Digitalization of Arctic shipping along the Northern Sea Route

A V Vicentiy¹,²

¹Institute for Informatics and Mathematical Modeling, Kola Science Centre of the Russian Academy of Sciences, Apatity, Russia.
²Apatity branch of Murmansk Arctic State University, Apatity, Russia

alx_2003@mail.ru

Abstract. The proportion of scientific papers devoted to studying and scientifically substantiating climate change and ice melting in northern latitudes has been steadily increasing in recent years. Of particular interest to our country are researches studying climate change in the Arctic and the consequences of these changes. One of the effects of climate change is the retreat of Arctic ice to the North. Thereby, it becomes possible to more effectively use the Northern Sea Route. The Northern Sea Route is very promising both economically and strategically. Therefore, its development and active use is an important task for the state. However, there are a large variety of obstacles and problems related to the effective development of the Northern Sea Route. One of the most important is the underdevelopment of transport and logistics infrastructure, as well as insufficient digitalization of the basic services required for safe navigation in the difficult conditions of the Arctic zone of the Russian Federation. In this context, the digitalization of Arctic shipping along the Northern Sea Route is an urgent task. The aim of the study is to develop approaches, methods and tools to ensure the digital transformation of Arctic shipping. Such infrastructure elements as Arctic ports, as well as services for ice and pilotage of vessels are considered separately. As the main research methods, we selected system analysis, conceptual modeling, ontological modeling and engineering. Two ontologies are presented as scientific and practical results obtained in the work: the ontology of the Arctic seaports of Russia and the ontology of shipping support in the waters of the Northern Sea Route. The paper also considers several promising directions for the development of the results obtained. One of these directions is related to the digitization of the most important components of the transport and logistics system for shipping along the northern coasts of the Russian Federation. This will provide better access to maritime transport infrastructure along the Arctic routes through the use of a single digital platform. We believe that the development of knowledge-based decision-making systems and machine learning approaches for maritime logistics management in the Arctic is a promising area for further research.

1. Introduction

Today, there are many different studies of climate change. Some of these studies are devoted to the causes and impact of global warming on various sectors of the economy and production in the Arctic [1]. Of greatest interest for our work are studies related to logistics [2], shipping [3], transport infrastructure [4], cargo delivery [5], and life support in the Arctic latitudes [6].

This paper presents some of the results of our work on the study of Arctic transport logistics and infrastructure. At the first stage of the work, a preliminary analysis of the existing experience in Arctic
shipping was carried out. The analysis showed that the main problems hindering the development of this sector of the economy are the underdeveloped shipping infrastructure in the Arctic [7] and the low level of digitalization of the transport complex and basic services that ensure the safe and efficient use of the Northern Sea Route (NSR). These problems significantly slow down the development of the Northern Sea Route and do not allow getting the maximum return on funds invested in the digital transformation of economic processes [8].

However, it should be noted that at present, digital transformation is a priority for the development of the country [9]. This statement can be confirmed by the adoption of a number of legal acts aimed at the development of digital technologies in various fields. Among them, it is worth noting, for example, the program “Digital Economy of the Russian Federation” [10] and the Strategy for the Development of the Information Society in the Russian Federation [11].

Currently, there are many factors and restrictions that impede the development of the Northern Sea Route (or Northeast Passage NEP). The most important constraint is the low level of infrastructure development to support shipping routes along the northern shores of the Russian Federation. However, Russia is making great efforts in the development of a transport and logistics system to ensure safe navigation in the Arctic seas. [12] A large number of infrastructure projects are being implemented at the expense of budget funds and funds of public-private partnerships. Currently, the number of such projects is over 150 and new projects are constantly emerging. Russia plans to significantly increase cargo traffic along its northern borders by developing the infrastructure of the Arctic zone of the Russian Federation (AZRF).

A large number of projects are also related to shipbuilding. The development of the icebreaker fleet and the necessary coastal infrastructure for servicing ships of various ice classes is of particular importance for Russia. The share of such projects is about thirty percent of the total number of infrastructure projects in the Arctic zone of the Russian Federation. The largest infrastructure transport and logistics projects are the projects “Integrated development of the Murmansk transport hub” [13], “Northern Latitudinal Way” [14] and “Belkomur” [15]. The creation of each new object of transport infrastructure, the launch of each new icebreaker, the creation of each new project aimed at the development of navigation in the Arctic waters, contributes to the development of a new transport artery between Europe and Asia and, as a consequence, the strengthening of Russia as a northern maritime power.

Despite the development of the Arctic transport infrastructure and the solution of a number of problems in the field of digital transformation of the economy, efforts in this direction are still insufficient. It is necessary to create new digital services and platforms that allow all interested participants to interact with each other. The digitalization of Arctic shipping along the Northern Sea Route is no exception. In this context, the development of new approaches, methods and tools that contribute to the digitalization of the transport complex is an urgent task. And the methods and means of digitalizing the Arctic shipping and related infrastructure, as part of the global transport system, proposed in this work, are also of scientific and practical importance. At the same time, the results of the work can be used as components of the developed information platform.

2. Goal and tasks
The overall goal of our work is to develop scientifically based approaches, methods and tools to ensure the digital transformation of Arctic shipping. To achieve the goal, at this stage of the work, the scientific and practical task of developing basic ontologies of the subject area was formulated. As a result of solving this tasks, two basic ontologies were created:

- Ontology "Arctic Seaports of Russia" (ASPR).
- Ontology “Providing Shipping in the Water Area of the Northern Sea Route” (PSWANSR).

The developed ontologies represent the basis for creating a knowledge base in the field of Arctic shipping along the Northern Sea Route. Also, these ontologies can be used as elements of a digital platform for Arctic marine logistics, including transportation along the Northern Sea Route.
3. Materials and methods
In the process, we used the tools and methods of system analysis and structural decomposition of complex systems, conceptual modeling, ontological design and engineering. Methods of system analysis and decomposition were used at the stage of analysis of the studied systems and their division into interconnected parts in order to select the most significant subsystems and their further, more detailed study. Conceptual modeling was used at the stage of analysis of the main elements of the studied subsystems, their relationships and the most significant characteristics and properties. Thus, we got an exhaustive idea of the main studied concepts and the relationships between them. The data obtained were then used to create ontologies using methods of ontological design and engineering.

We have used heterogeneous data from publicly available sources of information as our main research material. In particular, we have analyzed various publications on transport and logistics infrastructure in the Arctic, including sea, rail, air, road and pipeline transport. We also used various data on the number of Arctic ports in the Russian Federation and the capacity of these ports to store and handle cargo, as well as to service ships, including icebreakers and high ice-class ships. We paid particular attention to collecting and analysing materials on navigational and maritime safety in challenging Arctic conditions. Among other things, we studied the current state and problems of pilotage along the Arctic shores of the Russian Federation, as well as the specifics of using icebreakers to ensure navigational safety.

Large volumes of information on companies offering icebreaking assistance and pilotage escort services for vessels along the northern coast of Russia were also analyzed.

Data was collected and analyzed about the types of services, their cost, the ordering system and methods of selling services. The data on ice classes of vessels were also studied and the composition, structure and capabilities of the ice fleet of Russia and other countries were analyzed. After the analysis, cleaning, structuring and formatting of the data, they were used to create ontologies “Arctic Sea Ports of Russia” and “Ensuring Shipping in the Water Area of the Northern Sea Route”. The ontology editor Protégé was used as a software tool for implementing ontologies [16].

4. Results
The main scientific and practical result of the work at this stage is the creation of two domain ontologies:

1) “Arctic Seaports of Russia” ontology;
2) “Providing Shipping in the Water Area of the Northern Sea Route” ontology.

The composition and structure of each of them are briefly described below.

To create the “Arctic Sea Ports of Russia” ontology, it was necessary to collect primary data on Russian seaports, taking into account their most significant characteristics. One of the problems was that at the moment there is no clear classification that would unambiguously assign this or that port to the Arctic port. In this regard, we had to create our own classification of Arctic ports, based on the aggregation of several existing classifications. Table 1 presents the main Arctic seaports of the Russian Federation with their main characteristics and coordinates.

| Name of port | Capacity (thousand tonnes per year) | Number of berths | Exact coordinates | Name of the sea |
|--------------|------------------------------------|------------------|------------------|-----------------|
| Varandey     | 12 100.4                           | 2                | 68°49′28″ n.l. 58°04′08″ e.l. | Barents Sea     |
| Murmansk     | 24 647.2                           | 110              | 68°58′25″ n.l. 33°03′33″ e.l. | Barents Sea     |
| Naryan-Mar   | 501,016                            | 6                | 67°38′48″ n.l. 52°59′39″ e.l. | Barents Sea     |
| Arkhangelsk  | 11 772.9                           | 75               | 64°32′04″ n.l.   | White Sea       |
As a result of the creation of the “Arctic Sea Ports of Russia” ontology, a set of essential characteristics for Arctic seaports was determined, a large number of heterogeneous information sources were processed, a structure for describing Arctic sea ports was created, which allows describing any port through a combination of the most significant characteristics.

Based on the obtained data, several variants of the “Arctic Sea Ports of Russia” ontology structure were proposed. After evaluating each variant of the structure, one of them was implemented using Protégé tools. The structure of the ontology includes higher-level classes (basins), subclasses of basins (seas) and subclasses of seas (ports). A fragment of the created ontology is presented in Figure 1. The current ontology version includes all the Arctic ports of Russia: Murmansk, Arkhangelsk, Kandalaksha, Vitino, Onega, Mezen, Varandey, Naryan-Mar, Sabetta, Dudinka, Dikson, Khatanga, Tiksi, Anadyr, Pevek, Providence, Egvekinot and Beringovsky.

| Port       | Town     | Population | Latitude      | Longitude     | Sea          |
|------------|----------|------------|---------------|---------------|--------------|
| Vitino     | 11 000   | 4          | 67°04’46" n.l. 32°19’28" e.l. | White Sea     |
| Kandalakha | 1 500    | 5          | 67°09’14" n.l. 32°23’24" e.l. | White Sea     |
| Mezen      | 132      | 3          | 65°52’01” n.l. 44°12’21” e.l. | White Sea     |
| Onega      | 261,5    | 7          | 63°55’50” n.l. 38°01’57” e.l. | White Sea     |
| Pevek      | 330      | 3          | 69°41’41” n.l. 170°15’32” e.l. | East-Siberian Sea |
| Dikson     | 120      | 2          | 73°30’14” n.l. 80°29’59” e.l. | Kara Sea      |
| Dudinka    | 1 885    | 9          | 69°24’32” n.l. 86°09’19” e.l. | Kara Sea      |
| Sabbeta    | 30 317,8 | 8          | 71°16’00” n.l. 72°04’00” e.l. | Kara Sea      |
| Igarka     | 100      | 4          | 67°27’42” n.l. 86°33’19” e.l. | Kara Sea      |
| Tiksi      | 67       | 2          | 71°37’59” n.l. 128°53’22” e.l. | Laptevih Sea  |
| Khatanga   | 95       | 5          | 71°58’49” n.l. 102°27’24” e.l. | Laptevih Sea  |
| Anadyr     | 900      | 6          | 64°44’11” n.l. 177°30’51” e.l. | Bering Sea    |
| Beringovsky| 646      | 4          | 63°03’47” n.l. 179°21’20” e.l. | Bering Sea    |
| Provideniya| 345,4    | 3          | 64°26’08” n.l. 173°13’03” e.l. | Bering Sea    |
| Egvekinot  | 350      | 3          | 66°14’44” n.l. 179°05’03” e.l. | Bering Sea    |
The following characteristics were identified as the most significant characteristics of the Arctic seaports:

- The address;
- The coordinates;
- The navigation period;
- The number of berths;
- The number of stevedores;
- The length of the mooring front;
- The water area;
- The area of the land;
- The area of covered warehouses;
- The area of open warehouses;
- The capacity of cargo terminals;
- The capacity of passenger terminals;
- The ocean.

All these characteristics are reflected in the ontology for each port using the port properties. An example of a list of properties and their values for the port of Murmansk is shown in Figure 2. If necessary, the set of properties and their values can be changed and supplemented.
To create the “Providing Shipping in the Water Area of the Northern Sea Route” ontology, it was necessary to collect primary information about the types of ice vessels, the rules of navigation in Arctic waters at different times of the year and describe their most significant characteristics.

In addition, it was necessary to collect primary information about organizations providing icebreaking assistance services and organizations providing ice piloting services. The collection of data necessary to create an ontology was complicated by the fact that information was presented in a large number of heterogeneous sources. In this regard, the effective use of automated methods and means of collecting and processing information was impossible. Most of the data had to be collected manually, studying various open data sources, websites of various organizations, ship classification, etc.

Based on the study of the obtained data, a list of vessels of various ice classes operating in the Northern Sea Route was compiled. Particular attention was paid to the icebreakers used for ice pilotage. Their main characteristics and capabilities were introduced into the ontology.

After collecting the necessary data, the ontology structure was developed. The software implementation of the “Providing Shipping in the Water Area of the Northern Sea Route” ontology was implemented by the Protégé ontology editor. The ontology includes detailed information about more than 100 different vessels engaged in various activities in the waters of the Arctic zone of the Russian Federation. The ontology also contains data on all organizations providing icebreaking assistance and ice piloting services. Basic data on these organizations, their fleet, types and characteristics of ships, the number and qualifications of pilots and other data are stored in the ontology.

As an example, the Figure 3 shows a fragment of the “Providing Shipping in the Water Area of the Northern Sea Route” ontology, which depicts the nuclear icebreakers fleet of the Atomflot company.
Figure 3. Fragment of the ontology, which shows icebreakers owned by the state enterprise "Atomflot".

In addition, for each vessel in the ontology, a set of basic properties is stored, such as:

- The ice class
- The deadweight
- The displacement
- The length
- The width
- The height
- The draft
- The top speed
- The gross tonnage
- The net capacity.

5. Conclusions
As a result of the work, the ontologies “Arctic Sea Ports of Russia” and “Providing Shipping in the Water Area of the Northern Sea Route” were created. These ontologies have scientific and practical value as a formal conceptualization of the subject area. In addition, they are the basis for creating a knowledge base in the field of Arctic shipping and ensuring safe navigation along the entire coast of the Arctic zone of the Russian Federation and the Northeast Passage. Also, the results obtained in the work will be used to scientifically substantiate new approaches, methods and tools for digital transformation of Arctic transport logistics and digitalization of Arctic shipping.

6. Future works
Further research involves the development of approaches, methods and means of digitalization of the main components of Arctic shipping and the expansion of access to services that ensure year-round use of the Northern Sea Route on the basis of a unified digital platform. As the individual elements of a unified digital platform, both the results obtained in this work and third-party developments can be used. We also plan to create a knowledge base and an information decision support system for managing Arctic marine logistics. In addition, tasks will be solved on the development of methods and means of integrating newly developed digital platforms and existing services at various levels.

We are currently developing and using various methods of automatic analysis of natural language texts to identify named entities with geographical meaning and the relationships between them [17]. These methods allow us to identify new entities and relationships in the Arctic transport and logistics...
system based on text analysis in the subject area of Arctic transport logistics. Based on the findings, we will adjust and supplement the developed ontologies.

Another area of research where the results described above will be used is the development of complex geoservices based on the integration of different types of geographic information systems. Such geoservices are usually used in decision support systems for territorial and maritime management [18]. We will use the ontologies "Arctic Sea Ports of Russia" and "Providing Shipping in the Water Area of the Northern Sea Route" to geographically support the analysis of cargo flows, transport and logistics infrastructure, economic activities in the coastal zone, as well as shipping along the northern shores of the Russian Federation.

References
[1] Skripnuk D F and Samylovskaya E A 2018 Human Activity and the Global Temperature of the Planet IOP Conf. Ser.: Earth Environ. Sci. 180 012021
[2] Kikkas K and Romashkina E Potential Opportunities for the Arctic Transport Space 2018 IOP Conf. Ser.: Earth Environ. Sci. 180 012016
[3] Lasserre F and Faury O 2019 Arctic Shipping Climate Change, Commercial Traffic and Port Development (London: Routledge) p 288
[4] Konovalov A M et al 2018 Evaluating the global climate change influence on the infrastructure development at the Arctic zone of the Russian Federation IOP Conf. Ser.: Earth Environ. Sci. 200 012044
[5] Yunzhuang Z and Amy K 2017 Rethinking business-as-usual: Mackenzie River freight transport in the context of climate change impacts in northern Canada Transportation Research Part D: Transport and Environment 53 276-289
[6] Qianqian D, Amy K and Yunzhuang Z 2017 Modeling multimodal freight transportation scenarios in Northern Canada under climate change impacts Research in Transportation Business & Management 23 86-96
[7] Gutman S S, Zaychenko I M and Rytova E V 2017 Development strategy of Far North transport infrastructure: Problems and prospects Proceedings of the 29th International Business Information Management Association Conference - Education Excellence and Innovation Management through Vision 2020: From Regional Development Sustainability to Global Economic Growth 1439-1449.
[8] World Bank Group. 2016. World Development Report 2016: Digital Dividends. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/23347
[9] World Bank Group. 2018. Competing in the Digital Age: Policy Implications for the Russian Federation. Russia Digital Economy Report:. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/30584
[10] The Russian Federation Government 2017 Order dated 28 July 2017 No. 1632-p on Approval of Programme “Digital Economy of the Russian Federation”, http://static.government.ru/media/files/9gFM4FHj4PsB7915v7yLVuPgu4bvR7M0.pdf
[11] President of the Russian Federation 2017 Decree of the President of the Russian Federation No 203 “On strategy of development of information society in the Russian Federation in 2017-2030” http://static.kremlin.ru/media/acts/files/0001201705100002.pdf
[12] Strategy for the development of the Arctic zone of the Russian Federation and ensuring national security for the period until 2020. http://docs.cntd.ru/document/499002465
[13] Official site of the project “Integratted development of the Murmansk transport hub” http://ppp-transport.ru/ru/o-retu/proekty-retu/kompleksnoe-razvitie-murmanskogo-transportnoho-uzla
[14] The Russian Federation Government 2018 Order dated 8 August No. 1663-p. http://static.government.ru/media/files/1XA6VqKeHz83g8ATkA4XZBbiAi9ARtro.pdf
[15] Official site of the Belkomur project http://www.belkomur.com
[16] Official site of the Protégé https://protege.stanford.edu
[17] Pilecki B M and Vicentiy A V. 2020 Development of a method for extracting spatial data from
texts for visualization and information decision-making support for territorial management

IOP Conf. Ser.: Earth Environ. Sci. 539 012087

[18] Vicentiy A V. 2020 The use of different types of geographic information systems for the construction of geoservices to support management of the Arctic territories IOP Conf. Ser.: Earth Environ. Sci. 539 012131