Lecture Notes in Networks and Systems 951

Tessaleno Campos Devezas
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Understanding the Digital Transformation of Socio-Economic-Technological Systems

Dedicated to the 120th Anniversary of Economic Education at Peter the Great St. Petersburg Polytechnic University

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Preface

Dear colleagues,

On the occasion of the 120th anniversary of economic education at Peter the Great St. Petersburg Polytechnic University, we are pleased to present the materials of the Institute of Management, Economics and Trade representatives and its colleagues from different points of the world. This book includes the contributions from *Graduate School of Business Engineering, Graduate School of Industrial Economics, Graduate School of Industrial Management, Graduate School of Public Administration, Graduate School of Service and Trade and the Department of Economic Theory.*

The part of the book, performed by the *Graduate School of Business Engineering*, describes the vast range of topics, covered by the school in view of digital transformation of economy. It includes the results of research in effective management systems in healthcare, mathematical modeling and digital transformation of the Arctic region, development of Smart Port solutions, digitalization of engineers' trainings, integration of digital transformation and energy transition, implementation of Integrated Logistics Support methodology and approach to choosing predictive models. The results presented in the chapters were obtained during the implementation of research grants or projects in the real sector, which indicates their relevance and validation.

A valuable contribution to the digital transformation of socio-economic systems was made by the Head of the *Graduate School of Business Engineering*, Prof., Dr. Sc. Igor Ilin. Prof. Ilin has been working at Peter the Great St. Petersburg Polytechnic University for more than 35 years, of which more than 20 years in the field of economic education. Since the beginning of 2000s under his leadership, the research in theoretical foundations and practical approaches to the digital transformation of companies, industries and regions has been performed. In 2008, he founded the educational direction Business Informatics at Peter the Great St. Petersburg Polytechnic University, aimed at training specialists in the integration of business and IT technologies and the development of methodology and applied IT and digital solutions for business. Since then, the educational and research school headed by

Prof. Ilin has taken its rightful place in its niche in Russia. Professor Ilin's team follows technological trends and continuously modernizes educational and research programs in line with market requirements and the opportunities offered by digital technologies. The arsenal of know-how in the field of business informatics includes reference architecture solutions for various industries (healthcare, energy, resource extraction and processing, transportation, maritime logistics, IT consulting), active research with technological market leaders in the field of generative AI for business and data processing and analysis systems.

A part of the book, authored by the *Graduate School of Industrial Economics*, is dedicated to recent topics in the field of digitalization and economics. This segment presents recent research focused on the modeling of socio-economic systems, industrial entrepreneurship, import substitution, intellectual capital and financial risks.

The Graduate School of Industrial Economics offers both classical and interdisciplinary programs. Classical programs encompass enterprise management, energy economics, finance and credit, international economy and accounting. Interdisciplinary programs are developed in collaboration with technical institutes of Peter the Great St. Petersburg Polytechnic University, including master's programs in bioeconomy, energy economics, transportation economics and planning. Additionally, the *Graduate School of Industrial Economics* is actively involved in the creation of programs that utilize econometrics, data analytics and data science methodologies for the analysis and modeling of socio-economic systems.

The development of the scientific school of industrial economics has undergone a dynamic and evolving process, tracing its origins back to the establishment of Peter the Great St. Petersburg Polytechnic University. Under the leadership of Prof. Dr. Dmitrii Rodionov, the *Graduate School of Industrial Economics* continues to adapt to contemporary challenges, with ongoing research addressing issues such as technological disruption, globalization and the role of institutions in shaping industrial dynamics.

The part of the book presented the *Graduate School of Industrial Management* shows the history and legacy since the 1930s to the 1990s and examines the current trends in the development of production management theoretical and practical aspects, taking into account modern conditions of economic and technological development of industries. In the materials of the part, one can trace the continuity of generations of researchers among which famous scientists, teachers, heads of university structures, postgraduate students and students of the Peter the Great St. Petersburg Polytechnic University, as well as representatives of the real sector of the economy.

Since its foundation, the *Graduate School of Industrial Management* has been headed by Professor, Doctor in Economic Sciences Olga Vladimirovna Kalinina. Professor O. V. Kalinina has been working at Peter the Great St. Petersburg Polytechnic University for more than 20 years. Under her leadership, projects related to the sustainable development of smart territories within the framework of logistics, marketing and digital solutions are being implemented, as well as research is being

conducted on the theoretical foundations and practical approaches to the digital transformation of enterprises and industries, human capital management and assessing the higher education organizations personnel potential.

The materials in this chapter of the book, produced by the *Graduate School of Public Administration*, are focused on a single task, namely the search for ways of effective management and public regulation both within the framework of the concept of sustainable development, and in modern conditions of a rapidly changing external and internal environment, in which digital and information technologies are becoming increasingly important. The results of studies of possible options for the development of such areas, objects and processes as the waste processing industry, territorial socio-economic development, educational tourism, regional innovation and industrial clusters, gamification technologies in the educational process, interaction of local authorities with citizens and the concept of "green" management by human resources are presented. The results presented in the chapter were obtained during the implementation of research grants or projects in the real sector, which indicates their relevance and validity.

During research in the recycling industry, the application of the fourfold innovation spiral model, it is concluded that a motivated team with a professional leader, with the support and active participation of the population, contributes to the active implementation of innovations and the development of the waste recycling industry. When assessing the sustainability of socio-economic development of territories, it is concluded that it is important to consider digitalization, in general, and the share of Internet use population, in particular, as one of the main factors in the development of the territories of the new era. During the process of approbation of the DEA methodology as a tool for assessing the potential for the implementation of educational tourism, as a direction for the development of inbound tourism in Russia, a conclusion is made about the prospects of this type of activity and the need for state support for its development, considering regional features. During the process of studying the factors of development of innovative industrial clusters, it was concluded that it is necessary to develop and implement a model of adaptive public administration as a factor in increasing the competitiveness of the region's economy. When studying the role of the internet in the interaction of authorities with citizens and local communities, it is concluded that the effectiveness of such online communication depends on the segmentation of users, understanding of consumer behavior on the internet and the creation of a single information platform for such interaction. And finally, while studying the current state of research in the field of human resource management within the context of the "green" agenda, it is concluded that such research and practices in Russia are only in their infancy, are mainly theoretical in nature and require further deepening and development.

Historically, *the Graduate School of Service and Trade* embodies the traditions of the scientific schools of St. Petersburg Trade and Economic University. The latter

was founded in the first half of the twentieth century and recently became a part of Peter the Great St. Petersburg Polytechnic University. The origins of scientific thought were formed in the departments of trade economics, commodity science and trade management.

The main milestones in the evolution of the scientific and academic school of *the Graduate School of Service and Trade* of Peter the Great St. Petersburg Polytechnic University are listed below. They embrace the academic works and main directions of development listed below.

First of all, it is essential to mention the main works of Professor, Doctor of Economic Sciences Grigory Leonidovich Rubinstein. His writings laid the foundation of trade economics as an industrial science in the USSR. The most famous of his works are the textbook Economics and Planning of Soviet Trade (published in 1939) and the monograph Development of Domestic Trade in the USSR (published in 1964). It is important to note the vital role of such academicians as Prof. Alexander Ivanovich Abaturov, Nina Alekseevna Gagloeva, Vladimir Fedorovich Egorov and Alexander Nikolaevich Solomatin in the development of the school of thought in the field of economics and trade management. Their works and publication form the whole series of textbooks on economics, management and technical processes of a trading enterprise and have been in high demand since the 1970s of the twentieth century. It should be noted that several generations of trade specialists in the USSR and the Russian Federation studied with these textbooks. A huge contribution to the formation and development of the Russian school of commodity science was made by scientists specializing in the field of physicochemical, microbiological and technological properties of consumer goods. The most outstanding among them are Prof. Alexander Ivanovich Grimm, Shota Kirillovich Chogovanze, Matvey Maksimovich Danilov, Alexander Mikhailovich Goldovsky, Evgeny Nikolaevich Lazarev, Vera Valerianovna Shevchenko, Nikolai Ivanovich Egorkin, Mikhail Nikolaevich Ivanov and Fatima Vasilievna Khetagurova.

Professor Irina Vasilyevna Kapustina has been integral to the transformation of the trade and economic academic school into the academic *Graduate School of Service and Trade* at the turn of the 2010–2020s. The emphasis has shifted from theoretical reasoning about the essence, properties and factors of development of the main phenomena in trade to the technological aspect of analytical and forecasting procedures crucial for the management process of a trading organization. This is a characteristic of the modern scientific school. Scientific approaches to the digital transformation of logistics, marketing and services have been actively developing under Prof. Kapustina's tenure. Currently, the modern stage of the evolution of *Graduate School of Service and Trade* is embodied in the formation of a set of scientific approaches to the system integration of digital logistics, service and trade.

The main directions of the scientific school of the *Department of Economic Theory* are related to the development of methods of strategic planning for the development of economic entities at different levels (countries, regions, enterprises), taking into account the peculiarities of regional conditions and factors, as well as historical aspects of the economic development of regions of Russia and the world. In particular, Professor, Doctor of Economics Elena Milskaya, Associate Professor Ekaterina

Afonichkina, Associate Professor Naumova O. N. and Senior lecturer Sergey Antipov developed an ADL model for the development of the Arctic region of the Russian Federation.

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Arctic Sustainable Development: Digital and Logistics Infrastructure in the Region

Alexandra Borremans, Alissa Dubgorn, Anastasia Levina, Nina Trifonova, and Dayana Gugutishvili

Abstract The issues of Arctic exploration and development in the twenty-first century have become an important item on the agenda of many researchers and scientific schools in Russia and other circumpolar countries, as well as China and others. The combination of the distinctive features of the Arctic territories determines the need for special systematic scientific approaches to the issues of exploration and development of this macro-region. The purpose of this research is to identify areas that play a key role in the sustainable development of the region, as well as in the formation of tasks relevant for positive change in the region. Through a systematic literature review conducted by the authors, the design and modelling of an efficient logistics and digital infrastructure has been identified as an important prerequisite for the development of the Arctic zone. Moreover, their interconnected development is an important element of the comprehensive digital transformation of the Arctic. The results of this analysis are the first step in a project to create a conceptual model for sustainable development of the region, as well as to develop methods and models for the formation of logistical and digital infrastructures to support the development of the Arctic. This research can be adapted to address sustainable development challenges in other macro-regions of the world as well.

Keywords Arctic zone · Digital transformation · Transport infrastructure

1 Introduction

The socio-economic development of the Arctic zone has been the subject of much attention from both government agencies and the research community. Recently, Russia has adopted a number of legal and regulatory documents, the main purpose

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of which was to regulate certain aspects of political, industrial, economic and social development of these territories.

The concept of sustainable development implies harmonious development of three spheres: economy, ecology and social sphere. However, existing Arctic development projects are often characterised by a single criterion for decision-making—economic growth at the expense of other components.

The purpose of this research is to analyse scientifically-based approaches to the issues of integrated sustainable development of macro-regions based on the development of its key subsystems. In order to cover this topic, three research questions have been formulated, which will form the basis of this analysis:

- RQ1 What are the constraints to sustainable development in the Arctic?
- RQ2 Which areas of development affect the progress of the region's development?
- RQ3 What are the key challenges to supporting sustainable development in the Arctic zone?

This research is divided into the following parts: method—description of the process of collecting previous work on sustainable development of the Arctic; results—analysis and classification of the articles studied; discussion—interpretation of the results and answers to the research questions, description of future research activities; conclusion—summarizing the results of the research.

2 Method

This research uses a systematic literature review method that collects, synthesises and analyses numerous articles on topics related to the research questions. For these articles, criteria are used to both include research in the list of sources analysed and to exclude them.

Therefore, according to a predetermined review protocol, in which the source search was conducted in several iterations, the following criteria were defined:

- keywords for search: sustainable development of the Arctic, negative factors, development challenges, development of the region;
- books, citations, monographs are excluded from the search, only journal articles are used;
- studies written earlier than 2013 are excluded from the search;
- articles can be written in both Russian and English languages;
- the articles to be analysed are not limited to the Russian Arctic, but this study will focus on it.

The articles were collected using a combination of automatic and manual author search, which provides extensive quantitative and qualitative results of the study. Thus, 54 articles were analysed.

3 Results

Among the studied publications, scientific articles by Russian authors predominate, as the issues of Arctic zone development are of fundamental importance for Russia from the economic, social and political points of view.

Consider the articles that bring us closer to answering RQ1, " What are the constraints to sustainable development in the Arctic?".

One of the most obvious and frequently mentioned factors is climate stress. Such harsh conditions affect various areas of the zone, such as labour potential. Researchers point out the detrimental effect of cold on life in Arctic conditions: difficulty in adaptation, specific diseases, etc. Moreover, the working capacity of the population is negatively affected by the limited spheres of labour application, resource intensity of labour, transport inaccessibility of the region [1].

Moreover, researchers have noted the negative economic consequences of neglecting eco-services that hinder the development of the region. It is important for the region to combine management methods and economic incentives to prevent environmental pollution [2]. The authors also note that the emerging circular economy may also have a critical impact on the environment, citing the accident at TPP-3 in Norilsk in 2020, which caused an environmental catastrophe [3].

International authors examine the global approach to sustainable development of the Arctic as a region and the specific challenges of sustainable development in the Arctic, viewing the region as a source of resources, a "sanctuary" and a "home for indigenous communities" [4].

Furthermore, tourism was recognised as one of the most controversial factors influencing the development of the region. Despite the importance of attracting tourists and investments to the region, Canadian scientists noted the detrimental impact of tourist flows on the ecosystem and the habitat of indigenous peoples. Tourists cause anthropogenic pollution, soil erosion and deformation of vegetation. It is very important to regulate such processes [5].

It is also important to note the theme that runs through a large number of studies—the underdevelopment of logistics infrastructure. The authors point to logistics as a "pillar" of sustainable development, and the term is understood to include both transport logistics (freight and passenger), freight forwarding services, customs, trade, and various services. Moreover, the authors note the weakness and complexity of the organisation of information flows that provide and support logistics information systems [6].

The importance of developing the resource base and realising transport potential is also discussed in another article. The authors note the lack of development of research related to the provision of transport and logistics, energy and information and communication infrastructure [7]. There are also infrastructural constraints on the growth of hydrocarbon production on the Arctic shelf [8]. Other authors also consider the lack of engineering and logistics infrastructure as a significant factor and a threat to the sustainable development of the region, noting the need for a long phase of initiation to develop the potential of the Russian and global Arctic [9].

Spatial factors constraining the sustainable development of the economy are also noted in another study. Among the threats, the authors highlight the remoteness and transport inaccessibility of the region, as well as the low level of development, connectivity and reliability of the transport system [10].

Besides, one of the factors that currently constrains the strengthening of the region is the low level of information and technological development. The researchers analysed and assessed the potential of technology supply in the region to determine the region's position in relation to inter-regional or international competition, and were able to note a deficit in the ratio of supply and demand for new technologies [11]. The low level of technological and innovative development is also noted by other authors, nevertheless highlighting the emerging objects of innovation infrastructure such as innovation and technology centres and innovation-industrial complexes, as well as technoparks and science cities [12]. The authors also note the importance of work on communication and information technologies, as they have long been out of focus. The implementation of pilot IT projects gives a strong impetus to the development of the region, but the long period of reduced funding for "northern projects" is still a significant obstacle [13]. Investments in the region's digital environment are a highly relevant issue, as the remoteness of the region imposes limitations on the speed of management and data processing. The implementation of information technology and the realisation of information channels in the Arctic is a complex and really expensive portfolio of projects [14].

As the next phase of the research, we will turn to the sources where the theses that are important for analysing the answers to RQ2 "Which areas of development affect the progress of the region's development?" are displayed.

One of the most frequent theses of existing studies is logistics and digitalisation of the Arctic region.

The Arctic zone of the Russian Federation represents a unique set of opportunities for logistics projects. As global climate change leads to the melting of polar ice, the region is becoming increasingly accessible, opening up new shipping routes and resource exploration [15]. However, harsh weather conditions, vast distances and lack of infra-structure create serious logistical obstacles.

International authors consider the prospects for logistics development in the region, taking into account the existing risks and trends of the Industry 4.0 concept [16], for example, noting the importance of the concept of digitalisation of emergency response logistics[17], the potential of IoT technologies to ensure security and reliability of supply [18], digital technologies and biotechnologies for the transport of raw materials and energy [19], and the importance of forecasting systems for Arctic marine logistics to analyse the risk of heat loss from ship icing [20]. The researchers also analyse conceptual theories and ideologies of sustainable development in the Arctic in the era of the 4th industrial revolution. The Arctic region is currently facing pan-European as well as regional and global challenges. At the same time, the Arctic is currently one of the high-tech stakeholders. Using the Arctic region as an example, it is possible to examine the preconditions for a change in the value development of countries [21].

A large number of authors devote their research to the development of transport and logistics infrastructure in the Arctic zone of Russia. Researchers consider the issues of improving the optimisation of supply processes in the Arctic territories using a high-tech approach, which includes the concept of "green" logistics [22]. In particular, the possibility of organising logistic support of the region's facilities using economic-mathematical and transport modelling, as well as the development and application of digital terrain and surface models for detailed logistic planning is investigated [16]. Moreover, it is noted that it is important to formulate transport requirements for offshore mining for the development of the region's potential [23], as well as recalculation of the cost of modernisation of the Northern Sea Route (NSR) transport infrastructure taking into account various unfavourable factors [24].

The works of various authors consider the conditions for coordinated development of transport, energy, information and telecommunication infrastructure of the Arctic region on the basis of transport and logistics corridors on the basis of the NSR (Fig. 1). The authors note the importance of international co-operation [25], application of mathematical models to analyse transport routes [26], and the apparatus of the theory of large-scale transport systems [27] in this issue.

Moreover, the authors' research examines the implementation of the global Sustainable Development Goals, opportunities to monitor progress, and emphasises the need for additional attention to demography, including migration; indigenous peoples' rights; Arctic-related economic development measures; and social capital and institutions that can support adaptation and transformation in this rapidly changing region [28].

The authors also note the need for interdisciplinary research into what sustainable development of the Arctic and the Far East might look like as global environmental changes and economic priorities of countries accelerate and globalised societies

Fig. 1 The map of the Northern Sea Route

emerge. The authors propose a system of indicators for balanced regional development that takes into account the environmental, economic and social needs of sparsely populated areas [29].

Furthermore, some authors note that when analysing the prospects for Arctic development, it is necessary to take into account many factors—not only economic, but also ethnic, geopolitical, the factor of "deferred benefits" (due to the planned exploitation of the NSR, etc.). (in connection with the planned exploitation of the NSR), etc. The need for restructuring and restructuring of the Arctic is essential. It is necessary to restructure the regional economy within the framework of significant centres, which implies the emergence of new branches of specialisation within the existing resource base, the development of high-tech production, the expansion of services (including tourism), transport, informatics, communications, etc. [30].

It should be noted, that the Arctic is of interest from the point of view of strategic economic development. The authors examine issues from the perspective of the concept of sustainable development and scientific and technological progress, aimed at clarifying management decisions in the field of internalising external factors of economic development of the Russian Arctic zone [31].

It is also worth highlighting a separate set of existing studies that have mapped the challenges and projects that are the basis for the region's prosperity. These articles reflect the theses applicable to RQ3 "What are the key challenges to supporting sustainable development in the Arctic zone?".

One of the most frequently mentioned tasks is the improvement of freight transport. A number of fundamental works by both Russian and foreign scientists are devoted to the issues of improving their quality and efficiency, transport and logistics systems as a combination of transport infrastructure and transport. For example, the authors note the importance of ensuring environmental safety of road transport [32], creation a digital twin of the car [33], application of multi-criteria evaluation method of complex characteristic of vehicle safety [34], optimal use of technical monitoring tools in the operation of the driver-vehicle-road system [35], optimal management of the transport system and logistics services for companies in the Arctic zone [36]. Selected cases of harmonisation of stakeholder interests in the region, including environmental protection [37], attention to climate factors, use of innovative approaches to maintain environmental safety of the region [38] and support for international law [39] are described. It also highlights the possibility of building new transport routes and a logistics system in the Arctic [40] and their potential cost-effectiveness by reducing transcontinental transport distances [41].

Another equally significant area was various IT projects and initiatives.

The application of key digital technologies in this area is very important. Using innovative approaches and various digital technologies in transport and technological processes, it is possible to minimise the risks inherent in the Arctic region and move closer to ensuring sustainable development of the Arctic zone. The research group of SPbPU and TUHH 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 to improve the efficiency of interaction between participants in the maritime logistics sector [42]. Other authors present a review of

the project for the development of an innovative digital platform aimed at creating a unified multimodal transport and logistics environment in the Russian Federation [43]. The issue of using 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 robotics systems performing technological operations in the Arctic [44], and in the context of supply chain management of oil and gas companies in the Arctic [45].

Considering the cases of digital transformation of the region, it is also worth highlighting a number of important logistics projects.

The Russian government has authorised subsidies for the development and implementation of the NSR digital ecosystem [46]. This ecosystem consists of a unified platform of digital services, onboard automated information and measurement systems, operational ice monitoring systems and an information database on the NSR water area. The goal of the development is to create an "Ice navigator" for safe routing and improved meteorological and navigational assessments. The created data will be available to registered users on the SMP Unified Digital Services Platform. This initiative is part of the federal project "Development of the Northern Sea Route" and was initiated by Rosatom. It was a response to the Pevek crisis of November 2022 and is aimed at ensuring reliable navigation along the NSR.

For example, Sitronics Group, a division of Sistema Group, is actively developing a set of solutions aimed at the digital transformation of the Russian Arctic. These solutions are primarily focused on information and logistics services that contribute to the development of the region [47].

Addressing the challenges associated with the NSR is crucial for the security and sustainability of the Arctic territories. An important aspect of transport and logistics systems is the provision of reliable, real-time satellite data. In response, the company is developing services for monitoring ship traffic (using an automatic vessel identification (AVI) system) and civil aviation (using ADS-B (Fig. 2)). Sitronics Group is actively testing AVI data, has developed a visualisation platform and provides access to IT systems, including via APIs, for its customers. The digitalisation of transport involves the use of ship traffic management systems, ensuring safe separation, monitoring and control. Sitronics Group develops critical infrastructure for technological sovereignty by offering a platform for multimodal logistics and Arctic solutions. Their system manages cargo traffic, routes, logistics processes, cargo status and weather risks, and includes information sharing services and monitoring of hydrometeorological and ice conditions. They also note the importance of establishing a common vision of the future target architecture of the NSR for its comprehensive assessment [48].

It is obvious that without long-distance railway approaches the development of Arctic ports has low prospects. The Belkomur project envisages the construction of missing sections (Karpogory-Vendinga) of the railway along the Arkhangelsk-Perm route to connect the Arkhangelsk seaport with Syktyvkar, Kudymkar and Solikamsk. This will ensure access of the products of these regions to foreign markets. In this regard, the implementation of such projects as the construction of the Sosno-Gorsk-Indiga ("Barentskomur") and Vorkuta-Ust-Kara lines, as well as the North–South

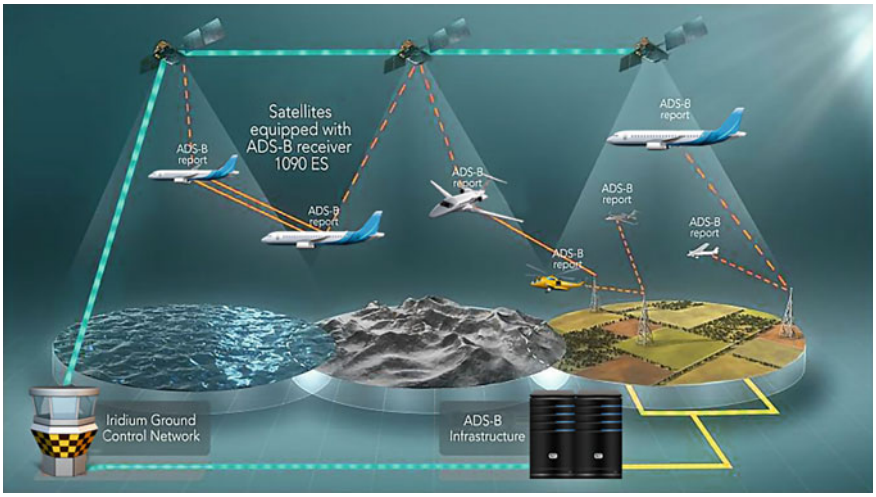

Fig. 2 Case of ADS-B organization

corridor, designed to connect the Persian Gulf states, India, Pakistan via the Caspian Sea with the countries of Eastern and Central Europe and Scandinavia, is becoming more relevant [49].

The Northern Latitudinal Railway project aims to connect remote northern communities with vital transport infrastructure. Covering vast northern regions, the railway will promote economic development and improve access to vital resources. The initiative aims to overcome logistical challenges caused by the harsh climate and geographical barriers. By linking isolated areas, the railway will facilitate trade, strengthen regional ties and improve overall accessibility. The success of the project is important for promoting economic growth, sustainability and improving the quality of life in the northern latitudes [50].

One of the most notable international projects aimed at improving transport communications in the Arctic is the European Union's Northern Dimension project, which covers the countries of Northern Europe, the Baltic States and Russia. "The Northern Dimension, initiated in 1997, was originally an EU policy on cross-border co-operation. In 2006, it was expanded to include Russia, making it a joint policy involving the EU, Russia, Norway and Iceland. EU Member States also participate individually, along with Belarus, the USA and Canada as observers. The policy aims to promote long-term mutually beneficial co-operation in the region. The 2006 Summit resulted in a Political Declaration and Framework Document, which will enter into force on 1 January 2007 [51].

The project "Logistics Development in the Barents Transport Corridor" is an example of international logistics and trans-port co-operation aimed at improving transport and regional logistics in the Murmansk region. These efforts continued with the Barents Logistics 2 project, which aims to increase professional competence

in logistics, develop logistics expertise and expand the supply chain in the Barents region [52].

The potential for effective strategies needed to respond and adapt to a range of environmental, social, economic and political stressors is also explored [53]. In addition, a set of interrelated measures for the sustainable development of the Arctic territories of the Russian Federation is considered for the main spheres of human activity in the Russian Arctic: environmental, production, innovation, social and economic [54].

4 Discussion

In summarising the preceding systematising analysis of the literature, it is worth revisiting the research questions.

In terms of the factors constraining the sustainable development of the Arctic (RQ1) and complicating the development of the region, the following can be identified based on the analysis conducted:

- difficult climatic conditions;
- lagging values of indicators characterising the quality of life in the Arctic zone;
- legal aspects;
- energy constraints;
- transport, logistical and technological constraints.

Nonetheless, research has shown that digital and logistics infrastructure is currently one of the region's growth points (RQ2). The development of communication systems is one of the key areas that provide a fundamental opportunity for the development of any region, especially a region such as the Arctic. Communication means both the ability to move people and material values and the transfer of information. In this regard, the design and modelling of an efficient logistics and digital infrastructure is an important prerequisite for the development of the Arctic zone.

However, it is worth noting that this study is important to emphasise the value of the continuous and interrelated development of these two key subsystems that ensure the communication of the Arctic region's elements—logistics and digital infrastructure. In fact, they play the role of the region's circulatory and nervous systems: the first provides the ability to move material resources, while the second ensures the transmission and processing of data and information. It is impossible to ensure sustainable development of the Arctic zone without a well-established transport system in the region. 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 the development of the Arctic.

In highlighting the region's priorities (RQ3), the researchers again emphasise the need to develop IT and logistics solutions for the Arctic zone. Modern information

and digital technologies provide unique, previously unavailable opportunities for data collection, processing, analysis, transmission and, most importantly, data-based management of socio-economic systems. This will allow mankind to make significant progress in the development of such a complex region as the Arctic. Sustainable development of the Arctic zone is impossible without a well-established transport system in the region, which is currently based on the NSR. To ensure the livelihood of the Arctic regions, it is necessary to develop shipping, road and railway networks, to increase cargo transit, to ensure the development of mineral deposits, to ensure the possibility of delivery and rapid movement of labour resources. Information and communication and digital technologies allow to provide effective and operative data transmission and processing, as well as to carry out control (up to real time mode) on the basis of data (including remotely). These properties of the designated communication systems in combination with the developed logistic processes make them indispensable elements of the integrated system of Arctic exploration and development.

Discussion on the topic of this article, of course, it is worth noting the extensiveness of the analysis. Nevertheless, it is worth outlining directions for further research, the topics of which were not disclosed in this material. For example, the above research can be a basis for a certain methodological framework in the form of a set of principles, algorithms, methods and models describing the communication subsystems of the region (logistics and digital infrastructure) with regard to the requirements of its sustainable development.

5 Conclusion

At the moment, the digital transformation of the Arctic is one of the main areas affecting progress in the development of the region. In turn, the digital transformation of the Arctic region is driven by technological advances and the growing need for sustainable development in the face of climate change. This transformation encompasses various aspects, including logistics processes. The creation of an extensive transit-port system and infrastructure is a high priority task, the solution of which will allow not only to overcome obstacles to the use of transit potential and increase transport accessibility of populated regions, but also to significantly mitigate infrastructural constraints on the expansion of mineral extraction in the Arctic region of Russia. Transport and logistics services could become the main export commodity in the Russian Arctic after oil and gas. With a strong strategy to participate in international Arctic projects, Russia, as a Eurasian maritime transport power, can generate significant revenues and reduce the risks associated with oil price fluctuations. Full utilisation of digital technologies and transport potential has a strong ripple effect, requiring government support, international cooperation and full consolidation of resources.

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Methodology for Modeling the Impact of Multimodal Transportation on the Development of the Arctic Region of Russia

Nikolay Didenko and Djamilia Skripnuk

Abstract This article outlines the methodology of modeling the impact of multimodal transportation on the development of the Arctic region of Russia on the example of the Murmansk region. The Murmansk Oblast is the northernmost region of the European part of Russia, mainly located above the Arctic Circle. The region borders the Republic of Karelia in the south and Finland and Norway in the west. For modeling, a model of single regression equations was formed. The model includes five mutually dependent equations. Endogenous variables of the model are indicators of the processes of development of the Arctic region of Russia. The predetermined variables of the model reflect the impact of multimodal transportation in the Murmansk region. There are eight such variables in total: the volume of industrial output, the share of the region's industrial output in the all-Russian volume of industrial output, the length of public railroads and others. To analyze and find the parameters of the model, we used the methodology developed in the System Dynamics Laboratory of the University. The approach to model development based on the use of endogenous and exogenous variables can provide an opportunity to analyze and consider the consequences of changes in feedbacks in the systems of which they are a part. According to the obtained results from an analysis of the constructed model, the approach to modeling of multimodal logistic systems for remote fields and objects of the Arctic territories of Russia, and taking into account their service, an expected development of transport infrastructure on the basis of graph theory tools is proposed. To solve such a problem, it is possible to apply the method of searching for the minimum graph frame.

Keywords Arctic Region · Multimodal transportation · Simultaneous regression equation model · Development

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