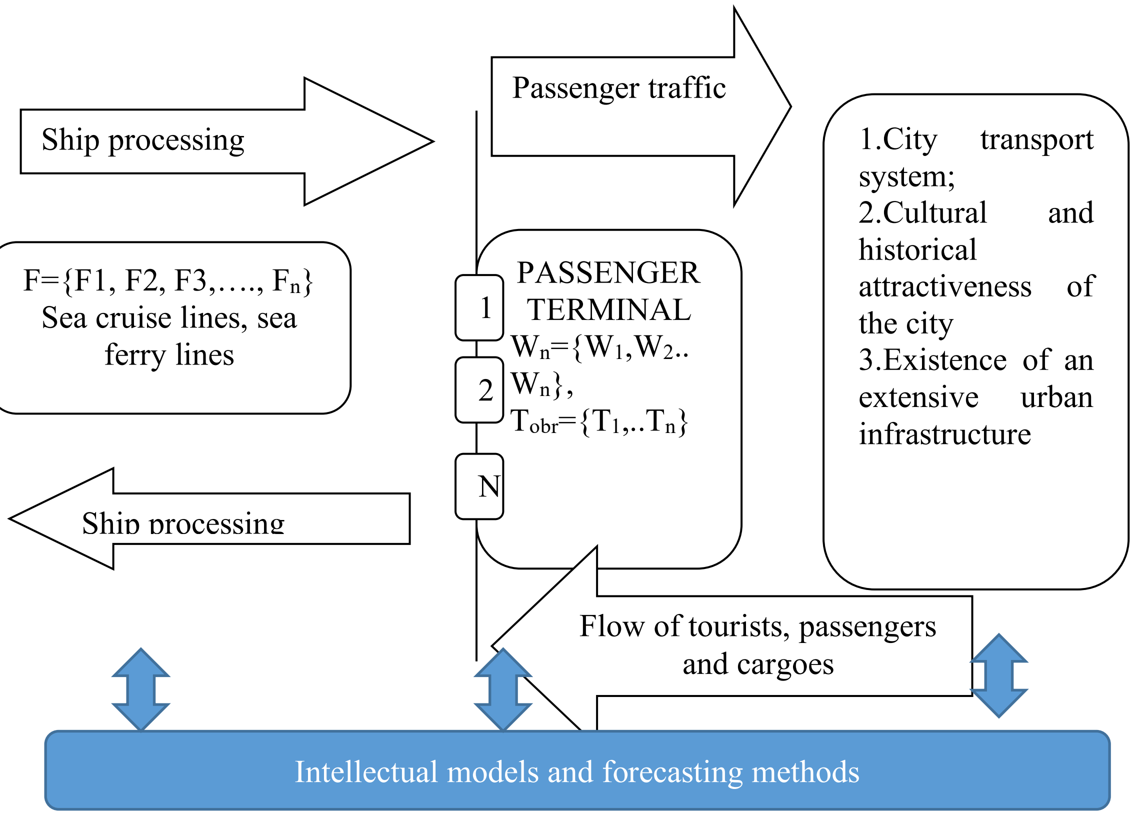

Fig. 2. Interaction scheme «cruise line (carrier) – passenger terminal – city»

Actual research questions are the study of the organization forms for marine ferry networks. The number and diversity of passenger ports directly affects the development of the region, tourist attractiveness and transport infrastructure. On the contrary, system changes can be identified through different network forms. By sampling the route network through the research process, we can identify key time points that should be compared with identified trends. Based on the different routes organizing form in some time evaluation, it is theoretically possible to substantiate the evolution of the route network. Based on the presented questions, the research of route organizing forms for marine cruise lines and ferry lines is extremely important in order to identify basic conditions for analyzing the transition possibility to the new level. The next important task is a modification of routing network, changing the position and the role of passenger terminals. To solve all these questions, it is necessary to construct objective functions that should be the main elements in the simulation of the system.

2. PARAMETERS IN THE TASK OF ORGANAIZING FERRY AND CRUISE LINES

For effective management of ferry routes, it is necessary to use information intelligent system. These systems should solve forecasting problems based on real data that can be taken from available geo-information systems. These information systems can be attributed with existing system, as we know the system of monitoring the ship's movement «Marinetraffic.com» [4]. However, before starting the simulation, it is necessary to determine the main input variables, based on which, changes in route network should be determined. The main variables for simulation process are as follows:

1. economic efficiency (profitability of the route);
2. time of the routes;

3. the number of ports and terminals on the route;
4. route load;
5. based on the costs of organizing the route.

Different target variables determine the use of different models and methods. For example, authors in [5] studied the problem of design for the shipping route network under the condition of the given number of ships, mainly concerned with fleet design, scheduling and shipping route; authors in [6] studied the joint transportation planning and dynamic route selection of the shipping network, and established a two-stage randomized programming model; authors in [7] took a minimum cost of the total system as the target value to select the transit port for four kinds of container types in the import and export transportation network. Author in [8] studied the efficient heuristic for non-linear transportation problem on the route with multiple ports, and a new model is presented for optimal voyage planning in container shipping.

Unlike container shipping lines, ferry and cruise lines have a number of unique features. These features include the conditions for the route formation of passenger and cargo traffic, seasonality, and the need for transport links with remote regions. In addition, one or more associated ports may be added to the existing ports system. Therefore, it is necessary to research the processes of route formation and possible changes in route network for practical realization in simulation model as intelligent decision-making instrument (tool).

The Baltic Sea region was selected as a research region. There is a tendency to increase the number of cruise and ferry routes today [9]. In research of the routing problem for ferry and cruise lines of the Baltic Sea, the following initial data are presented (tab. 2).

Table 2

Sample from set of cruise and ferry line routes in the Baltic Sea

Shipping Company Name	Main routes	Shipping Company Name	Main routes
DFDS Seaways	Kiel-St. Petersburg (ro-ro); Klaipėda-Fredericia (ro-ro); Cuxhaven-Immingham (ro-ro); Gothenburg-Brevik-Immingham (ro-ro); Klaipėda-Kiel (ro-pax); Klaipėda-Karlshamn (ro-pax); Paldiski-Kapellskär (ro-pax); Newcastle-Amsterdam (ro-pax); Dover-Dunkirk (ro-pax); Dover-Calais (ro-pax); Newhaven-Dieppe (ro-pax); Copenhagen-Oslo (ro-pax); Paldiski-Hanko (ro-pax)	Finnlines	HansaLink (ro-pax); Nordö-Link (ro-pax); FinnLink (ro-pax); Helsinki-Rostock (ro-ro); Hanko-Rostock (ro-ro); Helsinki-Gdynia (ro-ro); TransRussiaExpress (ro-ro); Germany-FinlandRo-Ro (ro-ro); Uusikaupunki-Germany (ro-ro); Helsinki-Rostock-Aarhus (ro-ro); NorthSeaService (ro-ro); IberiaService (ro-ro); Lübeck-Turku (ro-ro); Germany-FinlandRo-Ro 1 (ro-ro)
St. Peter Line	St. Petersburg-Helsinki (ro-pax); St. Petersburg-Stockholm (ro-pax); St. Petersburg-Tallinn (ro-pax);	Tallink/Silja	Stockholm-Turku (ro-ro) Paldiski-Kapellskär (ro-ro) Stockholm-Helsinki (ro-pax) Stockholm-Tallinn (ro-pax) Stockholm-Turku (ro-pax) Stockholm-Riga (ro-pax) Helsinki-Tallinn (ro-pax)

KESS	Baltic Sea Express (car-carrier); Södertälje-Cuxhaven (car-carrier); Baltic Sea Express II (car-carrier)	Transfennica	Baltic Network (ro-ro) HaminaKotka-Lübeck (ro-ro) Finland-Tilbury (ro-ro) Finland-Antwerp 1 (ro-ro) Finland-Antwerp 2 (ro-ro)

Despite the presented examples of routes in the table 2, in the form of discrete segments and separate routes between some ports, in practice, there is a more extensive network. The five main areas (St. Petersburg, Copenhagen, Tallinn, Helsinki, and Stockholm) account for an average of 67% of the cruise ship traffic [10].

3. METHODOLOGICAL REPRESENTATION OF THE ROUTE NETWORK

The theoretical positions for ferry network are as follows:

1. each route has one departure port and one destination port;
2. in passenger ports and sea terminals, the passenger traffic is necessarily concentrated and this ensures the required profitability of the line;
3. the route network is expanded by adding new nearest ports with the formation of separate sections consisting of a limited number of ports, forming closed routes (loops);
4. the organization of the maritime transport network is designed in such a way that between any two ports, there is a regular route, and the region is completely covered (blocked) by the network;
5. the duration of cruise routes according to market rules should be planned.
6. the voyage cycles can be classified to 1–3 days, 5–6 days, 6–8 days, and 9–16 days, and even more than 16 days, to satisfy the various needs of customers.
7. the arrangement of the voyage should meet the tourist demands;
8. furthermore, it is essential to ensure that the cruise ship can be affiliated to different ports as much as possible, to improve the attractiveness of the routes.

By connecting all ports through line routes, a physical transport network is obtained [9]. Such a network is characterized by a specific set of traffic flow management tools, which consists of the set of passenger ports, connected by maritime transport vessels. By allocating a separate route or designing a new one in the existing network, some new virtual (abstract) connection is created. From the set of possible options, taking into account intermediate hub elements (intermediate ports), a new route is formed. The new route is the object of analysis, since it is possible to analyze the patterns of changes in the route network on its basis. Based on the initial data of the ferry and cruise lines, the following forms of routes are organized:

a) a direct ferry route (liner shipping), connecting the particular (specified) ports or the route with the inclusion of additional ports located in the direction between starting and ending port (fig. 3. (a)). This figure shows the options for organizing both direct routes and multi-stop routes, taking into account visits to the nearest ports. The second option is obtained, if the required loading of the ferry is not provided or the necessary passenger traffic is not concentrated in the port, or the route that collects passengers to some larger port, which is a transit hub. For example, fig. 3 is a fully consistent route network, St. Peter Line, connecting the ports of St. Petersburg–Helsinki–Tallinn–Stockholm.
b) figure 3 (b) presents the options for the organization of route networks in such a way that sub-networks are created among a number of sea (passenger) ports, for which individual ferries are allocated organizationally or a single route network is formed with ships assigned to certain designated routes. In the second case, a similarity of the matrix structure is obtained, in which the user can independently form his/her route, to ensure the specified profitability of each segment. For example, such a form of organization corresponds to one of the routes, Finnlines (connecting the ports of St. Petersburg–Helsinki–Tallinn–Ust–Luga–Hanko–Turku–Paldiski–Gdynia–Rostock).

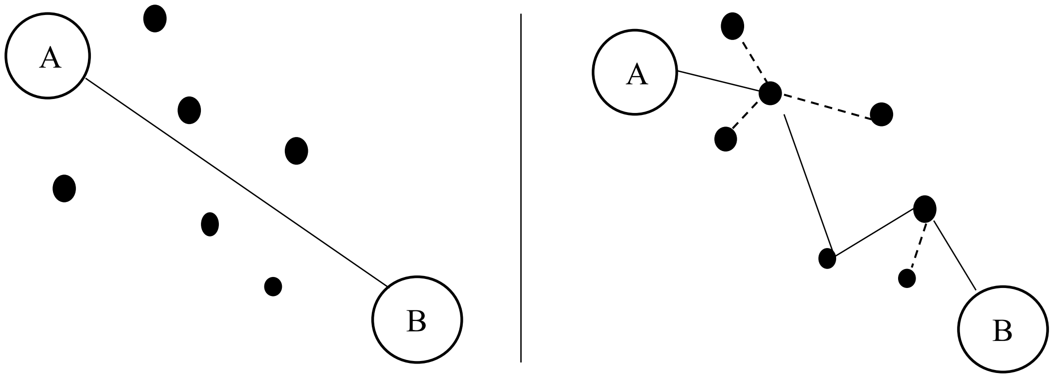

Fig. 3 (a). Basic forms of organization of ferry and cruise lines

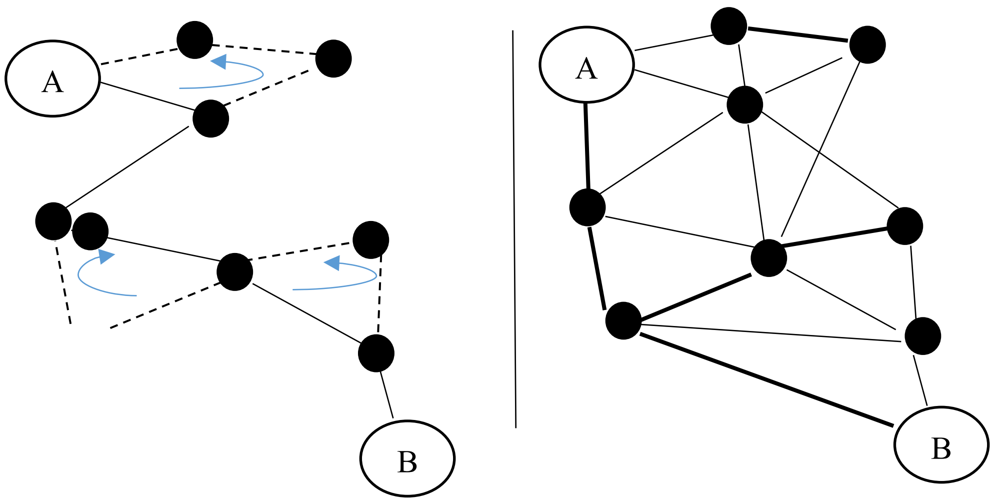

Fig. 3 (b). Fixed ferry routes with the formation of additional sections and an example of expanded transport network covering all ports of the region

The presented schemes (fig. 3a,b) can be theoretically the stages of development or evolution of route networks, as applied to one transport ferry or cruise company, and groups represented on the market. From the point of view of maximal profit, one line will try to expand its presence in other ports and increase the number of ferry vessels. In the case of gradual development, from liner shipping, the route network will pass through all forms of organization. Each form of organization is one step in the development of the route network. In the case of entering into competition for passenger traffic and cargo traffic, a new condition will be formed in the regional market, which, over time, will lead to the fixation of certain routes for specific carrier companies. This situation is extremely relevant and is observed on the entire ferry service network of the Baltic Sea. In some routes, we can see duplication of directions by different carriers. This is mostly due to the possible shortage of ferries. On the other hand, it can be determined by the price policy.

The main conditions for the development of the route network are as follows: to attract passenger traffic, consolidate it in ports and sea terminals, and create prerequisites for using the ferry as an alternative, which is a more convenient way to reach it. Taking into account the conditions presented above, it is possible to formulate a system of equations that will form the objective function ensuring the efficiency of transportation:

$$\begin{cases} T_{\Pi} = T_1 + T_2 + \ldots + T_n \rightarrow \min, \\ C_n = \sum_{i=1}^{n} QT_n \rightarrow \min, \\ F(s) = N \cdot T_m - C_{зi} \rightarrow \max, \\ F(\theta_i) = F(\theta_1, \theta_2, \ldots, \theta_n) \rightarrow \min, \end{cases} \quad (1)$$

where T_n is the time spent by passengers on movement (consisting of all possible movements of passenger traffic); C_n is the transportation cost, taking into account possible transfers; Q is the number of ferry rides by sea; T_m is some base rate, which is set for a certain season; *F(s)* is the carrier profit function; *N* is the number of passengers; $C_{зi}$ is costs (operating, seasonal, costs in the event of a ship breakdown); and $F(\theta_i)$ is environmental influence function.

In forming this system of equations, the practical exclusion of the influence of the external environment and the discrete nature of research processes were taken.

4. PRACTICAL DEVELOPMENT OF MATHEMATICAL MODEL FOR SIMULATION OF THE FERRY NETWORK

Intelligent Transport Systems and Services (ITS) refers to the integration of information and communication technologies with transport infrastructure to improve economic performance, safety, mobility and environmental sustainability. Intelligent transport systems must address not only the task of monitoring ships, but also forecasting. The project of intellectual system for evaluating the performance of the marine passenger terminal based on dynamic behavior of passenger traffic is presented in article [11,12]. Intelligent simulation models use mathematical or logical constructions and calculate the final solution. A specific feature of the systems under consideration is a dynamic change of passenger traffic, which requires the development of models for studying the interaction between the "city–sea passenger terminal–cruise and ferry network". If passenger traffic is not generated, the ferry or cruise route will not be organized. On the other hand, new ports can be included in the existing route to increase profitability [16]. Therefore, it is necessary to predict a large number of scenarios. Different scenarios require the usage of new optimization models. At the same time, we know that only the usage of probabilistic models does not obtain exact solutions. The transport scheme based on the data in table 2 (fig. 4) can be considered.

Fig. 4 shows a system of sea passenger terminals and an extensive network near the port infrastructure. This network is formed by a large number of different types of transport and a variety of transfer nodes. The formation of transport and transfer hubs around each port is due to both the historical characteristics of the region and the different conditions for the development of each port separately.

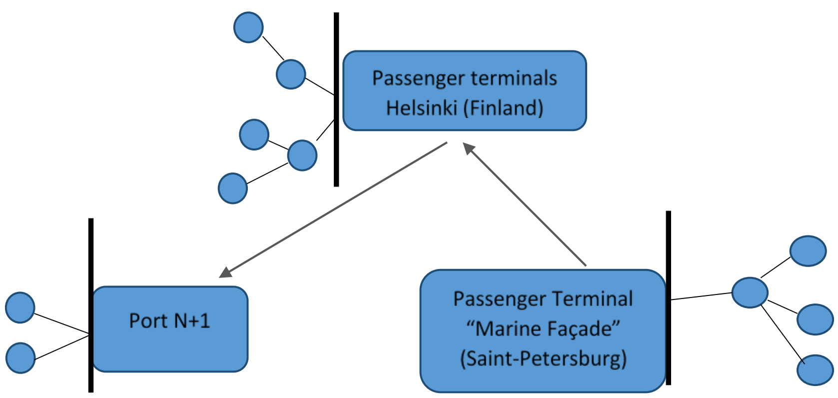

Fig. 4. Presentation of the route network, taking into account the city infrastructure

Transport network of such a system can be investigated on the basis of current data on passenger traffic. In contrast to probabilistic models, the exact number of passengers will allow to separate the workload of each section of the network. The initial data for the simulation are data on the movement of passengers through the transport network, i.e. the number of movements between ports and transport hubs, as well as data on the basis of geographic location of ports generating passengers' movement through the network. For the prediction of the structure of traffic, the calculation of correspondence matrices [12] between the passengers ports (terminals) and transfer nodes must be made. Each transport route connects different types of movements for the purpose of delivering the passengers and their cargo in accordance with the schedule of cruise or ferry ships. The basic mathematical model of the movement of passengers and condition of transport balance is represented as follows:

$$\begin{aligned} T_{ij} &= A_i B_j Q_i D_j f(c_{ij}), i = 1,..,N, j = 1,..,N, \\ A_i &= \left[\sum_j^M B_j D_j f(c_{ij}) \right]^{-1}, i = 1,..,N, \\ B_j &= \left[\sum_i^N A_i Q_i f(c_{ij}) \right]^{-1}, j = 1,..,N, \\ f(c_{ij}) &= e^{-\beta c_{ij}}, \end{aligned} \tag{2}$$

where $\sum_i^N Q_i = \sum_j^M D_j$, which means total numbers on departure and entry must be equal; T_{ij} is passenger correspondence matrix; Q_i is the number of passengers (volume) on departure; D_j is the number of passengers (volume) on arrival; $f(c_{ij})$ is some function of attraction of passenger traffic; it is the primary factor characterizing the distribution of passenger movements in range (for the research of urban infrastructure $\beta \approx 0.065$).

A_i and B_j can be determined from the following conditions:

$$\begin{aligned} &\sum_i^N T_{ij} = D_j, j = 1,..,N, \\ &\sum_j^M T_{ij} = Q_i, i = 1,..,M, \\ &T_{ij} \geq 0, i = 1,..,N, j = 1,..,M \end{aligned} \tag{3}$$

Each movement of passenger traffic in network is calculated by the following equation:

$$T_{ij}^n = T_{ij}^{n-1} + Q_i^{n-2} D_j^{n-2} f(c_{ij}) \left[(D_j - \sum_i T_{ij}^n) f(c_{ij}) \right]^{-1} \tag{4}$$

The simulation model is developed on the basis of the presented mathematical model and the existing marine route network. Fig. 5 shows a window form of the basic softwaresimulation model.The simulation model and new algorithms are created in a separate software on the basis of C # In the developed algorithm, passengers are represented as agents [13], who move along their routes in transport network.

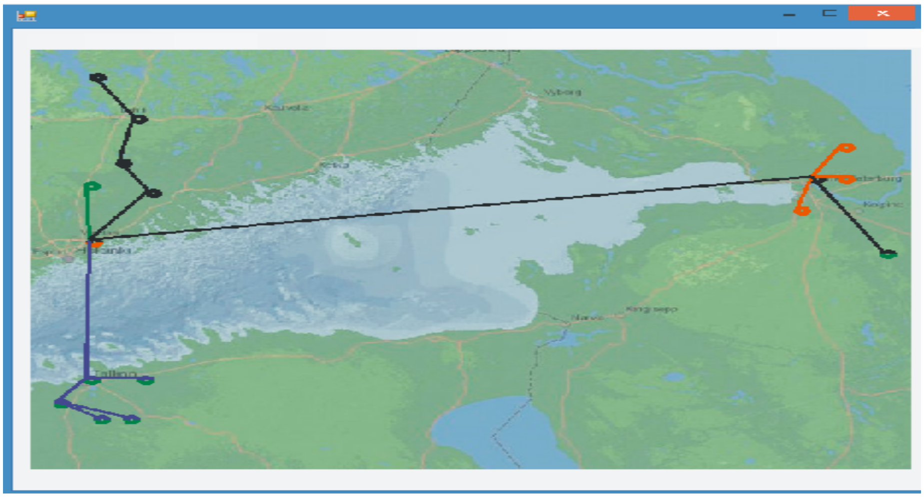

Fig. 5. Practical realization of the transport network (city–passenger terminal–sea ferry network) in software simulation model

Fig. 6 shows the transport route including three sea passenger ports (St. Petersburg (Russia) – Helsinki (Finland) – Tallinn (Estonia)). The number of passengers is set in each point of this transport system. In this case, the decision maker can change the number of passengers following the route. Based on the calculation of the matrices of correspondence, the decision maker can determine the following:

1. most loaded sections of the land transport system;
2. workload of ferry lines;
3. workload of marine passenger terminals;
4. evaluating the existing route network;
5. analyzing the traffic congestion between interchange nodes in transport system.

We have to ensure statistical data from the routes of ferry ship. The number of passengers is determined by the capacity of the ferry vessel, but the number can be dynamically changed. Baseline data can be entered on the basis of the cruiser route and ferry cruising schedule. The decision maker may enter different map details and scaling. Around the passenger port transport area, we have very complicated situation, presented by various transport routes, along which passengers will arrive at the terminal. The simulation result of the program in the form of workload points is presented in fig. 6.

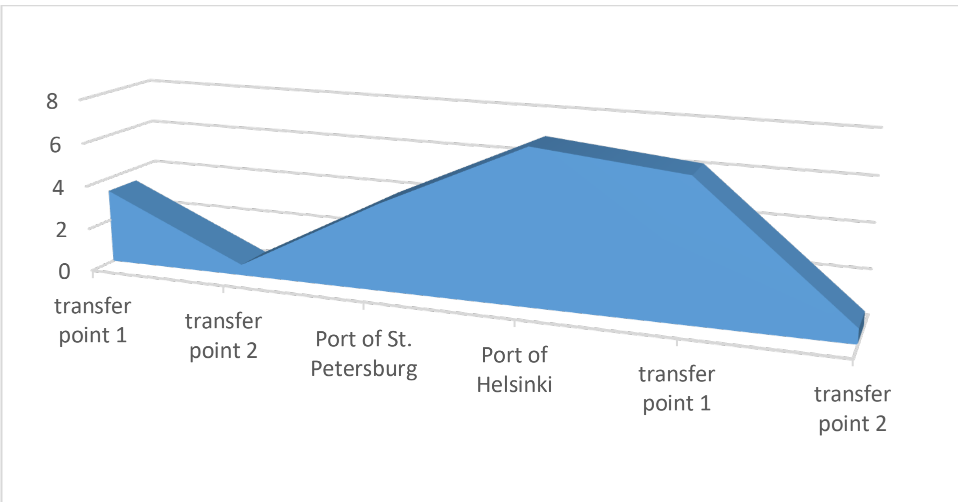

Fig. 6. Results of the simulation of the load ferry line between St. Petersburg and Helsinki

According to fig. 6, the ferry vessel on the St. Petersburg–Helsinki route is loaded and has high efficiency. The increase of traffic in the passenger terminal Helsinki is due to routes to the passenger terminals in Tallinn.

The simulation model for decision making allows saving the results of workload nodes in the database, which is useful for better decision making. The data allow the construction of various options for organizing route networks, especially if we want to add new passenger ports to the existing route network.

This intellectual simulation model takes into account all features of the most important elements of the transport network, affecting passenger traffic on both micro level and macro level. But one of the main difficulties in the way of solving the problem of modeling is the complexity of collecting data on passenger flows throughout the system. This model allows to explore the ferry and cruise route network, taking into account the centers of the formation of passenger flows.

5. CONCLUSION

The article presents a new simulation tool for network analysis of cruise and ferry lines. It also presents the main trends in the development of this industry and substantiates the need to study changes in the route network based on research of the interaction between the «city–passenger terminal–cruise line (ferry line)» systems.

Based on the analysis of cruise and ferry routes, it is clear that we need to research new methodological models and forms of route organization that reveal changes in the ferry network under the influence of the external environment. In addition, the role of passenger terminals in accordance with it has to been changed. The feature of the system is determined in connection with the dynamic processes of changing passenger traffic. Based on the selected region, the routes were analyzed and methodological forms of route organization were built. The presented forms of the route network can be scaled to other regions.

To solve the problems of strategic management, a target function has been proposed, including the task of optimization of the route network. In this research, we have to take into account the influence of parameters such as the conditions of passenger traffic and the assessment of the external environment. For practical simulation purpose of the transport system, the use of correspondence matrices and agent-based simulation has been proposed. Entering data into the simulation program, the decision maker is able to predict various passenger flows in the system, to determine the efficient workload in every point of network and find out the best organization of ferry lines. Due to the possibility of data saving for various network options, the simulation model ensures that the decision maker can choose the best option for organizing the transport system.

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Received 16.10.2017; accepted in revised form 04.06.2019