Geoinformation system use for transportations planning in water area of Northern Sea Route

E Ol'khovik

Admiral Makarov State University of Maritime and Inland Shipping, 5/7, Dvinskaya Str., Saint Petersburg, 198035, Russia

E-mail: olhovikeo@gumrf.ru

Abstract. The possibilities of the geoinformation system (GIS) using for the planning of transportation and export of mineral and raw materials from the water area of the Northern Sea Route (NSR) are considered. In the near future, in 2018-2020, the number of large-capacity vessels in the western part of the NSR can be increased due to LNG (liquefied natural gas) tankers in the Yamal-LNG project to 16 units (currently only 5 gas tankers are in operation), due to the petroleum tankers in the New Port project and due to the vessels with general cargoes to the new projects - Arctic LNG and VostokUgol. The analysis of maritime transport flows in the NSR significantly differs from other kinds of transport, navigation follows the recommended routes, i.e. there are no clear boundary conditions for the movement, the parameters of the vessel's movement substantially depend on the ice situation and the hydrometeorological conditions, with which there is a constant interaction. The developed GIS for the NSR make it possible to calculate the models of potential hazard, which are taken depending on the following criteria: a distance between the vessels, courses crossing, an ice situation and hydrographic study of the navigation area. The developed model of the ship security domain is a geographic area associated with the route, course and speed of the vessel movement, for which security conditions were determined in the selected time period. The calculated analysis of the number of vessels and their average speed in the water area of the NSR along several zones during the summer and winter navigation was performed. The completed study of the movement routes of LNG tankers in the NSR water area (Kara Sea – port Sabetta) showed that the most stable traffic parameter is the average speed on the certain sections of the route, which coincides for each of the vessels. The relative values of speed, route distance, ice situation, flow complexity, etc. with the processing of AIS data of previous periods are the most logical to use for construction of a model of marine transport flows in the NSR water area

1. Introduction

The navigational and environmental risks are one of the deterrents for the development of the Northern Sea Route (NSR). Environmental risks, as a rule, are a consequence of navigational accidents, therefore they are decisive. Navigation risks are associated with the probability of accidents connected with vessels grounding, touching the ground, ice damage, storms and the unquiet of the sea, with ships bulk accidents on each other and on mooring facilities. The Polar Code came into force in 2017. It is based on the principles of formal safety assessment (FSA) set out in the interim manual for the FSA application, which was developed in 1997 and approved by the Maritime Safety and Marine

Environment Protection Committees of the International Maritime Organization (IMO). The essence of the FSA concept is a priori assessment of the risks of marine environmental incidents and the development of measures aimed at reducing of these risks.

The statistics of the accident rate of the world fleet [1, 2] shows that the accident rate increases with the increase in shipping intensity, with vessels tonnage growth, in shallow areas with insufficient hydrographic study, in case of mismatch of vessels design to the ice conditions, during violation of maneuvering rules in complex hydro and meteorological conditions, during towing, moving in caravans and under other circumstances. At the same time, according to the Central Marine Research and Design Institute (CNIIMF) [3], the actual navigational accident rate on the NSR routes as of 2006 is several times less than the accident rate of the non-Arctic seas.

Since 2012, the conditions and the mode of navigation have been changed on the NSR routes. First of all, the following is noted [4-6]:

– change in the intensity of navigation;
– increase in tonnage and draft of vessels;
– the development of a network of routes on which year-round or extended navigation is realized;
– commissioning of transport vessels capable of self-navigation in heavy ices;
– vessels navigation with an extremely low water reserve under the keel.

The nature of the conditions change corresponds to the trend of the risk increasing of navigational accidents on the NSR. The issue about the risk limits of navigational accidents and about the rationale of measures to improve the navigational safety of Arctic navigation and the ecological safety of the Arctic seas becomes particularly actual taking into account the ecological vulnerability of the Arctic seas. Numerous studies have been devoted to solving this problem, which consider separate routes and areas of the NSR, certain types of vessels and types of sea operations, and efforts on development of models of the NSR sea transport system are under way.

All the developed navigational models of marine transport systems can be conditionally divided into three levels:

- 1st level - Micromodels, where the navigational risks of one particular vessel are taken into account;
- 2nd level - Mesomodels where navigational risks belong to a group of vessels operating on the individual directions, areas or objects;
- 3rd level - Macromodels designed to study transport flows in the water area of the NSR as a whole.

Navigational models of marine transport systems are designed to study of the interaction of individual vessels, their groups and the entire fleet with the environment and the limits determination of their safe operation.

The basic structure of models implies the presence in it of three formalized parts:

- models of vehicles and the parameters of their movement;
- models of navigational hazards;
- models of vehicles interaction with potential sources of navigational hazards.

Assessment of navigational risks in models refers either to vehicles, which is especially characteristic for micromodels, or to the navigation area and the navigational period, which is more typical of macromodels.

Theoretically, the issues associated with the complex conditions of a single vessel's navigation are the most developed for the NSR. Studies of the causes of vessels accident rates associated with collisions with other vessels, grounding and priming touch, severe ice conditions and other factors are discussed in [7-11]. Geo-referencing of navigational risks, as a rule, is not made. The parameters of the transport flows are not taken into account.

The influence of navigational, hydrographic and hydrometeorological factors on the navigation safety in the separate directions and areas of the Arctic seas is comprehensively explored at the design and operation of new routes of vessels traffic. During the research, the most navigationally dangerous areas of the investigated water area are determined and recommendations on a decrease of the risk of navigational accidents at these sites are developed. The most significant examples of recent studies are the works on the formation of high-latitude NSR tracks, routes of large-tonnage marine vessels in the Kara Sea (the Dudinka port and the ports of the Ob Bay) [11-13].

The NSR is a complex transport system where different-scale processes occur with varying intensity. These processes are associated with changes of the density and dynamic characteristics of marine transport flows. The formation of an information system that unites models of all levels should precede the research of these processes.

The search for approaches to the formation of such system is being actively made at the present time. Examples are the following works. In the series of works [14-16], an interdisciplinary approach to designing and analysis of the marine transport systems operation in the Arctic using geoinformation systems (GIS) is substantiated. A technique for constructing the stochastic models of the local transport systems, which can be referred, according to the classification proposed earlier, to mesomodels is proposed. The ways of transition from particular to general models of marine transport systems based on the intellectual GIS are offered in work [17]. Work [18] where a multilayer 3D GIS model is used to plan navigational routes for the Northwest Passage of the Arctic also refers to such works. A formalization method of the safety assessment of the NSR water area, which is based on the model of vehicle interaction with potential sources of navigational hazards, was developed in work [19]. Thus, an idea about the necessity to build a holistic GIS of the NSR has been formed at the present time.

The purpose of this work is to substantiate the composition of the GIS elements, the structure of the information model of the marine transport flows of the NSR, and also to illustrate the solution of problems obtained using GIS.

2. Methods and Materials

The information basis of the GIS is the daily data on vessels and their coordinates coming to the Administration of the Northern Sea Route. The name of the vessel, its ice class and draft are used as additional information. Thus, daily layers showing the vessels location are formed in the GIS database (DB). A collation of the daily layers allows us to identify the main transport flows and to evaluate their parameters, including the flux density, its speed and intensity. The GIS facilities allow one to form queries to the database according to the values of the traffic parameters of individual groups of vessels.

An example of a response to a request for the vessels location in the water area of the NSR for a fixed time interval is shown in Fig. 1. Each vessel on the scheme is indicated by an arrow, the direction of which corresponds to the direction of the vessel's movement for the previous twenty-four hours. The color of the arrow indicates the speed of the vessel.

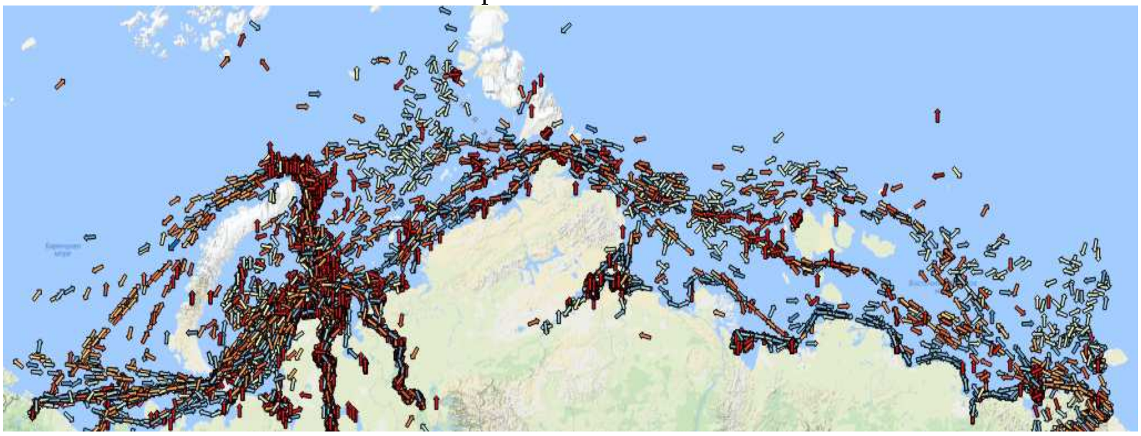

Figure 1. An example of an information GIS layer of the NSR in 2017.

The flux density value at the selected section of the water area (the flux density is equal to the ratio of the vessels number to the area of the allocated site), the vessels number that had not had a course during the last 24 hours, the icebreakers number, the number of vessels with a predetermined draft and other information can be obtained on an additional request for a fixed date.

If necessary, on the screen you can trace the traffic routes of one vessel, group of vessels or all vessels, related to a given time interval. Different types of requests, including requests by years, navigational periods, dates, areas, directions, etc. can be used.

3. Results

All the data in the GIS of the NSR allow one to obtain the general results over the past years for further comparison. Fig. 2 shows the distribution of the number of requests for passage into the water area of the NSR (data from the Northern Sea Route Administration) and the actual number of vessels (Fig. 3) for 2013-2017. The given data show that the number of permits issued in 2013, 2014 and 2017 was approximately the same. In 2015 and 2016 the number of issued permits increased by about 10%. The maximum number of vessels and requests falls to 2015-2016. It is connected with the delivery of constructional and technological cargoes to the port of Sabetta and with its construction (Ob Bay). The oil terminal "Gateway to the Arctic" (Kamenniy Cape) was also building in this period. The number of issued permits is not directly related to the intensity of the transport flows on the NSR. A redistribution of marine transport flows took place from 2013 to 2017 that caused a significant increase in the density and intensity of navigation in the Kara Sea and a general decline of the indicators in the eastern part of the NSR water area. Vessels are divided into several groups: vessels not of the Arctic class and vessels of the Arctic class, which have glacial strengthening of the hull. The vessels with categories of the glacial strengthening Arc4 and above belong to the vessels of the Arctic class.

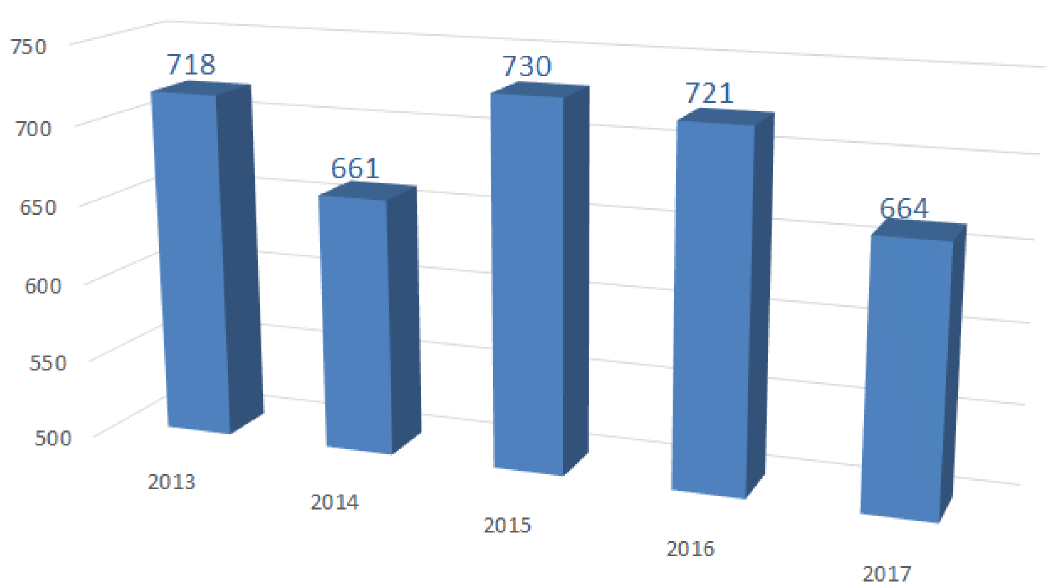

Figure 2. Number of requests for passage through NSR.

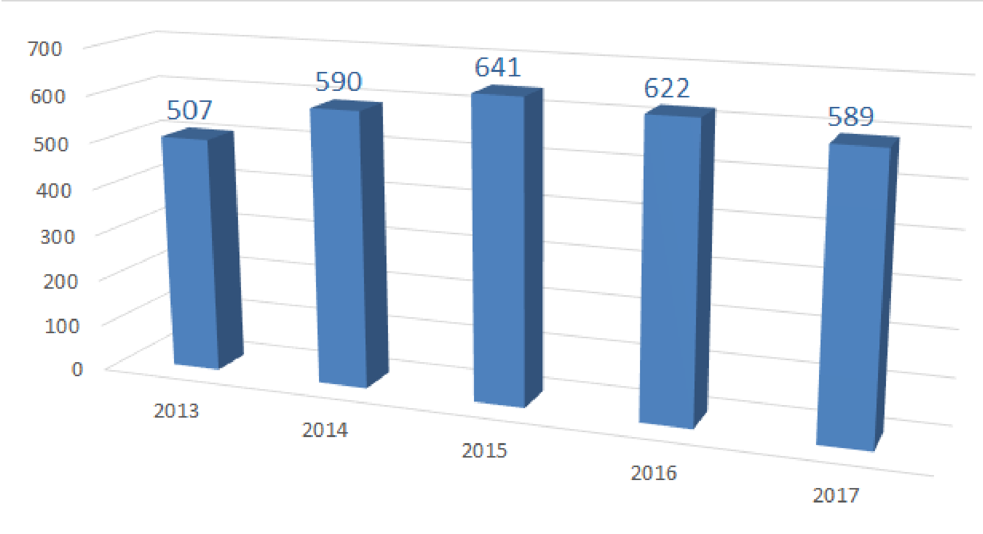

Figure 3. Number of ships in NSR water area.

The Northern Sea Route Administration issues permits for navigation depending on the ice class and navigation period, herewith the vessels of Arc7 class can move without an icebreaker, i.e. independently. The number of such vessels is constantly growing from year to year (Fig. 4). In 2018 the fleet was replenished with 5 LNG tankers of YamalMax class, which can independently move in ice with a thickness of 2.1 meters. By the end of 2018, 4 more new LNG tankers will be delivered to the NSR. According to our forecasts, by 2020 the number of large-capacity vessels of high ice class Arc7 will increase to 40 vessels. To ensure their safe passage in the Ob Bay, it is planned to create a vessel traffic control system.

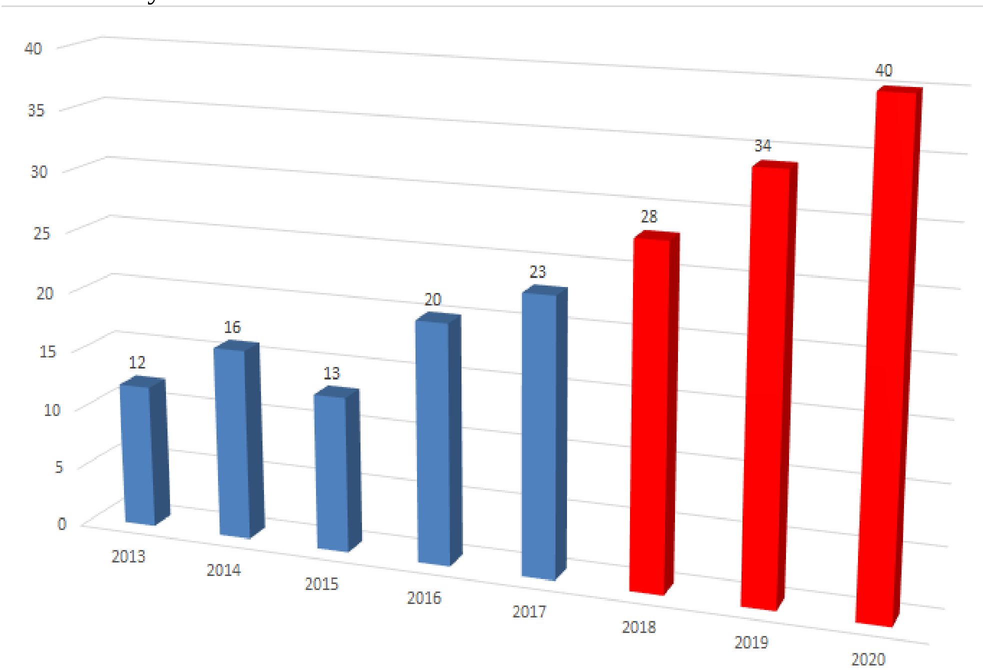

Figure 4. Number of ships with ice class Arc7: blue – actual in 2013-2017, red - forecast for 2018-2020.

The number of ships with an ice class Arc4,5 was the maximum in the period of 2016, in the future their number probably will not increase significantly. A consolidated data of the number of such vessels is shown in Fig. 5. Icebreaking support which is limited by the number of nuclear icebreakers is necessary for their movement. During the winter navigation period, vessels of class Arc4,5 are used only in the western part of the NSR.

Figure 5. Number of ships with ice class Arc4,5.

Fig. 6 shows a sample of data from the GIS of the NSR; for its construction the data about the speed of the following ships were used: CHRIS. DE MARGERIE (IMO 9737187), FEDOR LITKE (IMO 9768370), BORIS VILKITSKY (IMO 9768368), EDUARD TOLL (IMO 9750696), VLADIMIR RUSANOV (IMO 9750701), SHTURMAN SHCHERBININ (IMO 9759927), SHTURMAN OVTSYN (IMO 9752101), SHTURMAN MALYGIN (IMO 9752096), SHTURMAN ALBANOV (IMO 9752084), SHTURMAN KOSHELEV (IMO 9759939), SHTURMAN SKURATOV (IMO 9759915) during the winter navigation in the period of 2017-2018.

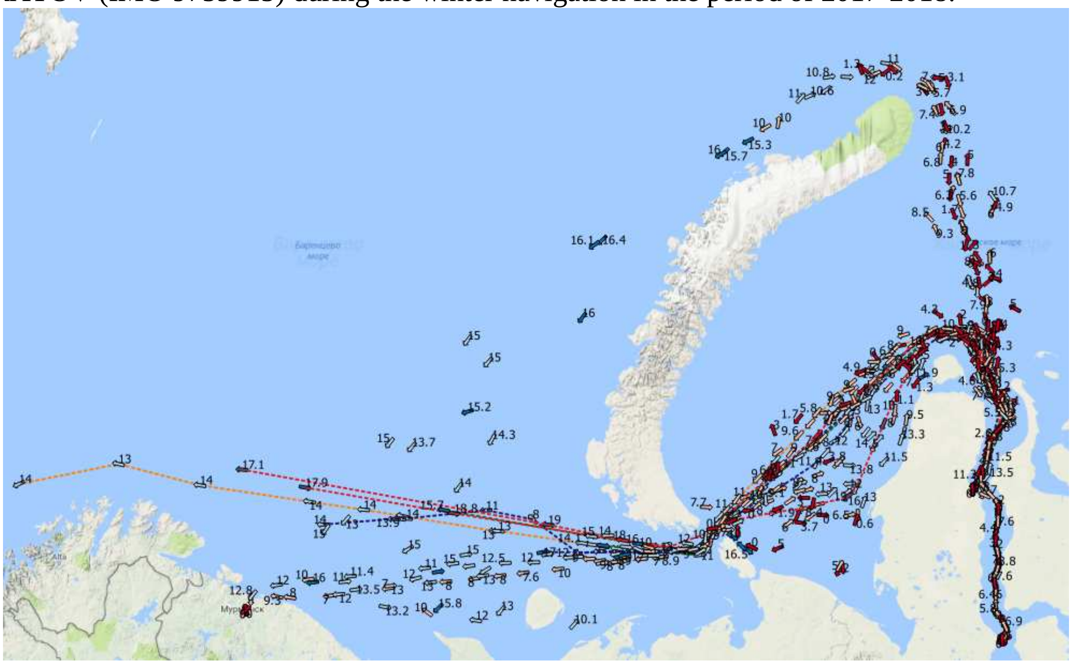

Figure 6. The routes of LNG-tankers and petroleum tankers in the western part of the NSR in winter navigation in 2017-2018.

The obtained data in Fig. 6 give a good representation of the density of marine transport flows. The largest density corresponds to the entrance to the Ob Bay, two streams are connected here: the first one - from the Kara Gate strait, the second - from the Mys Zhelaniya, the connection of flows occurs to the northeast of the Bely island. The highest speed corresponds to clean water in the Barents Sea, in the water area of the Kara Sea, the speed is significantly reduced in the ice fields.

4. Discussion

It should be noted the laboriousness of the formation of the GIS database associated with the analysis of a large amount of information on the vessels operating in the water area of the NSR. In prospect, it is planned to develop and implement the technology of automated data input, which will increase the efficiency of the formation and daily updating of the GIS database.

The results of queries to the GIS database allow analyzing the current state and dynamics of the NSR transport system, taking into account that the information about the vessels position is updated in the database no more than once a day. This information, taking into account the superposition of additional layers, including ice and hydrometeorological situations, the fields of depths, areas closed for navigation, etc., can be used to assess the risks of navigational accidents at the micro, meso- and macro levels.

GIS allows exploring the density and dynamics of transport flows in the entire water area of the NSR in the different navigational periods, which makes it possible to distinguish separate groups of vessels in the transport flow, including by draft and by destination.

5. Conclusion

The methods of transportation planning based on GIS, allowing one to achieve the maximum commercial efficiency can be developed on the basis of the analysis of data about the routes of marine vessels movement over the past few years.

1. The structure of the composition of the GIS elements of the NSR in the form of separate information layers designed for the research of transport flows in the NSR water area as a whole was first formulated and justified.

2. The information model of the marine transport flows in the NSR as a tool allowing forming the operational data on vessel traffic graphically and informatively and obtaining generalized information within a given time period was offered.

3. The results of this work can be used to design the aids of navigational barriers in the NSR water area, to plan rescue operations, to assess the risks of navigational accidents and to solve other problems.

References

[1] Katsman F M, Ershov A A 2006 *Transport of the Russian Federation* **5(5)** 82-84
[2] Fissenko A I 2015 *Transport business in Russia* **6** 260-262
[3] 2006 *Problems of the Northern Sea Route*. (Moscow, Science)
[4] Komkov N I, Selin V S, Zukerman V S 2014 *MID (Modernization, Innovation, Development)* **20** 4-11
[5] Marchenko N 2014 *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2014)* **10** doi:10.1115/OMAE2014-23626
[6] McWhinnie L H, Halliday W D, Insley S J, Hilliard C, Canessa R R 2018 *Ocean & Coastal Management* **160** 1-17 doi: 10.1016/j.ocecoaman.2018.03.042
[7] Dalaklis D, Drewniak M L, Schröder-Hinrichs J-U 2018 *WMU Journal of Maritime Affairs [Internet]* doi: 10.1007/s13437-018-0142-7
[8] Afonin A, Tezikov A, Ol'khovik E 2017 *Proceedings of the International Conference on Port and Ocean Engineering Under Arctic Conditions (POAC 2017)*
[9] Mikhalsky V A, Tyulkin M V 2006 *Navigation and hydrography* **23** 17-26
[10] Burakovskii E P, Burakovskii P E, Dmitrovsky V A 2013 *Proceedings of KSTU* **29** 159-164
[11] Sazonov K E, Ryzhkov A V 2013 *The world of transport* **11.4(48)** 40–47
[12] Spirin A M, Chachin D A, Smirnov A A 2015 *Arctic: Ecology and Economy* **3(19)** 88–95
[13] Ruksha V V, Belkin M S, Smirnov A A, Arutyunyan V G 2015 *Arctic: Ecology and Economy* **4**

(20) 104–110
[14] Kondratenko A A, Krest'yantsev A B, Tarovik O V, Topazh A G 2017 *Arctic: Ecology and Economy* **1(25)** 86–101
[15] Olhovik E O, Afonin A B, Tezikov A L 2018 *Vestnik Gosudarstvennogo universiteta morskogo i rechnogo flota imeni admirala S.O. Makarova* **10.1** 97-105 DOI: 10.21821/2309-5180-2018-10-1-97-105
[16] Tsvetkov M, Rubanov D 2018 *Information Fusion and Intelligent Geographic Information Systems (IF&IGIS'17)* Springer, Cham 71–86 DOI: 10.1007/978-3-319-59539-9_6
[17] Osipov V Yu 2011 *International Scientific and Practical Conference "Simulation and Complex Modeling of Marine Equipment and Marine Transport Systems" - "SCM MEMTS"* 88–92
[18] Chang K Y, He S S, Chou C C, Kao S L, Chiou A S 2015 *International Journal of Geographical Information Science* **29.8** 1375–1393 DOI: 10.1080/13658816.2015.1030672
[19] Tezikov A, Afonin A, Kljuev V 2017 *Proceedings of the International Conference on Port and Ocean Engineering Under Arctic Conditions (POAC 2017)*