PAPER • **OPEN ACCESS**

Information intelligent system of organization and management of arctic sea cargo transportation

To cite this article: E Yu Sobolevskaya *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **918** 012042

IOP Conf. Series: Materials Science and Engineering **918** (2020) 012042 doi:10.1088/1757-899X/918/1/012042

Information intelligent system of organization and management of arctic sea cargo transportation

E Yu Sobolevskaya[1], **N G Levchenko**[2], **S V Glushkov**[2]

[1]Vladivostok State University of Economics and Service, 41, Gogolya Str., Vladivostok, 690014, Russia
[2]Maritime State University named after admiral G.I. Nevelskoy, 50a, Verkhneportovaya St., Vladivostok, 690059, Russia

E-mail: study_z@list.ru

Abstract. To organize, support and manage the process of cargo transportation, taking into account the difficult navigation conditions in the Arctic and Subarctic of Russia, an information intelligent system for organizing and managing sea cargo transportation has been developed: architecture of the information intelligent system; a module for calculating the route between two ports, taking into account the ice situation, based on the A-star algorithm for finding the shortest route between two ports; a module for calculating the cost and the number of travel days for sea cargo transportation, taking into account the ice situation, the modules are developed on the basis of fuzzy logic using a Mamdani fuzzy logic model; a module that, on the basis of the first and second modules, calculates a faster or a more cost-effective route depending on the season, taking into account the current ice situation. To check the adequacy of the Mamdani fuzzy logic model, a sample was formed based on the analysis of data from the captain's voyage reports. Each voyage report contains information on the navigation conditions on the route, which allowed us to create a sample consisting of information on the actual navigation conditions.

1. Introduction

Sea cargo transportation in the Arctic region of Russia has many specific features, some of which are obvious and lie on the surface, while others can only be found when closely examined, an integrated approach to solving any problem is required. Ensuring the delivery of goods in polar conditions depends on many factors. These are harsh climate conditions, such as ice, high and low tides, which are exacerbated by wind-driven water movements. This is the lack of developed infrastructure that ensures the process of sea transportation, forcing a lot of transshipment outside the port water area, that is, there are often such specific features as unloading in the road. There is a shortage of technical specialists, which presents a serious personnel problem. And the most important feature is a pronounced seasonality, therefore, it is important to form shipments in a timely manner and to plan deliveries very precisely taking these features into account.

Planning and tracking of sea transportation in such difficult conditions is impossible without modern intelligent information support.

Otherwise, it is difficult for transportation companies to avoid economic losses, as well as problems for cargo shippers and receivers, delays in the delivery schedule, which results in some goods being inevitably damaged or a production process being disrupted due to undelivered goods. The fundamental role in coordinating the work of the transport system is played by the adoption of such management decisions, the correctness and timeliness of which is achieved using modern information technologies of analysis and calculation, one of the directions of which is the apparatus of fuzzy sets, fuzzy relations, and soft intelligent modeling [1].

Analysis of existing software and information resources in the field of the organization of sea cargo transportation in the Arctic and Subarctic zone of Russia has shown the need to develop an intelligent information transport and logistics management system capable of optimizing logistics operations [2].

The main goals of intellectualizing the organization of sea cargo transportation process are: improving the efficiency of the logistics infrastructure and the quality of ports, transportation systems [3,4].

2. Development of an information intellectual system

The development of an intelligent information system for the organization and management of sea cargo transportation (IISMSCT), taking into account the difficult navigation conditions in the Arctic and Subarctic of Russia, is a new approach for organizing, providing and managing the process of cargo transportation.

First of all, the architecture of IISMSCT was developed taking into account the difficult navigation conditions in the Arctic and Subarctic of Russia:

- a module for calculating the route between two ports, taking into account the ice situation;
- a module for calculating the cost and number of travel days of sea cargo transportation, taking into account the ice situation;
- the third module, based on the first and the second modules, calculates a faster (travel days) or a more cost-effective (cost) route depending on the season, taking into account the current ice situation.

The module, the interface of which is shown in Figure 1, calculates the optimal route between two ports, taking into account the ice situation. The possibility of the vessel to pass through the ice field or to bypass it is determined or the need for icebreaker services is indicated. The interface of the module provides the choice of the necessary map, on which it is necessary to indicate the port of departure and port of destination and indicate the ice conditions. Next, you need to set the parameters of the vessel and start the calculation process with visualization of the optimal route and displaying the distance from the port of departure to the port of arrival, taking into account the ice conditions.

The core of the program is the A-star algorithm for finding the shortest route between two ports. The program is implemented through the mathematical package Matlab. This program allows you to calculate the distance between two ports, taking into account various ice conditions and the choice of vessel class. The obtained data can be used to calculate the distance of sea cargo transportation in the Arctic navigation conditions.

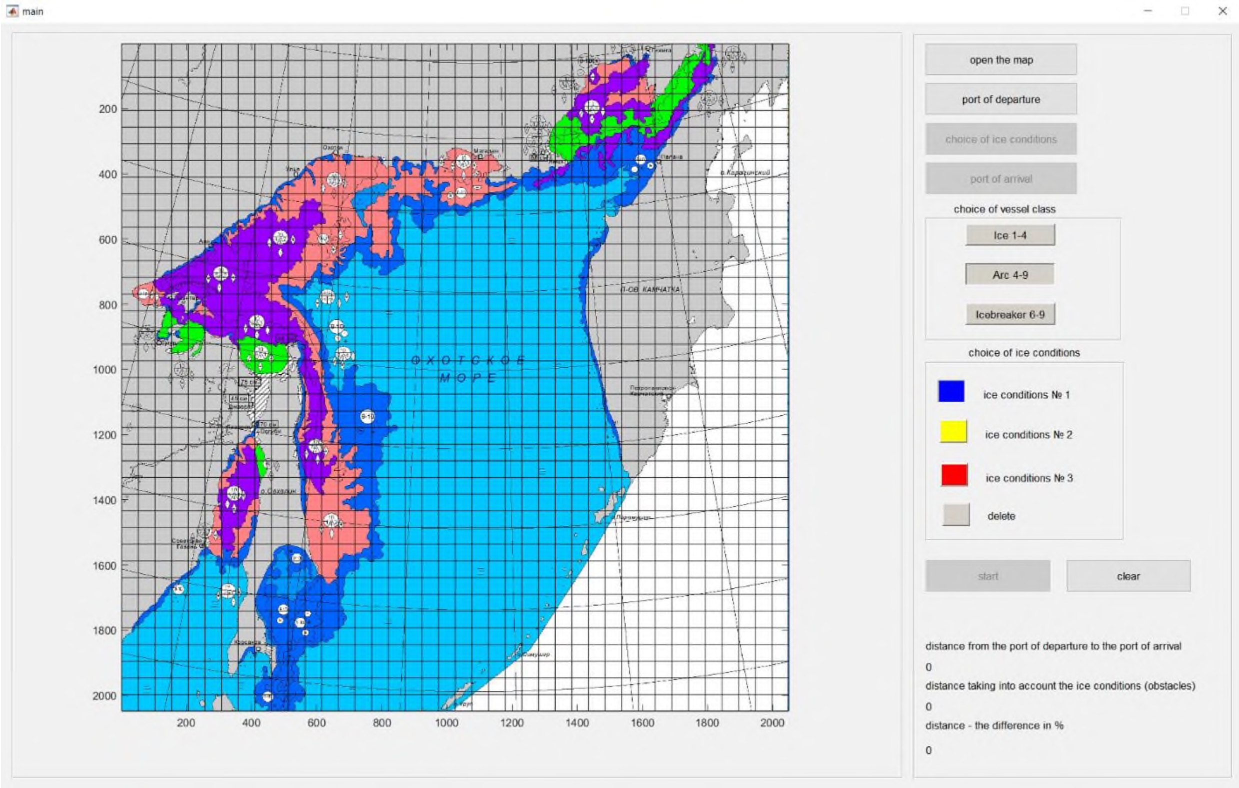

Figure 1. The interface of the program for calculating the route between two ports, taking into account the ice conditions.

A module for calculating the cost and number of travel days in sea cargo transportation, taking into account the ice conditions, was developed on the basis of fuzzy logic using a Mamdani fuzzy logic model.

Mamdani knowledge base is defined by fuzzy terms and can be interpreted as dividing the space of influencing factors into subdomains with blurred boundaries, within which the response function takes a fuzzy value.

Mamdani fuzzy inference is carried out according to the knowledge base (1) [5]:

$$\left(x_1 = \tilde{a}_{1j}\ u\ x_2 = \tilde{a}_{2j}\ u_j \ldots u_j\ x_n = \tilde{a}_{nj} \text{ with weight } w_j\right) \Rightarrow y = \tilde{d}_{1j}, j = \overline{1,m} \quad (1)$$

where $\tilde{a}_{ij}$ is a fuzzy term by which the xi variable is evaluated in the j rule, i =1,n; $\tilde{d}_j$ is fuzzy conclusion of the j rule; m is number of rules in the knowledge base; wj ∈ [0,1] is weight coefficient reflecting the adequacy of the j rule.

All values of the input and output variables of the system are given by fuzzy terms.

To implement an intelligent information transport and logistics system for the management of sea cargo transportation on the basis of the Mamdani fuzzy logic model, a fuzzy production rule base (FPRB) is formed and implemented using the Fuzzy Logic Toolbox of the mathematical package Matlab [6].

In FPRB, terms of linguistic variables that are used to form input parameters are identified and formed. Terms of linguistic variables: «Season»; «Vessel»; «Ice breakage»; «Route»; «Hummocked ice»; «Ice compaction»; «Age of ice»; «Ice shape»; «Ice under pressure»; «Snow cover ice».

Then, the main terms of linguistic variables are identified, which served as the basis for the formation of the FPRB for the Mamdani fuzzy logic model.

To compile the FPRB, a sample is formed, the basis of which was the data from the analyzed maps of the chosen route of the vessels. We analyzed 445 maps from 2004 to 2019.

When compiling the sample, the following algorithm was used:

- select the ice situation for each route point (the route number consists of ports; a route point is a port of call);
- combine the data for each factor in one set;
- combine data by month;
- write in the resulting table the factor from the set that is the most severe / the largest, since it is the severe navigation conditions that slow the speed of the vessel, so they must be taken into account first.

The module, the interface of which is shown in Figure 2, allows you to calculate the cost of the route and the number of travel days in the Arctic sailing conditions. The basis of this program is the Mamdani fuzzy inference system and the formed FPRB implemented using the Fuzzy Logic Toolbox of the mathematical package Matlab.

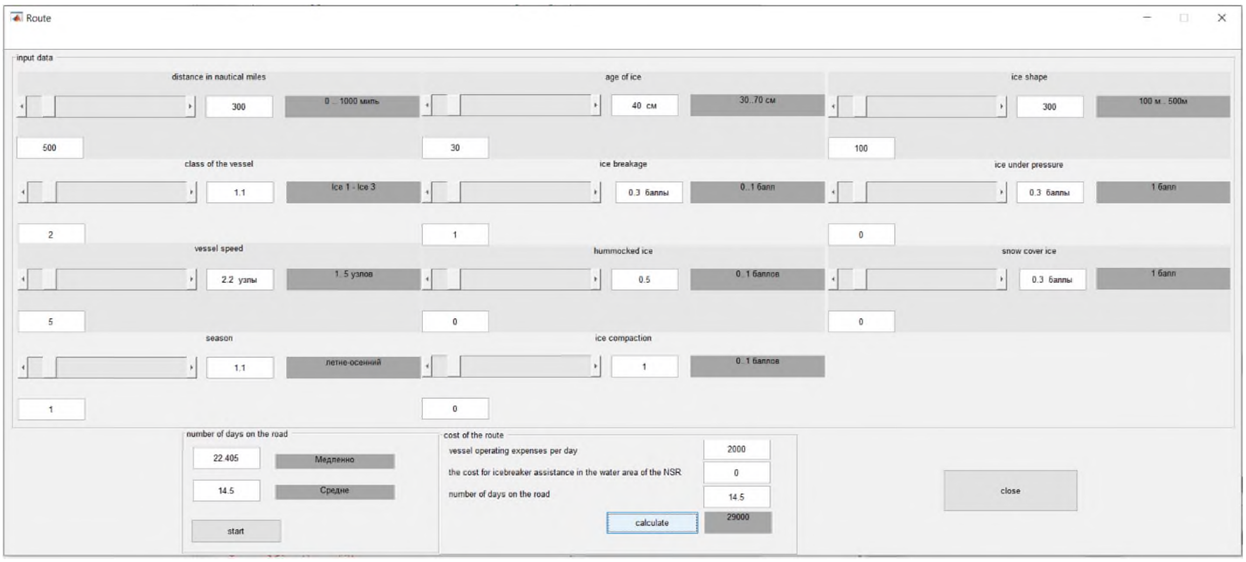

Figure 2. Mamdani fuzzy inference FPRB interface.

The input data for the program are the navigation season, the vector of ice conditions parameters (age of ice; hummocked ice; ice compaction; ice shape; ice breakage; ice under pressure; snow cover ice), ice class of the vessel, vessel speed, distance in nautical miles.

The program provides:

- connection of FPRB;
- calculation of the number of days in transit, taking into account the input parameters;
- calculation of the cost of the route.

The result of the program is the number of days in transit and the cost of passing the route.

FPRB of the module for calculating the cost of sea cargo transportation, taking into account the ice situation, is based on calculated data.

Setting up the Mamdani fuzzy logic model consisted of determining such vectors $(\vec{P}, \vec{W})$ that the root-mean-square error (Root Mean Square Error, RMS Error, RMSE) tended to a minimum (2)[5].

$$\mathrm{RMSE}(\vec{P}, \vec{W}) = \sqrt{\frac{1}{M} \sum_{r=\overline{1,M}} (y_r - F(\vec{P}, \vec{W}, +X_r)^2} \rightarrow \min \quad (2)$$

where, P is the vector of parameters of membership functions of the terms of input and output variables; W is the vector of weight coefficients of the knowledge base rules; $F(\vec{P}, \vec{W}, Xr)$ is a function that determines the result of the output from a fuzzy Mamdani knowledge base with parameters $(\vec{P}, \vec{W})$ for the value of inputs X_r; M is the sample size.

The fuzzy model settings consist of:

- weight coefficients of the knowledge base rules;
- coordinates of maxima of membership functions of terms of input variables and maxima of membership functions of non-extreme terms of output variables;
- concentration coefficients of membership functions of terms of input and output variables.

The adjusted fuzzy model adequately reflects the behavior of the identified dependence, which is confirmed by the small value of RMSE = 3.190.

To check the adequacy of the Mamdani fuzzy logic model, a sample was formed based on the analysis of data from the captain's voyage reports, for example, voyage reports from icebreakers such as "Magadan"; "Admiral Makarov"; "Krasin." Each captain's voyage report contains information on the navigational situation along the route, which made it possible to form a sample consisting of information on the actual conditions of navigation (a fragment of the data is presented in Table 1) [7].

Table 1. Sampling of field data.

Season	Age of ice	Hummocked ice	Ice compaction	Ice shape	Ice under pressure	Snow cover ice	vessel / class of vessel	Average speed in knots	Route	Days in transit
2	10 – 15 cm	0	2-6	2 – 20 m	1-2	0	LL4	7,6	3	5
2	15 – 30 cm	2	10	2 – 20 m	0	0	LL4	7,9	3	8
2	15 – 30 cm	1	2-3	2 – 20 m	1-2	3	Icebreaker	3	5	24
1	10 – 15 cm	0	5-6	2 – 20 m	0	0	L2	9	4	3
1	15 – 30 cm	0	8-10	20 – 100 m	1	0	L2	5,7	4	12
1	15 – 30 cm	0	6-7	0 m	0	0	L2	7,25	4	3

The sample data served as input parameters for checking the adequacy of the model, a fragment of the result is presented in Table 2.

Table 2. Model verification data.

Sample No.	Number of days in transit according to the captain's voyage report	Number of days in transit according to the results of the Mamdani model	% deviation of model result from field data
1	5	4.85	3.00
2	24	24.32	-1.33
3	8	7.68	4.00
4	10	10.12	-1.20
5	5	5.05	-1.00
6	14	14.01	-0.07
7	3	3.26	-8.67
8	12	12.15	-1.25
9	18	17.95	0.28
10	2	1.68	2.00

Analysis of the model verification data showed that the number of days in transit according to the captain's voyage reports and the result of the program's work are approximately equal, which confirms the adequacy of the adjusted Mamdani model (the largest error is 8.67%) [8].

A method has also been developed for determining the optimal route of the vessel using a genetic algorithm for organizing and managing sea cargo transportation, taking into account the difficult navigation conditions in the Arctic and Subarctic.

A program has been implemented to determine the optimal vessel route, taking into account the cost between ports on the route. The basis of this program is the solution of the optimization problem (traveling salesman problem) - using the forward search algorithm - the genetic algorithm. The essence of the algorithm of the program is that on the map, points specify the ports and indicate the cost / number of travel days between the ports on the route. In the process, the program generates routes to which the mutation and crossover operation is applied. The result of the program is the optimal route with the sequence of visits to ports and the optimal cost of the entire route (Figure 3). The program is implemented in the high-level programming language MATLAB using the interactive GUIDE tool.

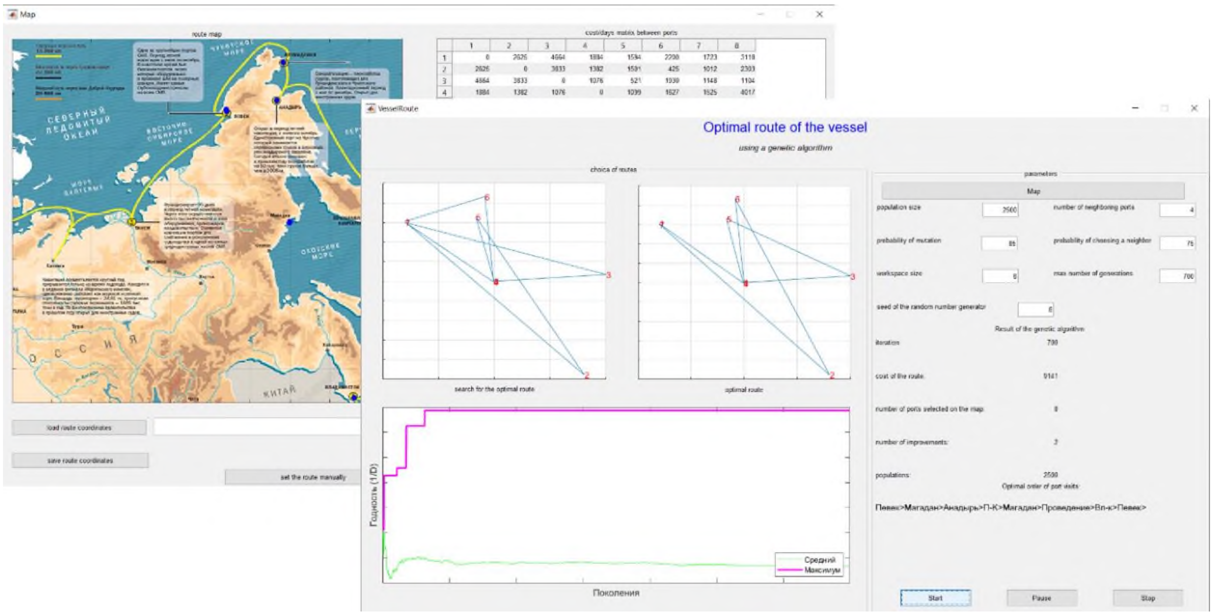

Figure 3. Search for the best route.

Thus, the result of the work of these modules are the optima of two objective functions, firstly, the minimum cost of the route (3):

$$I_1 = \min_{Z \in D} t \quad (3)$$

where Z= $\{\vec{V}, \vec{K}, \vec{L}, \vec{S}; \}$V is routes; K is types of ships; L is icebreakers; D is the area of possible resources; t is the time; S is the cost.

Which means the optimal use of the fleet, taking into account the choice of a lower cost-effective vessel for each step along the route.

And, secondly, the risk of delays in the delivery schedule is minimized (4):

$$I_1 = \min_{Z \in D} |t_{zi} - t_r| \quad (4)$$

where i = 1, n; n is the number of ports; t_{zi} is set time; t_r is estimated time of arrival; Z= $\{\vec{V}, \vec{K}, \vec{L}, \vec{S}\}$;

V is routes; K is vessel type; L is icebreakers; D is the area of possible resources; t is the time; S is the cost.

This means the optimal use of the fleet, since the program allows you to pre-calculate the number of days in transit, taking into account the choice of different classes of the vessel for each stage (from port to port), therefore, the shipping company will optimally use the vessels taking into account the season and navigation, which, on one hand, will reduce the costs of the shipping company, and on the other hand, will ensure more efficient delivery of cargo.

IOP Conf. Series: Materials Science and Engineering **918** (2020) 012042 doi:10.1088/1757-899X/918/1/012042

3. Conclusion

The developed intelligent information system for the organization and management of sea cargo transportation, taking into account the difficult navigation conditions in the Arctic and Subarctic of Russia, consisting of a module for calculating the route between two ports, taking into account the ice situation, based on the A-star algorithm for finding the shortest route between two ports, a module for calculating the cost and number of days in the sea cargo transportation route, taking into account the ice situation, as well as the module, which on the basis of the first and second modules calculates a faster (days in transit) or cost-effective (cost) route depending on the season, taking into account the current ice conditions, which is based on the solution of the optimization problem (traveling salesman problem) - using the forward search algorithm - the genetic algorithm, will allow you to get a diagram of the most efficient use of the fleet and forecast ice conditions along the route, taking into account the class of the vessel, navigation period, speed along the way.

References

[1] Eglit Ya Ya, Eglit K Ya, Kovtun A A and Dmitriev A A 2019 *System analysis and logistic* **3(21)** 13
[2] Sobolevskaya E Yu, Glushkov S V and Levchenko N G 2018 *Modeling, optimization and information technology* **4(19)** 27
[3] Eliasson K, Ulfarsson G F, Valsson T and Gardarsson S M 2017 *Futures* **85** 14
[4] Malygin I G, Komashinsky V I and Asaul M A 2017 *Marine intelligent technologies* **2-2(36)** 55
[5] Shtovba S D 2007 *Design of fuzzy systems by means of MATLAB* (Moscow: Hotline-Telecom) p 288
[6] Sobolevskaya E Yu, Glushkov S V and Levchenko N G 2019 *Transport business in Russia* issue **2** 154
[7] Glushkov S V, Sobolevskaya E Yu and Levchenko N G 2020 *Marine intelligent technologies* **2-2(47)** 230
[8] Sobolevskaya E Yu 2019 *Bulletin of the Astrakhan state technical University* **3** 16