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Digital and Logistical Infrastructures of the Arctic Zone: Current State of Research and Ways of Development*

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Abstract. The subject of the article is the analysis of the current state of research and practice in the field of transport, logistics and digital infrastructures in the Russian Arctic. The authors consider logistic and digital infrastructures as key communication subsystems that ensure the movement of material values, people and information, and thus serve as a prerequisite for the development of the macro-region under consideration. The research methods used were literature review of scientific sources and analysis of the obtained material. A systematic literature mapping was carried out on Scopus, Google Scholar, Elibrary databases. Aspects of the Arctic region development, including the role of logistics and digital infrastructures in this process, are described by scientific schools of Russia, Canada, Norway, China, USA and other countries. The analysis has shown the highly variable state of the subsystems under consideration depending on the specific region, as well as the lack of a comprehensive approach to their joint development and integration. It was stated that there is no such problem statement about the development of communication subsystems of the Arctic zone. On the basis of the analysis, the key directions for the development of logistics and digital infrastructure of the Arctic zone of the Russian Federation were formulated. The authors' recommendations, apart from the obvious tasks of developing sea routes, building and modernizing roads, railways and airports, expanding access to broadband internet and other widely discussed measures, describe the need to integrate the communication subsystems under consideration and focus on the potential of digital technologies to replace and/or supplement the logistics infrastructure in certain aspects.
Keywords: *Arctic, Arctic zone of the Russian Federation, logistics, digital platforms, digital infrastructure, logistics infrastructure*

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Introduction

The combination of the following features of the Arctic territories determines the need for special systematic scientifically based approaches to the issues of exploration and development of this macro-region:

- extreme natural and climatic conditions of life;
- focal nature of territorial development;
- low population density, insufficient labor force, population outflow;
- remoteness from the main industrial centers, inaccessibility of facilities in the region;
- high resource intensity, dependence on resource supplies from other regions;
- low ecosystem stability, waste and pollution from human activities;
- rich resource potential.

Communication systems are one of the key factors that ensure the fundamental possibility of developing any region, especially the Arctic. In this article, communications are defined as both the movement of people and goods and the transfer of information. In this regard, the design and modeling of efficient logistics and digital infrastructure is an important prerequisite for the development of the Arctic zone.

Logistics and digital infrastructures are key subsystems that ensure communication between elements of the Arctic region, providing the ability to move material resources, as well as the transmission and processing of data and information. The region's transport and logistics infrastructure is one of the key factors in the economic, social and environmental efficiency of Arctic development, as it determines the fundamental possibility, accessibility and cost of territory development. In turn, modern information and digital technologies provide unique, previously unavailable opportunities for data collection, processing, analysis, transmission and, most importantly, for data-based management of socio-economic systems.

Sustainable development of the Arctic zone is impossible without a well-established transport system, the basis of which is currently the Northern Sea Route. To ensure the life-sustaining activity of the Arctic regions, it is necessary to develop shipping, road and railway networks, to increase cargo transit, to ensure, develop mineral deposits, to provide the possibility of delivery and rapid movement of labor resources. Information, communication and digital technologies allow for efficient and prompt data transfer and processing, as well as control (up to real-time mode) based on data (including remotely). These properties of the designated communication systems make them indispensable elements of the integrated system of Arctic exploration and development.

The purpose of this article is to determine the current state of research in the field of approaches to the development of the Arctic zone of the Russian Federation through the development of its transport, logistics and digital infrastructures.

Literature review
State of scientific research

Various aspects of the development of the Arctic region are described by scientific communities both in circumpolar countries and beyond. They include various universities and organizations in Russia, Canada, Norway, China, the USA and other countries.

A systematic literature mapping was conducted using Scopus, Google Scholar, and Elibrary databases: an electronic search was conducted to identify a set of articles on the following topics:

- Innovative digital technologies in the Arctic
- Digital platforms in the Arctic
- Digital infrastructure of the Arctic
- Logistics infrastructure of the Arctic
- Logistics in the Arctic

As a result of the search for articles over the past 5 years, 248 articles were found in the public domain (excluding articles by project participants), of which 44 were analyzed after manual selection of the most relevant articles for this study. Among the sources studied, scientific articles by authors from Russia predominate, as the issues of Arctic zone development are of fundamental importance for Russia from the economic, social and political points of view [1].

Among the works on the topic of logistics systems in the Arctic, publications in Russian language or by Russian authors, including the authors of this article, predominate. The works [2]–[7] consider the prospects for the development of logistics in the region taking into account the existing risks and trends of the Industry 4.0 concept. The works [8], [9] are devoted to the development of transport and logistics infrastructure in the Arctic zone of Russia. Researchers consider issues of increasing the efficiency of hydrocarbon development and improving the communication capacity of the region. In particular, the possibility of organizing logistics support for regional facilities using economic, mathematical and transport modeling is studied. The possibility of building new transport routes and a logistics system in the Arctic and their potential profitability due to the reduction of the distance of transcontinental transportation are also highlighted [10]–[12]. The works [9], [13], [14] consider the conditions for the coordinated development of transport, energy, information and telecommunications infrastructure of the Arctic region on the basis of transport and logistics corridors of the Northern Sea Route.

A number of fundamental works by both Russian and foreign scientists are devoted to the issues of improving the quality and efficiency of freight transportation, transport and logistics systems as a combination of transport infrastructure and transport [15]–[18]. Certain cases of reconciling the interests of stakeholders in the region are described, including environmental protection and support for international law [19]–[21]. The potential of effective strategies necessary for responding to and adapting to a number of environmental, social, economic and political stressors is also explored [20].

In the context of the application of innovative digital technologies in the Arctic zone of Russia, the following sources can be highlighted: [4], [22]–[28]. Using innovative approaches and various digital technologies in transport and technological processes, it becomes possible to minimize the risks characteristic of the Arctic region, as well as to come closer to ensuring the sustainable development of the Arctic zone. The research team of SPbPU (St. Petersburg, Russia) and TUHH (Hamburg, Germany) presented an overview of the current stage of development of the container shipping industry and assessed the possibilities of implementing blockchain technology as a tool for increasing the efficiency of interaction between participants in the maritime logistics sector. The works [21], [29] present an examination of the project for the development of an innovative digital platform aimed at creating a single multimodal transport and logistics environment in the Russian Federation, touched upon the use of innovative approaches to maintain the environmental safety of the region, and identified the expected positive effects and possible threats.

The use of digital platforms in the Arctic has been considered by researchers in the context of developing a digital platform for the implementation of distributed control and navigation systems for underwater robotic systems performing technological operations in the Arctic [30], and in the context of supply chain management for oil and gas companies in the Arctic [31]. It is necessary to conduct a study on the development of a digital platform that globally covers the transport and logistics structure of the region.

Digital infrastructure in the Arctic is becoming increasingly important as the region has become a center of interest for various countries and organizations. The papers and studies reviewed, including those organized by the Arctic Council (an international organization uniting eight Arctic states), the Norwegian Research Centre in Stavanger, and the International Arctic Foundation, examine the opportunities and challenges associated with the development of digital infrastructure in the region, its impact on the sustainable development of the Arctic, national policies of various Arctic countries regarding the development of digital infrastructure, and offer recommendations for improving the situation.

Logistics infrastructure in the Arctic is an important aspect of the development of this region, especially in terms of climate change and increasing interest in resources and transport routes in the Arctic. The analyzed papers consider current maritime transport routes taking into account changes in ice conditions, potential routes, obstacles to navigation and the need to develop logistics infrastructure to support safe and efficient transportation, infrastructure projects such as new ports and icebreakers construction, their role in supporting logistics infrastructure in the Arctic, changes in the political and regulatory situation, the economic potential of Arctic shipping; a comparative analysis of the Northern Sea Route and the Northwest Passage is conducted.

Projects implemented in the Arctic zone of the Russian Federation

Special attention should be paid to large projects implemented in the field of logistics and digital transformation in the Russian Arctic. Such initiatives can serve as an indicator of the role

assigned by large investors to the certain aspects of the region under study. The information portal “Investment portal of the Arctic zone of Russia” [1] contains information on ongoing and completed projects of various scales in the Arctic in a variety of areas: extractive industries, transport, infrastructure development, service, tourism, etc. It should be noted that most of the presented projects concern the western part of the Russian Arctic, which is considered more developed, including due to its greater accessibility from the European part of the country [32], [33].

The first among the largest regional projects is the Northern Sea Route (NSR) — both the transport artery itself and the digital platform for its support [32] — developed within the framework of the federal project “Development of the Northern Sea Route” [2] (Fig. 1). This transport corridor is intended to become an alternative route between Europe and Asia. It has a number of competitive advantages compared to long-established routes, but it is also characterized by challenges determined by the complex conditions of its passage. Providing proper digital support for navigation along the NSR is largely aimed at overcoming these challenges [34]–[36].

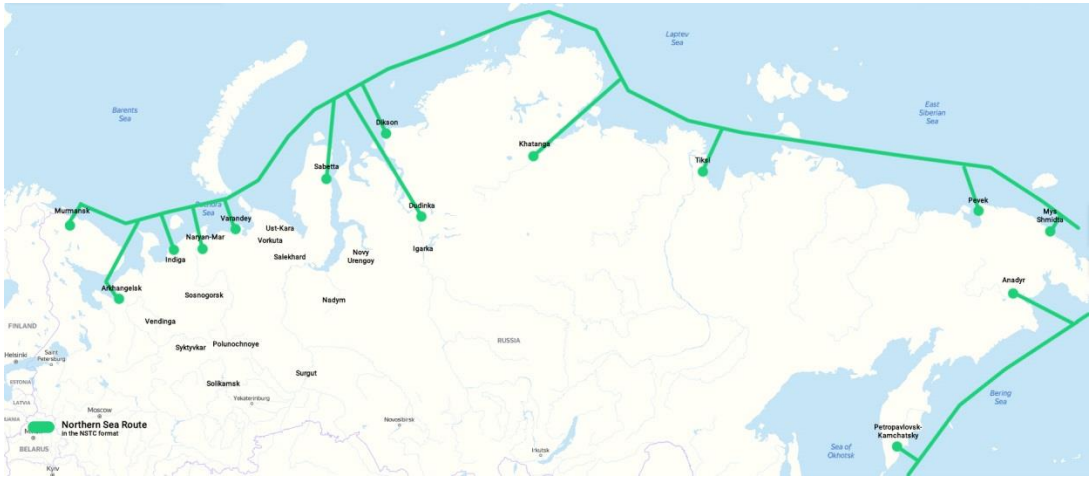

Fig. 1. Geography of the NSR [3].

The most ambitious initiative concerning the development of digital infrastructure is the laying of a fiber-optic cable along the Arctic coast of Russia on the bottom of the northern seas. Such projects include the Arctic Connect project [4], suspended in 2021, initiated by a consortium of Megafon and the Finnish operator Cinia Oy. The ROTACS (Russian Optical Trans-Arctic Cable System) initiative was developed — a project for a transcontinental telecommunications route that is to run along the Arctic Ocean floor on the London-Tokyo route. The total length of the communication line is 16,373 km. The throughput capacity of the line is 60 Tbit/s, the guaranteed service

[1] Severnyy morskoy put' segodnya i zavtra [The Northern Sea Route today and tomorrow]. URL: https://arctic-russia.ru/northsearoute/ (accessed 15 January 2024).
[2] Ministry of Transport of the Russian Federation. Passport of the federal project "Development of the Northern Sea Route". 2023. URL: https://mintrans.gov.ru/documents/8/12714 (accessed 15 January 2024).
[3] Yandex Maps URL: https://yandex.ru/maps/ (accessed 15 January 2024).
[4] «Megafon» reshil peresmotret' proekt podvodnoy linii svyazi Arctic Connect» [Megafon has decided to reconsider the Arctic Connect underwater communications line project]. URL: https://www.interfax.ru/business/769075 (accessed 15 January 2024).

life of the system is 25 years [5]. The "Polar Express" cable laying project (Fig. 2) of the Ministry of Transport of the Russian Federation and FSUE Morsvyazsputnik with the support of Rosatom State Corporation, aimed at the development of the NSR port infrastructure and the formation of a digital ecosystem in the region, is being actively developed [6]. In addition to the goals related to the development of the Arctic region, Polar Express also implements a number of national tasks in the field of digitalization, in particular, the development of the infrastructure of data processing centers (DPC or data centers) for processing large volumes of data in the Russian Federation. The creation of a data center base is one of the prerequisites for the transition to a data economy and the full-scale implementation of artificial intelligence systems in all areas.

Fig. 2. Cable laying map of the Polar Express project [7].

A separate point of application of public and private investment in the region is projects in the extractive industries. The extractive industry is one of the drivers of technological development in the region: both in industry technologies and in digital, logistics, and energy ones. Such major players in the oil and gas sector as Gazpromneft, Lukoil, Rosneft, Tatneft, NOVATEK are creating industry infrastructure for the extraction and transportation of resources, including using the NSR, and supporting and developing regional energy systems [8]. At the same time, companies note the necessity of digitalization of the industry and allocate significant shares of their profits for this purpose, including developing the Smart Field concept [9,10]. The latter is considered as a way to

[5] Rossiya postroit sobstvennuyu transarkticheskuyu kabel'nuyu sistemu [Russia will build its own trans-Arctic cable system]. URL: https://www.cnews.ru/news/line/rossiya_postroit_sobstvennuyu_transarkticheskuyu (accessed 15 January 2024).
[6] Polar Express. URL: https://полярныйэкспресс.рф/ (accessed 15 January 2024).
[7] Polar Express. URL: https://полярныйэкспресс.рф/ (accessed 15 January 2024).
[8] Novye neftegazovye proekty v Arktike [New oil and gas projects in the Arctic]. URL: https://goarctic.ru/work/novye-neftegazovye-proekty-v-arktike/ (accessed 15 January 2024).
[9] Official website of Lukoil, Digitalization. URL: https://lukoil.ru/Business/technology-and-innovation/digitalization (accessed 15 January 2024).
[10] Official website of Rosneft, Development Prospects and Strategy. URL: https://lukoil.ru/Business/technology-and-innovation/digitalization (accessed 15 January 2024).

solve a number of problems in the extraction of minerals in the difficult conditions of the Arctic (solutions without human involvement, remote control of equipment, etc. [37]). PJSC MMC Norilsk Nickel, for example, pays great attention to issues of protection against cyber threats in the Russian Arctic [38].

A major center of science and innovation in the region is the Digital Arctic IT Park, a science and technology park at the Northern Arctic Federal University (NArFU) and the government of the Arkhangelsk Oblast, opened in November 2022. The IT Park aims to create an interregional IT ecosystem for the development of digital competencies, personnel training and implementation of technological projects for the digital economy [11]. The activities of the IT Park contribute to the digitalization of the entire Arctic zone of the Russian Federation, and its products are used in various industries (E-Navigation, Smart Forest, Telemedicine projects, etc.).

The Decree of the Government of the Russian Federation dated March 30, 2021 No. 484 approved the State Program of the Russian Federation "Socio-economic development of the Arctic zone of the Russian Federation" (hereinafter referred to as the State Program). Russian President Vladimir Putin, addressing the Federal Assembly of the Russian Federation on February 29, 2024, placed special emphasis on the development of the Northern Sea Route and settlements located in the Arctic. Previously, the President has repeatedly stated that the development of the Arctic is a priority for Russia. This region has enormous economic potential and special strategic importance. The Arctic is largely associated with strengthening the energy potential of our country, expanding logistics capabilities, ensuring national security and defense.

Amendments have also been made to the Fundamentals of State Policy in the Arctic for the period until 2035. The strategy has been updated to emphasize "the development of relations with foreign states on a bilateral basis within the framework of relevant multilateral structures and mechanisms". The amendments also suggest an inclination to work with states outside the Arctic region, such as China. China received almost 30% of the shares in the Yamal LNG project and 20% of the shares in the Arctic LNG-2 project. China is also developing the Polar Silk Road and the broader Belt and Road Initiative (formerly known as One Belt, One Road), although sanctions and the inaccessibility of Western insurance for Russian cargo will make it difficult to expand maritime shipping in the region.

[11] STRBC "Pomorye", IT-park "Digital Arctic". URL: https://narfu.ru/digital-arctic/ (accessed 15 January 2024).

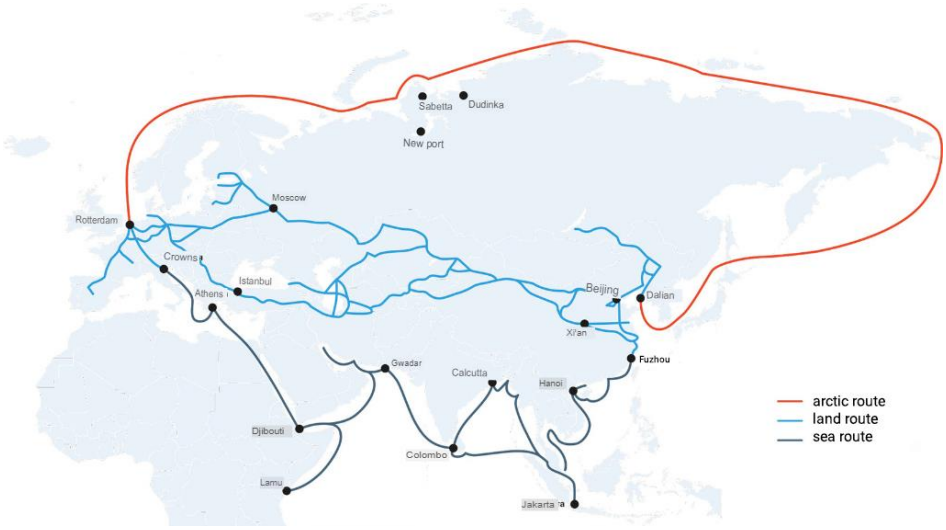

Fig. 3. Map of the Belt and Road routes [12].

Large-scale cooperation in Arctic shipping between Russia and India is also under discussion. The main focus is the development and use of Russia's Northern Sea Route and the proposed adjacent Eastern Maritime Corridor (EMC), which connects the Russian Far East with the Indian port city of Chennai.

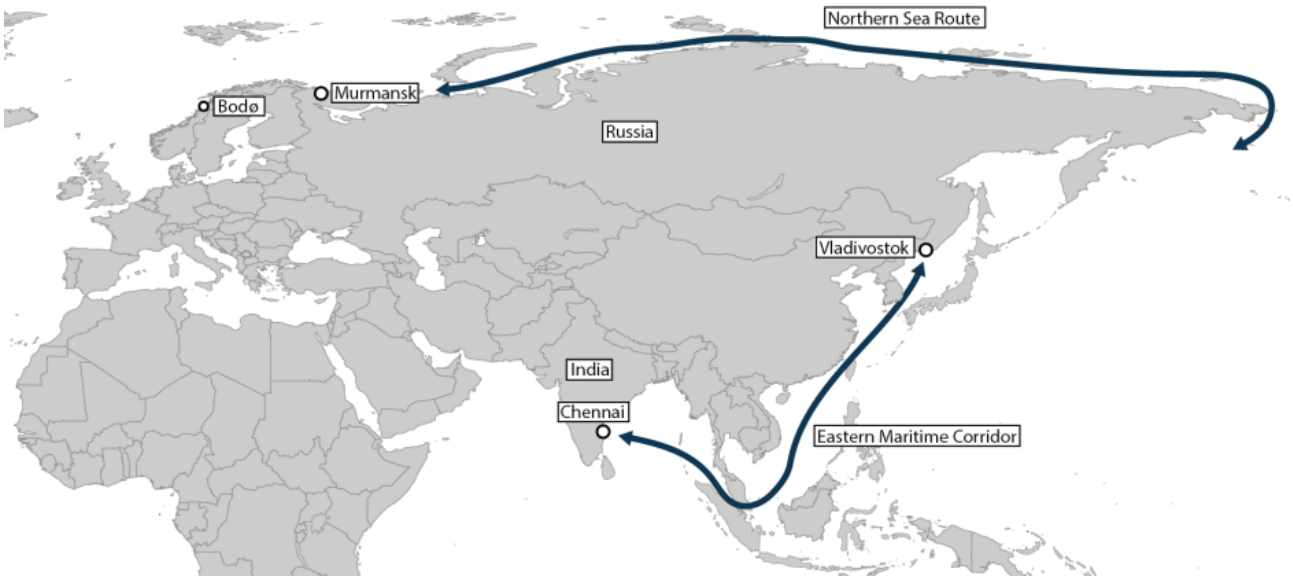

Fig. 4. The Northern Sea Route and the Eastern Maritime Corridor (relative to India) [13].

In 2018, the State Atomic Energy Corporation Rosatom was tasked with developing the NSR infrastructure and ensuring its sustainable operation. These include plans to expand the ice-breaker fleet, improve search and rescue, communications, port infrastructure, construction of

[12] Atomnyy ekspert, «Poyas, put', proekty i problemy» [Atomic expert, "Belt, Road, Projects and Problems"]. URL: https://trends.rbc.ru/trends/social/6308bea09a7947ff4889b9b6 (accessed 15 January 2024).
[13] HIGH NORTH NEWS, "India Looking To Cooperate With Russia on Development of Arctic Northern Sea Route". URL: https://www.highnorthnews.com/en/india-looking-cooperate-russia-development-arctic-northern-sea-route (accessed 15 January 2024).

airports, railway lines and weather forecasting [14]. Russia's Arctic Development Strategy 2035 identifies the route's development as a "competitive national transport corridor on the global market" as a key national interest in the region.

Results

The current state of digital and logistics infrastructure in the Arctic can be characterized as insufficiently developed for the goals and objectives that have been announced for this macroregion. Obviously, the key reasons for this level of infrastructure development can be considered the inaccessibility and extreme climatic conditions of the region, which cause technical difficulties in creating infrastructure facilities, as well as financial and political restrictions. On the other hand, the current development of technologies opens up opportunities for a new breakthrough in the Arctic.

Let us give a brief description of the key elements of the logistics and digital infrastructure of the Arctic zone of the Russian Federation, which were identified by analyzing the sources.

Currently, the main modes of transport in the region are sea and air. Sea routes, such as the Northern Sea Route, are becoming increasingly accessible due to the melting of ice. However, navigation in the Arctic is still limited by time frames and requires specialized vessels, equipment and navigation systems.

Air transport plays an important role due to the lack of developed land infrastructure. Airports in the Arctic are often key points for the delivery of goods and passengers. There is a practice of using unmanned drones for cargo delivery; heavy aircraft designed to carry about 150 kg of cargo have been tested. Despite successful tests, aviation equipment in the Arctic remains an unstable means of communication due to unpredictable weather conditions and the fact that air transport costs are significantly higher than of land transport. The use of wheeled vehicles with automated control systems can significantly reduce the risks for drivers. In addition, the lack of airfields and restricted flight capabilities in harsh climate limit the effectiveness of air logistics in the region.

There have also been several recent proposals to use unmanned aerial vehicles (UAVs) as means of delivering cargo to remote areas, autonomous vessels for ice reconnaissance, and other solutions. Rosatom is testing a maritime aircraft to monitor icebergs and ice cracks, the Arctic Research Center has built a pilot project for an automated vessel for exploration of coastal zones and rivers, and Yakutia is ready to sign a contract with Rostec to create a UAV system within the framework of the Northern Delivery. The issue of creating anti-jamming equipment, which allows controlling devices in difficult weather conditions, has been practically resolved.

The development of logistics infrastructure in the Arctic is also associated with the need to create base stations, ports and warehouses that can provide storage, transshipment and servicing

[14] ORF, "Russia and the Future of the Arctic". URL: https://www.orfonline.org/research/russia-and-the-future-of-the-arctic#_edn54 (accessed 15 January 2024).

of goods. These facilities require investment and technical support to meet the demands of harsh Arctic conditions. There is also some progress in this direction: for example, two trade and logistics centers are under construction in Yakutia as part of a state program.

Land transport routes in the Arctic also have their limitations. The lack of developed road networks and the difficulty of maintaining roads in conditions of severe frosts and ice cover create problems for the delivery of goods by land. The existing experience in the use of unmanned vehicles can be noted. Gazprom Neft uses unmanned trucks that run along the 140-kilometer road between the village of Tazovskiy and the Vostochno-Messoyakhskoe field. KAMAZ vehicles are equipped with an autonomous satellite navigation system and numerous sensors that scan the road within a radius of 200 meters. They are able to recognize both stationary and moving obstacles, make decisions to prevent accidents.

One of the main challenges to digitalization of the region is the lack of physical infrastructure, such as underwater and land cables, satellite communication systems and cell phone towers. Construction and maintenance of such infrastructure in Arctic conditions requires high costs and specialized technical solutions. In addition to the difficulties, extreme climatic conditions and ice cover can damage the infrastructure and complicate its maintenance.

The information on the key elements of the transport and logistics infrastructure of the Arctic zone of the Russian Federation can be summarized in the form of a model in Fig. 5. The model identifies 4 classes of elements that form the logistics and digital infrastructure: subjects (users of infrastructure services), infrastructure functions, communication channels and objects that allow communication infrastructures to implement functions.

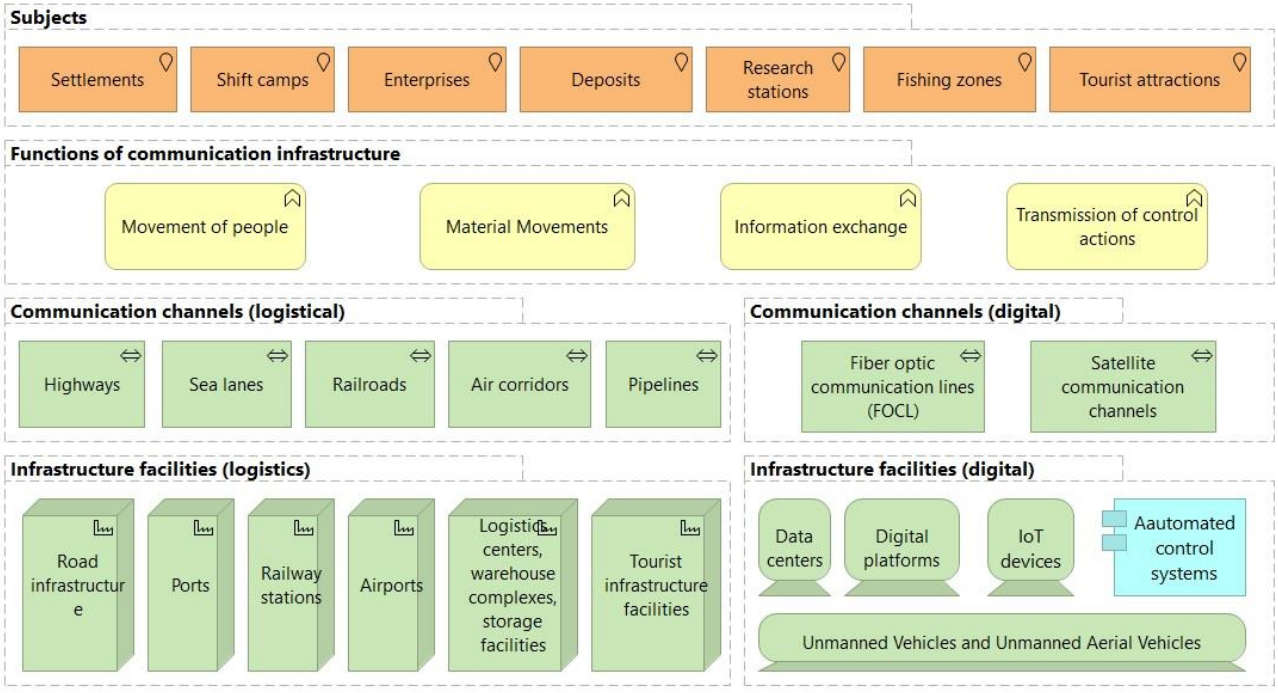

Fig. 5. Elements of the logistics and digital infrastructure of the Arctic zone of the Russian Federation.

The model presented in Figure 5 does not show numerous links between elements in order not to overload the figure: most of these links are obvious. The proposed model can be used to

analyze each communication route of individual entities and to understand the situation regarding the availability and sufficiency of logistics and/or digital channels and infrastructure elements for such communication. The results of such analysis and supplementing the presented model with links can serve as a basis for creating an ontology of the Arctic zone of the Russian Federation.

Thus, the function of moving material assets is important for all the selected entities, and for its implementation it is possible to use specific communication channels provided by the logistics infrastructure, depending on the specific situation under consideration. For example, to move products to shift settlements, it is possible to use the type of transport that is in a particular location. At the same time, in the absence of appropriate logistics infrastructure facilities, the option of delivering lightweight goods using UAVs can be considered — in this case, digital infrastructure will be used. This is an example of how elements of digital infrastructure can replace elements of logistics in a specific situation. On the other hand, the implementation of such a large-scale transport corridor as the NSR would not be fully possible without the proper support of digital services — from effective navigation to monitoring the ice situation.

Such considerations show the importance of the tasks of integrating digital and logistical infrastructures of the Arctic zone of the Russian Federation. In this regard, in addition to the obvious conclusions about the directions of development of the communication infrastructures of the Russian Arctic (they are outlined in Conclusion section), we propose to consider steps towards integrating these subsystems, comprehensively aimed at the development of the macro-region:

- creation of an ontology of the Arctic zone of the Russian Federation;
- creation and development of a knowledge base of the Arctic zone of the Russian Federation;
- determination of requirements to the services of digital and logistic infrastructures by the subjects, as well as mutual requirements of subsystems to each other's services;
- development of a roadmap for the development of communication systems of the Arctic zone of the Russian Federation, containing a list of substantively and chronologically interconnected measures for the systematic fulfilment of the subsystems' service requirements;
- in accordance with the roadmap and the pace of development of the region's physical infrastructure — creation and implementation of digital platforms for individual entities (groups of entities) and digital twins for individual elements in accordance with the requirements defined in the previous step.

Conclusion

Effective development of such a rich but hard-to-reach region as the Arctic is impossible without established communication routes: physical and informational. Moreover, these two subsystems should be developed in parallel and interrelatedly.

Analyses of the current state of the region's communication infrastructures made it possible to identify the following areas for their immediate development:

- development of sea routes;
- construction and modernization of roads, railways and airports;
- creation of logistics centers and warehouse complexes;
- expansion of access to broadband Internet by using satellite communication systems and laying underwater fiber-optic communication lines;
- creation of a data center base;
- development of unmanned vehicles for the needs of people and industry;
- development of remote control systems for objects.

The authors highlight the integration of the region's logistics and digital infrastructures as a separate task, since the two communication subsystems are interconnected, and their interconnected development can bring a synergistic effect in ensuring the connectivity of the region.

The development of energy transmission channels for supplying the subjects of the region remained outside the context of this article. This issue requires a separate study and is closely interconnected with the development of the communication subsystems discussed in the article.

As further research on the topic, the authors plan to develop the points of the infrastructure integration plan outlined in the Results section.

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