Journal of
Marine Science and Engineering

MDPI

Article

Arctic Development in Connection with the Northern Sea Route: A Review of Ecological Risks and Ways to Avoid Them

Irina Makarova [1,*], Dmitry Makarov [2], Polina Buyvol [1], Aleksandr Barinov [3], Larysa Gubacheva [4], Eduard Mukhametdinov [1] and Vadim Mavrin [1]

[1] Naberezhnye Chelny Institute, Kazan Federal University, Syuyumbike Prosp. 10a, 423822 Naberezhnye Chelny, Russia
[2] Institute of North Industrial Ecology Problems Kola Science, Centre of the Russian Academy of Sciences, md. Akademgorodok, d. 14A, 184209 Apatity, Russia
[3] Department of Energy and Transport, Murmansk State Technical University, Str. Sportivnaya, 13, 183010 Murmansk, Russia
[4] Institute of Civil Protection, Vladimir Dahl Lugansk National University, Molodezhnyj Quar., 20-A, 91000 Lugansk, Ukraine
* Correspondence: kamivm@mail.ru

Abstract: The unprecedented melting of Arctic ice provides new opportunities for shipping by decreasing the distance for commercial traffic between Asia and Europe by up to 40%. However, its development is associated with inevitable problems caused by the vulnerability of polar ecosystems. As research methods, we have chosen system and comparative analyses of open sources; national development strategies of the Russian Federation (primarily), China, Northern Europe, and the USA (partially); and scientific articles from the Scopus and Elibrary databases. As a result, we have identified the reasons for possible risk situations for the Arctic region's sustainable development: mining on the shelf, oil and oil product spills during the transportation of goods and fishing activities, etc. Black carbon (soot) emitted from using marine diesel fuel is the main atmospheric air pollutant. In addition, actively developing infrastructure (ports and new industrial zones) also has a negative anthropogenic impact on the environment. Within the framework of an ecosystem approach, we studied ways to prevent risky situations when planning logistics routes using the Northern Sea Route. We concluded about the need to expand the icebreaker fleet. We proposed a conceptual model of the risk management system based on the monitoring of the key indicators' system. We identified possible types of risks according to the place of their occurrence and according to the stages of the life cycle of such systems. Furthermore, we provided the steps of the risk management system and an example of the application of a "bow-tie" diagram—a qualitative method for assessing the risk of "collision".

Keywords: Northern Sea Route; risk management system; environmental problems

Citation: Makarova, I.; Makarov, D.; Buyvol, P.; Barinov, A.; Gubacheva, L.; Mukhametdinov, E.; Mavrin, V. Arctic Development in Connection with the Northern Sea Route: A Review of Ecological Risks and Ways to Avoid Them. *J. Mar. Sci. Eng.* **2022**, *10*, 1415. https://doi.org/10.3390/jmse10101415

Academic Editor: Tarannom Parhizkar

Received: 19 August 2022
Accepted: 28 September 2022
Published: 3 October 2022

1. Introduction

In recent decades, the role of maritime transport as part of the international transport system has changed. The extent of the Arctic ice melt has reached an unprecedented level. By 2008, the ice cover had shrunk to such an extent that non-icebreaking ships were able to navigate through the Arctic Ocean [1]. This opened up significant prospects in terms of reducing the time of transportation of goods between Asia and Europe by up to 40% [2]. The recent shipping traffic jam (March 2021) that blocked the passage through the Suez Canal made people think about the limited possibilities of traditional sea routes from Europe to Asia, opening up broad prospects for the development of the Northern Sea Route (NSR). In the seaports and terminals of the Barents and White Seas, as well as in the Far East, cargo flows and icebreaker services are formed, and comprehensive services are provided for ships [3]. Many Asian countries, especially China and South Korea, as senders and

European countries as recipients are interested in the NSR; however, restrictions should be taken into account, as well as those issues that need to be resolved for the successful development of northern sea ways.

The NSR development is associated with inevitable problems caused by the vulnerability of polar ecosystems. Marine basins and coastal areas are subject to ecological impact: due to mining on the shelf, oil and oil product spills during the transportation of goods and fishing activities, etc. Among the atmospheric air pollutants, black carbon (soot), which is emitted when using marine diesel fuel, has a particularly strong negative impact [4,5]. For the Arctic territories, this impact is associated not only with an increase in population diseases but also with snow and ice pollution, which negatively affects ecosystems. In addition, actively developing infrastructure (ports and new industrial zones) also has a negative anthropogenic impact on the environment. Air pollution provokes immediate health and economic risks due to the direct impact on climate change on a global scale.

In order to reduce the possible damage, it is necessary to identify the reasons causing the risk situations, as well as possible ways to prevent their occurrence and minimize the likely consequences. The relevance of the Arctic-based integrated development on the ecosystem approach is obvious. However, despite the obviousness of such decisions, there are many difficulties caused by both the unique natural and climatic conditions and peculiarities of the Arctic region's territorial development, including industrial, transport and logistics, socioeconomic, and other complexes. Risk management in this case will make it possible to predict problem situations and find solutions in the project stage.

Therefore, the main goal of the article was to study the environmental aspects of the concept of the Arctic zone development, taking into account the prospects for the NSR. To achieve it, we have identified two research questions:

1. What are the reasons for possible risk situations for the sustainable development of the Arctic region?
2. What are the ways to influence risk situations for preventing them when planning logistics routes using the NSR?

The result of the study was a developed concept for assessing potential risks that may arise during the implementation of regional development strategies, especially those that are environmentally vulnerable. The research goals and questions determined the article structure. Thus, the second section describes the research methods and design. The third section provides an overview of the articles currently available in scientometric databases, according to the identified factors and vulnerabilities that represent the most likely hazards and are associated with the greatest consequences caused by an increase in the transport and logistics load on the NSR. The fourth section is devoted to the development of the concept of a system for accounting and managing environmental risks in the development of navigation along the NSR and the territorial development caused by this circumstance. The fifth section includes generalized results and directions for future research.

2. Methods and Methodology

The issue of environmental sustainability is a priority for different regions of the globe, especially those where major strategic projects are being implemented. Since such projects are associated with the development of industrial production and urbanization of territories, a significant number of risks inevitably arose. They can lead to serious environmental consequences including manmade disasters. Numerous studies have been devoted to these issues. We have chosen the Arctic region for research because, in connection with global warming, opportunities for the development of territories are opening up, a significant part of which was previously sparsely populated. This comes with environmental risks.

At the same time, it is important to determine how different situations can be managed in order to reduce the impact of risks and create the most favorable conditions for both the individual and environment. The more complex the system we are analyzing, the greater the number of risks that can arise in it, and the risky situation can be caused both by the sequential action of various factors and their combination and simultaneous impact. In order to manage risks, it is necessary to understand which of them are most likely and can have the most significant consequences. For these purposes, classification methods are used. Classification is one of the important risk management tools. This is primarily due to the variety of risks, their causes, and manifestations. Based on the types of risks, there is a need for a scientifically based classification that will allow systematizing risks and identifying specific areas for their minimization and optimization. At the moment, there are different opinions on the issue of risk classification, and, therefore, a generally accepted and, at the same time, exhaustive risk classification has not yet been developed [6–10]. This is primarily due to the fact that, in practice, there are a very large number of different manifestations of risk, and the same risk can be called by different terms, as well as the fact that it is often very difficult to distinguish between individual types of risk.

There is an urgent need to create a risk classification as a multitasking tool that specifies the object of management and helps to identify not only the places where risks affect activities but also the ways for the most effective risk management, as well as determining the areas of responsibility of those involved in managing them and having mechanisms for adapting to the peculiarities of the activity of various organizations. Multitasking risk classification should be based on the already existing classification of risks by types, and in the second step, it is necessary to separate the risks within each type according to the source of occurrence.

Cargo shipping has a specifically tendency toward an increase in the size and carrying capacity of container ships. Thus, the largest container ship in the world—the CMA CGM Antoine de Saint Exupéry, with a 21,000 twenty-foot equivalent unit (TEU) capacity, 400 m long and 59 m wide—was put into operation in 2018 [11]. Along with this, there are innovative solutions for shipping and navigation systems that will bring the process of cargo shipping to a new level. Therefore, the world's first autonomous cargo ship—a small-sized electric container ship designed to transport 100–150 containers—is planned to be launched this year. It will transport fertilizers along the 37-mile route off the Norway southern coast from the Yara International production site in Porsgrunn to the Larvik port [12].

Such changes will inevitably affect the infrastructure (sea ports, terminals, dry ports, etc.). For this reason, in the first stage, we identified the main strategic directions, the development of which should be carried out in parallel to ensure the required efficiency, sustainability, and safety of the transport system. We analyzed the features of various regions of the Arctic zone, whereas information for the analysis was taken from open sources; national development strategies of the Russian Federation (primarily), China, Northern Europe, and the USA (partially); and scientific articles (from science databases Scopus and Elibrary). To analyze the existing literature in the area under consideration, we did not strive to follow the principles of PRISMA for sure since, in our case, it is not entirely suitable. This method is formalized and, at the same time, the current research on the Arctic is unique. This is not an area in which researchers in many countries are engaged. Thus, the southern countries are not interested in studying this issue. Therefore, the specifics of the Arctic cause a small number of researchers with unique single studies. In the first stage, we searched for the keywords "Arctic" and "northern sea route". Furthermore, in the second stage, a meaningful analysis was carried out by abstracts and keywords. During a more detailed analysis of the full texts of the article, we classified them according to the object of the study. It was found that, at this stage, it is necessary to highlight the main directions for the territories' development and the ecosystems' vulnerability, which will be affected by each specific change. Since our research is related to the development of the NSR, the main attention was paid to the impact of the growth of maritime traffic, providing port infrastructure and other factors that are associated with the solution of these problems. Accordingly, part 3 describes the reasons for the emergence of critical situations in the Arctic ecosystems due to human activities, the negative consequences of the transport complex development (shipping and port complexes) with the expansion of navigation along the NSR, as well as the main scientific research directions on this topic.

In the second stage, the risks that are inherent in these areas of development, reasons for their occurrence, and ways of solving them should be identified. The main tasks of this stage were the choice of an adequate method of risk classification, as well as a description of the classification procedure. Since there are many methods for classifying risks, but no single classification algorithm, we were guided by the purpose of the study—to assess the impact of the maritime transport system on the ecosystem of the Arctic zone. Accordingly, the recommendation for compiling classifiers of this kind is to highlight the environmental risks that are associated with any human activity due to the development of the maritime transport system and the implementation of infrastructure projects.

A variety of risk assessment and management techniques can be used for qualitative and quantitative analysis. For this purpose, we have chosen the tree method and bow-tie charting for critical events.

The next stage is to assess the possibility of using the existing NSR potential and the main strategic directions for its expansion. For these purposes, a system of performance indicators should be developed. When developing key performance indicators (KPIs), resources, threats, and vulnerabilities of each stage of the strategic projects' implementation should be taken into account, whereas, for each of them, a risk management map should be drawn up, which provides for measures to reduce the likelihood of their occurrence or reduce the severity of the consequences (if it is impossible to prevent the risk).

3. Research Directions into the Risks of Arctic Development, Taking into Account NSR Prospects

Numerous studies have been devoted to the prospects and risks of the Arctic development. This part outlines the main trends and problems in the development of the Arctic zone and its transport framework, taking into account the NSR prospects.

3.1. Sustainability of Arctic Ecosystems in Industrial Facilities Development

Climate change is irreversibly changing the ecosystems of the Arctic. The creation of the Russian Arctic specially protected natural areas preserves vulnerable arctic and tundra landscapes under the conditions of various anthropogenic activities [13]. It is important to monitor the Arctic landscape transformation, which, in the conditions of existing and created Russian Arctic protected natural areas, contributes to the solution of environmental problems, as well as the preservation of not only the natural but also historical and cultural heritage of Russia.

This is important in view of the development of ecotourism in the Arctic. Therefore, Chekmareva, A.C. et al. [14] considered the anthropogenic influence on the animal world in the high-latitude Arctic. The correlation of the damage values in the original ecosystems with the model values makes it possible to determine the level of negative changes in the system, level of its degradation, and level of additional allowable load at which the system does not lose the ability to recover. Territories for tourists to visit should be equipped with information on the stability of vegetation components and hazardous geological processes.

Sevastyanov, D.V. et al. [15] discussed the problems and opportunities for the development of tourism in the Arctic. The authors drew conclusions about the need to develop the transport infrastructure of the Northern Sea Route (NSR) and the operation resumption of the Dudinka, Pevek, Tiksi, Dikson, and Provideniya ports. In particular, as a result of modeling the constructed Bayesian network, Qiao, W. et al. came to the conclusion about the importance of emergency response factors, icebreaking capabilities, emergency rescue, and treatment facilities that affect the stability of the NSR [16].

The increased costs of production and life support, uncertainty of the economic situation, and need to minimize the anthropogenic impact on the vulnerable Arctic environment create problems for managing the ecological and economic system of the Arctic regions of Russia. Tsukerman, V.A. et al. [17] developed proposals for improving the ecological and economic management system of the Arctic regions of Russia: the need to improve methods for assessing the state of the environment; increase the efficiency of managing the ecological and economic system of regions; improve the regulatory framework; and ensure economic sustainability in the financing of environmental protection measures.

At the same time, it is necessary to remember the possibility of involving partner countries in the implementation of environmental projects in the Arctic because they are also interested in the development of the NSR. Therefore, Batova, T. et al. [18] analyzed the interests of China and the areas of cooperation with the countries of Europe, the USA, and Canada in the Arctic region. It was noted that, in the implementation of international projects, it is necessary to solve the problems of sustainable use of the natural resources of the Arctic region. China has significant interest in the development of polar scientific research, creation of a transport and logistics system, and development of hydrocarbon energy and mineral resources. Passing through the northern coast of Siberia is of great interest to China as it seeks to export goods to Europe and beyond using faster and less expensive routes.

In addition to the NSR, the development of the Arctic is facilitated by the presence of huge reserves of minerals, primarily gas and oil. Katansky, A. A. et al. [19] analyzed the industrial safety of coastal territories and water areas of the Kola Bay of the Barents Sea when modeling an oil or oil product spill. In [20], Pavlov, V. et al. simulated surface oil spills in the southeastern part of the Barents Sea. According to the authors, the use of the developed models will reduce the risk of manmade accidents with environmental pollution associated with an oil spill. The models make it possible to calculate the number of victims in case of an accident at a pumping station or in case of an oil or oil-product spill into the waters of the Kola Bay.

In general, the implementation of oil and gas projects in the Arctic is associated with high risks for the sustainable development of its ecosystems [21].

Alekseeva, M.N. et al. [22] showed that when solving the environmental problems of the Arctic waters, satellite imagery monitoring can help since they can be used to conduct an operational analysis of the state of oil-producing territories and timely identify and assess environmental risks in the unique ecosystems of the northern territories that are easily destroyed. The proposed methodology, using remote and ground data, makes it possible to identify areas of environmental risk of oil pollution and develop plans for preventive and remediation measures.

Modern information and communication technologies should also be maximally involved in ensuring the environmental safety of technogenic objects of the Arctic infrastructure. Yakovlev, S. et al. [23] developed a technology for assembling poorly structured problem-oriented data for safety management in the Arctic regions, as well as an information-analytical system for supporting emergency protection planning on the territory of such hazardous objects. The authors have tested the system in solving applied problems of reducing the environmental load on the Northern Sea Route and developing design documentation for a number of potentially hazardous facilities in the Murmansk region.

One cannot but agree with Varotsos, C.A. et al. [24], who considered the pollution of the Arctic Ocean one of the most important problems of this region. To assess the anthropogenic load during the development of the region, they recommended using big data methods and technologies, namely the geoecological information modeling system (GIMS). Conducted computer runs showed that heavy metals, petroleum hydrocarbons, and radionuclides are considered the main pollutants, and to predict the state of the Arctic ecosystem, indicators of biocomplexity and survivability were considered as informational values.

That is why a systematic approach is needed in the development of the Arctic.

3.2. Emissions from Marine Diesel and Potential Measures to Reduce the Harmful Effects of Maritime Transport

Emissions from marine diesel engines are one of the main pollutants of the Arctic territories. Fine particulate matter (FPM) in diesel and gasoline engine exhaust is associated with an increase in various diseases [4,25]. Wu, D. et al. [26] showed that FPMs are potentially hazardous and highlighted the importance of assessing the health risks posed by FPMs in exhaust gases. To a large extent, this problem will grow as part of the expansion of shipping in the Arctic because, as mentioned above, the combustion of liquid fuel in marine engines results in emissions of light-absorbing particulate matter (PM). As Corbin, J.C. et al. [27] have established, when heavy liquid fuel (HLF) PM is burned, the main particle of light-absorbing carbon (LAC) is the brC resin, which has key defining properties similar to those of black carbon (BC): it is insoluble, refractory, and significantly absorbs visible and near-infrared light, which causes darkening snow in the Arctic. This negative effect may intensify in the coming decades as Arctic shipping intensifies.

Corbin, J. C. et al. [28] characterized the chemical composition and optical properties of PM emitted by a marine diesel engine powered by HFO, marine gas oil (MGO), and diesel fuel (DF). The emission factors were found to slightly vary with the engine load. According to the authors, emissions and light-absorbing properties of organic light-absorbing particulate matter (OM) may vary depending on the engine performance, condition, and fuel type. For this reason, modeling studies are needed to assess the overall climatic effects of the ability of brC in exhaust gases to influence light absorption, especially in high albedo environments such as the Arctic.

Jiang, Y. et al. [29] examined the influence of the measurement method, type of fuel, and engine load on black carbon emissions from marine engines. Differences in black carbon emissions by load and type of fuel suggest that these parameters should be considered when developing test protocols for measuring black carbon emissions on ships. It also suggests that marine black carbon emission models should include a wider range of black carbon emission factors to account for fuels and loads. Various methods are used to reduce the negative environmental impact of diesel fuel. Thus, the moisture contained in the emulsion fuel contributes to the atomization of the fuel due to microexplosion, reducing the combustion temperature due to the latent heat of vaporization, which reduces the emissions of nitrogen oxides and particulate matter. Choi, I. et al. [30] found through experimental and numerical analysis that the combustion temperature of emulsion fuel containing 16% water decreased, and the degree of reduction of nitrogen oxide and black carbon was approximately 60% and 15%, respectively.

The reduction characteristics of black carbon and nitric oxide depending on the water content of the emulsion fuel were explored by numerical methods in [31]. By optimizing the compression ratio of the turbocharger, a reduction in fuel consumption, exhaust emissions, and, consequently, black carbon content was achieved. By adjusting the water content of the fuel, fuel consumption is reduced and power output is also greatly improved.

Choi, J.H. et al. [32] proposed to crystallize spent black carbon to transform it into an all-graphite nano-onion structure that can be used as a conductive material in batteries. The authors viewed thermally treated black carbon as a new type of black carbon, arguing that the black carbon material has many uses, such as shielding electrical cables and specialty electrical parts in automobiles where unique characteristics are desired.

One of the ways to reduce emissions is the use of alternative fuels, one of which is liquefied natural gas. Corbin, J.C. et al. [33] provided a detailed characteristic of PM composition emitted by a modern liquefied natural gas ship. The authors found that when running on diesel fuel, this engine emitted 8 times more particulate matter and 37 times more black carbon at loads above 25%, which, according to the authors, would reduce BC emissions by at least an order of magnitude. It was found that emissions at idle in both cases were significantly higher by an order of magnitude; therefore, idle should be avoided.

Park, J. et al. [34] showed that dimethyl ether has significant potential as a clean fuel with a reduced content of sulfur oxides and particulate matter. To prove this, the authors analyzed the characteristics of the combustion products in accordance with the timing of the injection and the change in the injector orifice. Another option for reducing carbon dioxide emissions in some niches of the merchant marine may be the use of nuclear installations.

Schøyen, H. et al. [35] explored three nuclear-powered merchant ships currently in operation in the world: Otto Hahn (West Germany), Savannah (USA), and Mutsu (Japan).

The fourth vessel, Sevmorput (Soviet Union or Russia, 1988—present), is a pioneer in terms of its logistic functions and nuclear facility. The authors have developed a theoretical basis for assessing the stability of a nuclear power plant in ocean-going merchant shipping.

Technical and organizational measures also help to reduce the emissions' harmful effects. For example, Lindstad, H.E. et al. [36] found that the combination of batteries with internal combustion engines for auxiliary vessels serving oil and gas operations on the high seas reduces pollution and climate impact (annual global warming potential by 40–45% in the Arctic regions and about 20% in the North Sea).

Kim, M. et al. [37] investigated the effectiveness of applications such as compression-ignition marine engines, engines that can be used with an existing installation of 2.0 L automobile engines with common rail direct injection. They improve the efficiency of combustion and contribute to the reduction of NOx and soot emissions.

The introduction of restrictions on the sulfur content in fuel forces the use of "purer" types, as, for example, Zetterdahl, M. et al. described in [38]. The authors analyzed air samples taken on board a vessel in the Baltic Sea. The results of the analysis showed that changing fuel reduced particulate emissions by up to 67%. In addition, emissions of total volatile organic compounds (VOCs), including SO_2, were reduced by 80%. The switch to RMB30 fuel has resulted in a decrease in the number of priority carcinogenic PAHs, although emissions of some monoaromatics such as benzene and toluene have increased.

As the use of scrubbers on ships to reduce sulfur emissions has increased, Winnes, H. et al. [39] believe that it is necessary to study the impact of this technology on the environment and human health. The study found that widespread use of scrubbers can reduce the predicted emission reduction effects that could be achieved with low sulfur fuels.

Since environmental problems in the Arctic are primarily associated with the use of traditional methods of burning solid and liquid fuels using coal or fuel oil that pollutes the environment, the transition to alternative fuels (LNG, dimethyl ether, nuclear energy) in conjunction with organizational and technical measures for energy supply significantly improves the environmental situation.

3.3. Contribution of Port Infrastructure and Ships in Ports to Environmental Pollution

As shown by Zhao, J. [40], as ports in China have developed, cargo ships and container ships with high engine power are the main sources of air pollution in port cities and surrounding regions. The authors tested the emission coefficients for particulate matter and gases from an offshore cargo ship operating in various real-world conditions, which they believe may be important data for the use of certification values for emission inventories.

In [41] Xu, L. et al. presented the results of serial monitoring of the activities of a port industrial facility. They sampled daily PM 2.5 in an urban area and a nearby port industrial facility on the coast of southeast China starting April 2015 for 10 months. The comparison results showed that ship emissions and port activities distributed in the wind sectors of the northeast, east, and southeast directions were responsible for the contribution of sources in the form of industry emissions, as well as ship emissions and secondary aerosols.

Wan, Z. et al. [42] monitored 28 sampling vessels that were plying through the Shanghai Port to investigate how air pollutants including oxysulfides (SOx), nitrogen oxide (NOx), and particulate matter less than 10 microns (PM 10) will change in accordance with ECA regulations. As a result, it was found that emissions depend on the type and size of ships, and the highest shares of pollutant emissions are occupied by cruise ships, container ships, and tankers for the transport of liquefied gas. Due to their higher-average gross tonnage, they have more powerful marine engines.

The need to study [43] the contribution of the port activity to the pollution of nearby territories was driven by the fact that several harbors are located close to the urban and industrial areas of Porto (Portugal), where there are residential urban areas, highways, and oil-refining industries. The study used numerical simulations based on web-based C-PORT study screening tool to assess the relative contribution of different sources to outdoor air quality concentration—port infrastructure, roads, and industrial facilities—that pose a direct threat to the nearby city's ecosystem and its population.

To compile an inventory list of emissions in the Oslo port, López-Aparicio, S. et al. [44] proposed to apply a bottom-up approach. This list is an important starting point for developing measures to reduce the environmental impact of shipping in port areas. The main emission sources from ocean-going ships are international ferries, cruises, and container ships, whereas the main sources of emissions from port ships are inland ferries. In the port of Oslo, the OGV is the emitter, especially when it is berthed. Therefore, onshore energy can provide an effective strategy to reduce the environmental burden.

Since ports are a place of ships' congestion and, accordingly, the concentration of emissions, they are mandatory objects for monitoring the environmental situation.

4. Results: Concept of a System for Accounting and Managing Environmental Risks in the Development of Navigation along the NSR

The NSR is becoming not only a short water route between the European part of Russia but also a unique transcontinental route of significant interest to the economies of many countries. The seaports and terminals of the White and Barents Seas, as well as the ports of the Far East, are necessary for the NSR operation. Cargo flows are formed in them, icebreaker support is based, and comprehensive services for ships are carried out. Moreover, since the climatic conditions in the region are extreme, such territories' development can lead to environmental problems with more severe consequences than in other climatic zones.

4.1. Opportunities for Growth in Cargo Traffic along the Northern Sea Route

The Arctic development is planned through a system of so-called "support zones" (SZs). Nine such zones will form the basis of the socioeconomic development of the Arctic zone, will link all the projects and resources of the Arctic zone, and will allow to obtain the maximum synergistic effect. They are comprehensive socioeconomic development projects that provide for the synchronous application of interrelated existing instruments of territorial and sectoral development, as well as mechanisms for the implementation of investment projects, including the principles of public–private and municipal–private partnerships.

The SZ spatial structure is formed by the transport and industrial complex, the main elements of which are (1) highways providing access to the Northern Sea Route, communication with neighboring regions and SZ, and transport accessibility of new sources of raw materials; and (2) transport (ports, stations), mineral resources (extraction and primary processing of raw materials), and multifunctional nodes and centers (processing of resources, transshipment of goods, social and cultural sphere, energy, construction, etc.).

In the location of the reference zones, there is an uneven distribution of them throughout the Arctic territory. In the western part, they are quite concentrated, and in the eastern part (Republic of Sakha—Yakutia and Chukotka), whose territories are large, there are a large number of settlements with a small number of people living in rather difficult socioeconomic conditions. In addition, the implementation of such a megaproject requires not only the attraction of public investment but also a large contribution of regional business structures, which do not yet have sufficient production and investment potential. All these problems require a comprehensive and systematic study of industrial and socioeconomic development potentials throughout the Arctic zone of the Russian Federation.

Closely related directions determine the development prospects, which depend on the characteristics of the transport framework, and in accordance with the development of which, the support zones can be clustered as follows: zones with a developing framework—Arkhangelsk, Kola, and Karelian; zones with an emerging framework—Yamalo-Nenets and North Yakutsk; zones with a projected frame—Nenets and Vorkuta; and zones where reconstruction and formation of a frame is required—Taimyr-Turukhansk and Chukotka. Based on this, goals are formulated to ensure the development of the transport network through all modes of transport; railway access to the NSR port; and strengthening of the main transport axis "road–sea" or "river–sea" with the reconstruction of ports on the NSR.

It should be borne in mind that during the ports' functioning, constant work is required to ensure the coastal navigational aid operability, including the GLONASS/GPS monitoring and corrective stations network [45]. Currently, the entire Northern Sea Route is covered by a network of control and correction stations. It is located on the islands of Oleniy, Andrew, Stolbovoy, and Kamenka; on Cape Sterligov; and on the Indigirka River. This can improve the accuracy and authenticity of finding the vessel location coordinates, which, in turn, contributes to the navigation safety [46].

4.2. Icebreaker Fleet Role in Sustainable NSR Development

It has been tried to locate transport hubs closer to the places of commodity flow formation, so the northern ports are brought as close as possible to the industrial complexes under construction and created on the Arctic Ocean coast, as well as in the mouths of deep-water rivers. To date, most of the cargo is hydrocarbons transported in tankers. Therefore, to ensure the economic viability of the NSR in the future, it is necessary to have a large-capacity fleet. However, traditional routes with insufficient depth are not suitable for its movement. In this regard, there is an urgent need for hydrographic studies that will help solve the problem of the shallow depth of traditional routes and form deep-water routes at higher latitudes. On the other hand, the importance of the Russian nuclear icebreaker fleet is growing. It should be noted that, at present, only the Russian fleet has ships of this class. Their main advantage is the ability to make passages for many months without entering the port for transshipment operations. Plans have been developed to upgrade the icebreaker fleet: by 2035, it should include five nuclear-powered icebreakers of the UAL type with a capacity of 60 MW, three icebreakers "Leader" with a capacity of 120 MW, four icebreakers using gas engine fuel with a capacity of 40 MW, and an atomic icebreaker "50 Let Pobedy" (Figure 1) [47].

Characteristics	Project				
	1052 (type Arctic)	10580 (Taimyr type)	22220 (type UAI)	10510 (Leader type)	10570 (offshore)
Status	Acting (Yamal, 50 years of Victory)	Acting (Taimyr, Vaygach)	Construction of the head and two serial	Since 2016 technical design	In 2015, a conceptual projectt
Main (possible) area of operation	Permanently - the Arctic Western region, in the summer-autumn period - the Eastern Arctic region	River s' mouths and Arctic areas shallow	Permanently - Arctic Western region, Arctic Bay shallow areas. In the summer-autumn period - the Arctic Eastern region.	Year-round - all Arctic areas, with the exception of shallow areas and river mouths	Arctic shelf and shallow Arctic regions
Planned operation period of the project	1975 -2040 (in 1975 started exploitation. AI "Arctic")	1989 - 2022	2019-2065 (taking into account 4 and 5)	2026 - 2066	2026 - 2066
Length (max), m	148	150	173.3	209	152
Width (max), m	30	29.2	34	47.5	31
Draft, m: - on waterline	11	8.1	10.5	13	8.5
- minimal			8.5	11.5	
Displacement (max), t	20,900	19,600	33,530	70,674	20,700
Shaft power, kW	49,000	32,500	60,000	120,000	40,000
Icebreaking capacity, m	2.25	1.95	2.9	4.1	2.4

Figure 1. Comparison of characteristics of operating vessels and new-generation icebreakers.

Project 22220 nuclear icebreakers (Figure 1) are the largest and most powerful in the world (for comparison, they are 4 m wider than nuclear ships of the Arktika type (Figure 1) and are 34 m wide). In addition to a nuclear installation, these ships have an electric propulsion system. This will reduce the cost of operation, and the work of the ship crew will become easier. The vessel favorably compares with the icebreakers of the previous generation: thanks to the new nuclear reactor, it will be able to make passages for more than 6 months without entering to the port for refueling. Reactors serve not only for the operation of steam turbines, which, in turn, drive the propeller shafts. They act as power plants and provide all the ship's consumers and engines with electricity. Icebreakers of Project 22220 will be able to pave the way in ice up to 3 m thick for ship caravans. First of all, this refers to tankers with a displacement of up to 70,000 tons, delivering hydrocarbons from the fields of the Yamal and Gydan peninsulas and the Kara Sea shelf to the countries of the Asia-Pacific region. The unique ability to effectively operate these vessels both in Arctic waters and the lower reaches of polar rivers is possible thanks to a special two-axle design with adjustable immersion depth [48].

In addition to the icebreakers themselves, ice-class vessels are used in the Arctic—tankers and others. New nuclear-powered ships are called upon to provide all-season navigation along the NSR and expeditions to the Arctic. The Arctic countries cannot claim leadership with Russia, which has the world's largest icebreaker fleet, both in quantity and quality. For example, the US icebreaking fleet is limited to only three diesel-electric shore-based icebreakers, two of which are highly depreciated with more than 30 years of operation. It seems that even the allocation of USD 9 billion for the construction of two more non-nuclear icebreakers will not be able to radically change the position of the United States in the international arena on this issue. The Canadian icebreaker fleet is also highly depreciated: out of 17 diesel-electric icebreakers, only 3–4 have reached their end of life. The Canadian government plans to allocate USD 550 million to build four military icebreakers and replace the flagship CCGS Louis S. St. Laurent. There are seven icebreakers each in the fleets of Sweden and Finland, four in Denmark, and one in Norway. Non-Arctic countries such as China, South Korea, and Germany also have one icebreaker each.

In Russia, a transport strategy has been adopted until 2030, according to which the marine fleet will be expanded in order to provide conditions for a safe navigation process and support year-round transit along the NSR [49]. This includes nuclear-powered icebreakers for escorting transport ships, diesel-electric icebreakers for servicing Arctic offshore fields, multifunctional rescue vessels, new-generation tugs, and means of technical rescue from offshore oil and gas facilities in ice conditions. There is a network of control and correction posts along the NSR. It ensures the operability of the coastal navigation infrastructure, GLONASS/GPS monitoring, and correction stations. Together, this makes it possible to ensure the reliability and accuracy of observations, calculation of the ship's coordinates, and, as a result, safety of the navigation process [50].

4.3. Risk Management in the Expansion of Shipping along the NSR

As follows from the above review, the main risks identified by numerous researchers can be grouped according to different criteria: by the object of influence (ecosystem, atmospheric air, water area of seas and rivers, etc.); by the type of activity (production, transportation, tourism, etc.); and by the duration of exposure (seasonal and permanent). In addition, it is necessary to understand what is the likelihood of a risk situation, whether its occurrence is inevitable, and whether its consequences can be reduced. Figure 2 shows the main types of risks at their place of occurrence, which must be taken into account when developing a strategy for the development of the Arctic. For risk management, a balanced scorecard (BSC) can be used, for which key performance indicators are developed. Figure 3 shows a conceptual model of a risk management system using a BSC.

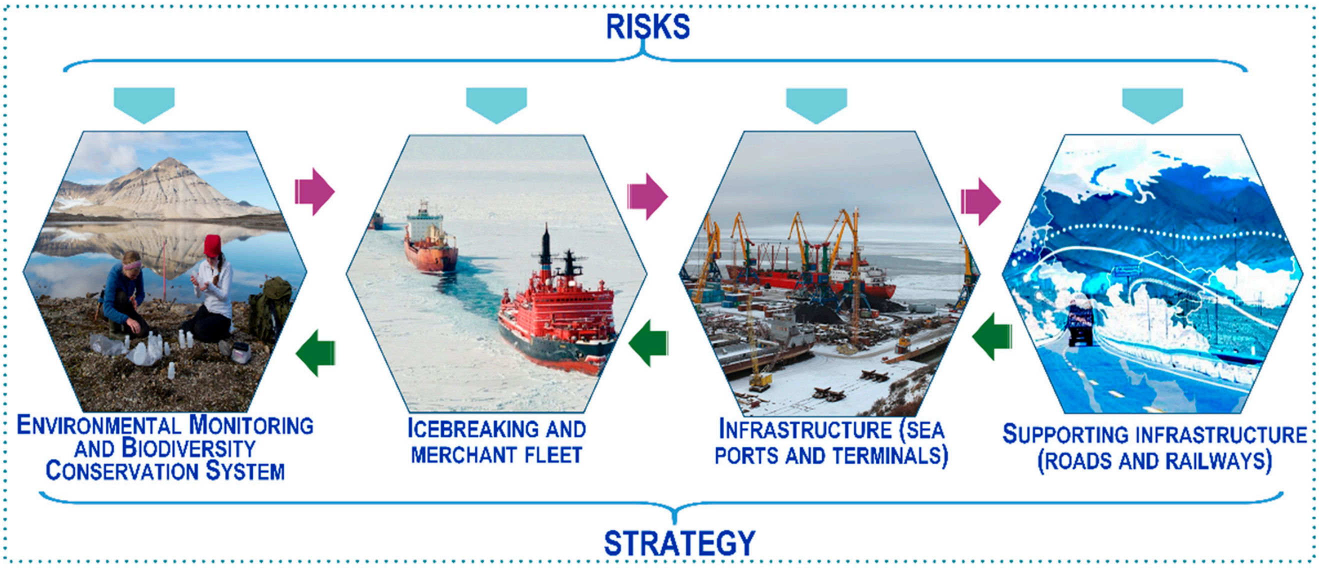

Figure 2. Types of risks.

Figure 3. Conceptual model of a risk management system.

Since we are considering development projects that involve the creation of large organizational and technical systems, it is logical to classify risks by stages of such systems' life cycle (Figure 4).

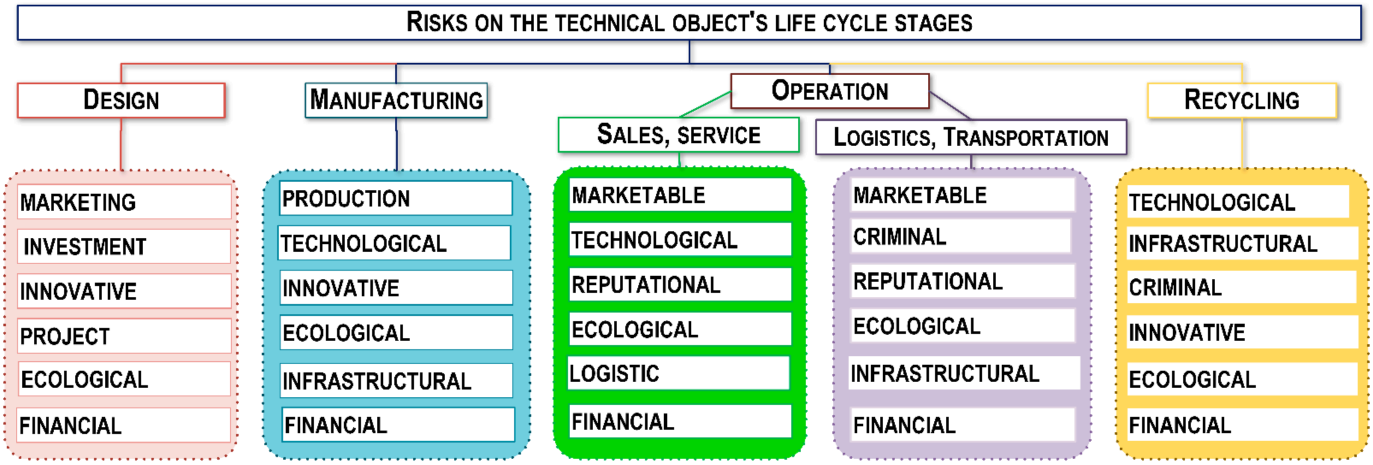

Figure 4. Risks classification by systems' life-cycle stages.

Risks can be classified according to different criteria; however, at each stage of the large project implementation, it is necessary to create a risk management system (Figure 5), since it is necessary to understand which of them can lead to serious (or even catastrophic) consequences, as well as what measures and steps should be taken to reduce both the likelihood of a risk situation occurring and the severity of its consequences if it does occur. In addition, it is necessary to understand whether the risks can be controlled and who will be responsible for this process.

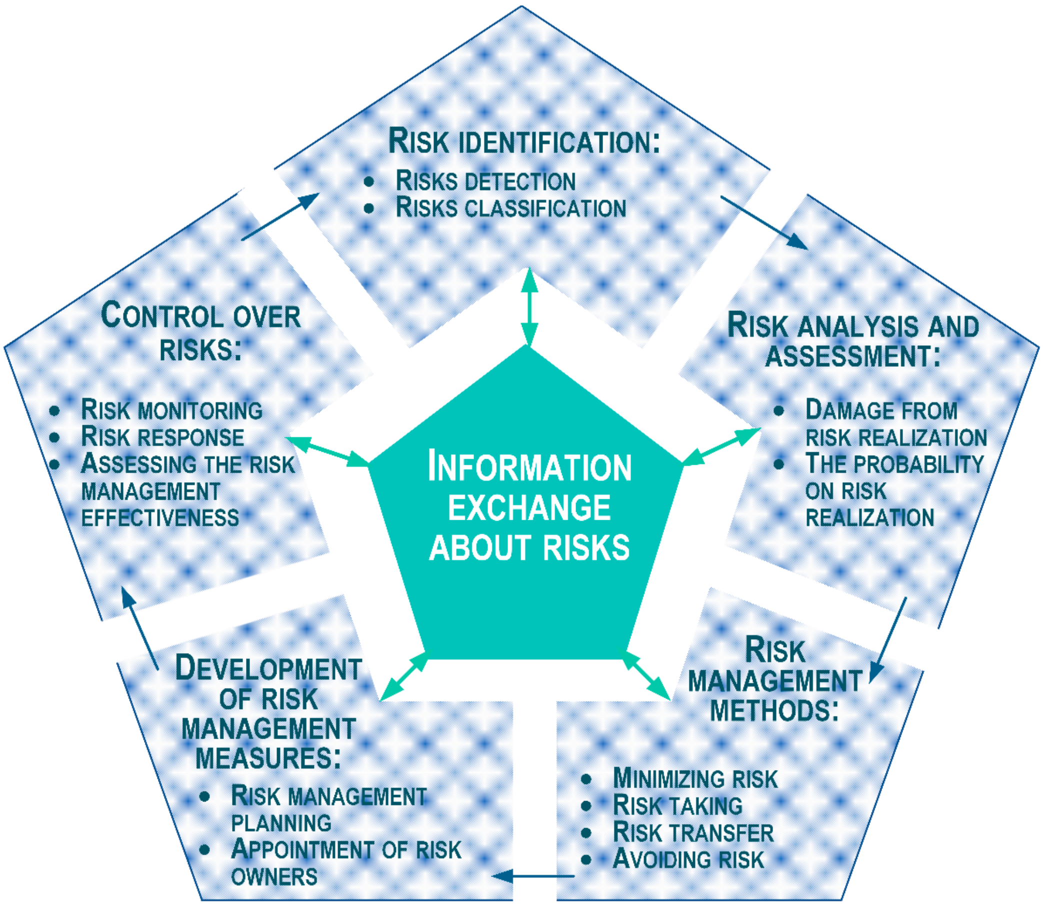

Figure 5. Stages of the risk management system.

For each stage of the risk management process, there are qualitative and quantitative methods; for each specific case, it is necessary to select the most effective. For example, in

Figure 6, for the risk of collision, we used the bow-tie method, which makes it possible to determine preventive measures to avoid a risk situation, as well as measures to mitigate the consequences' severity. In similar ways, one can consider any risk situation and highlight possible solutions.

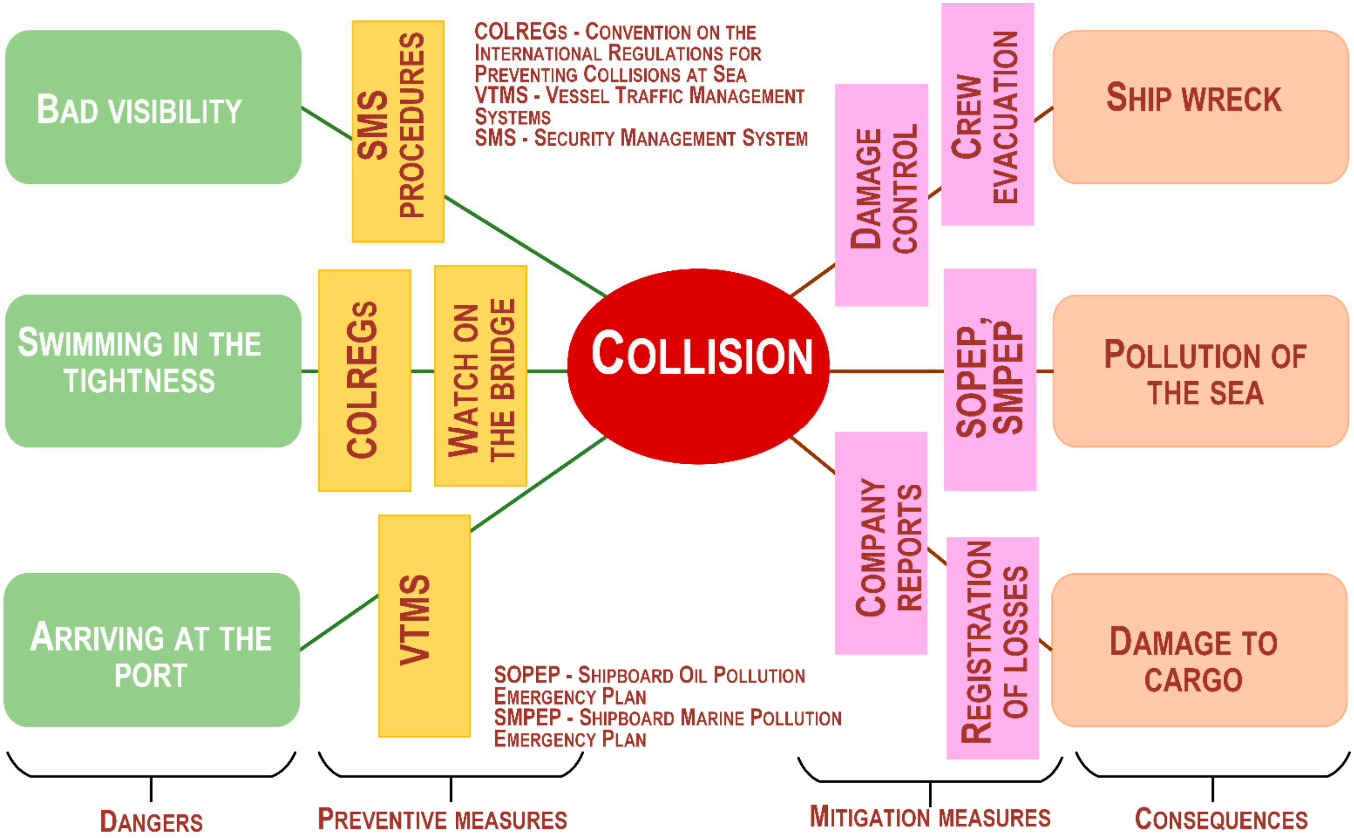

Figure 6. Example of bow-tie diagram for collision case.

5. Conclusions

Climate change opens up great opportunities for the development of the Russian Arctic, including the NSR. In general, it should be noted that for the development of new territories, complex projects are being implemented. They are related to the creation and development of urbanization, expansion of human economic activity, creation of transport and logistics infrastructure, and development of recreational and tourist areas. All this inevitably leads to various kinds of risks that can lead to serious consequences. Therefore, they must be carefully considered and, if possible, managed.

A number of complex projects are being implemented in the Arctic zone, and we can say that, along with the positive effects from the Arctic zone development, there will be problems caused by the vulnerability of its ecosystems due to increased emissions from the marine fleet, the activities of ports, industrial enterprises, the tourism industry, etc. Based on the results of the analysis of the literature, we have concluded that one of the ways to reduce emissions is the introduction of alternatives to diesel fuel, for example, gas piston and nuclear power plants. It is also important to model hazardous situations due to accidents at potentially hazardous production facilities and complexes, as well as the development of information and analytical systems to support emergency protection planning. It is necessary to form the ecological consciousness of the urban population and personal responsibility for maintaining the ecological balance in nature. However, without active and real support from the state, it will be difficult, if not impossible, to achieve the preservation of the uniqueness and further Arctic territories development.

A limitation of this study is that the areas of activity analyzed are not exhaustive. Thus, within the framework of the strategic Arctic development, the development of the mining complex is envisaged. About 70% of the total volume of mined rock is transported by road. Therefore, in addition to analyzing the impact of maritime transport on the surrounding area, road transport should also be analyzed. The second risk is associated with open-pit mining, which leads to a number of environmental problems, such as landscape degradation, soil pollution, and emissions of harmful substances. The resource potential of the Arctic zone is about 25% of the world's undiscovered mineral reserves, so the risks associated with hydrocarbon production are high. In any case, the construction of mining and industrial enterprises and the creation of a transport and logistics framework for the delivery of raw materials increase the risk of accidents and manmade disasters.

The collapsing Arctic cryosphere also creates environmental risks. In particular, thawing permafrost threatens to release biological, chemical, and radioactive materials.

Social risks constitute a separate group. Indigenous peoples in the Arctic face threats to food security and cultural disruption. Indigenous lifestyles and traditional livelihoods are closely linked to the Arctic environment. Furthermore, with the development of resources and of the trans-Arctic maritime trade, as well as the growth of interest in tourism, along with new opportunities, new threats for the indigenous peoples of the Arctic are growing.

Thus, any type of activity in the implementation of projects for the new territory's development is accompanied by risks. Moreover, they are interconnected and mutually influential. We can calculate some of them, such as manmade risks associated with tourism, fishing, oil production, shipping, and mining. However, other risks, related to natural conditions, can only be predicted by estimating how they will be superimposed on technogenic risks. In this sense, with the joint occurrence of risks, a synergistic effect arises; therefore, risks should be considered by various specialists in a complex, including social ones. Therefore, clearer classifications are needed. A good classification allows one to quickly select methods for dealing with risks. The problem tree method, which connects problems and their consequences, can be effective in this sense. If we formalize this, then it will be possible to predict the ways of risk management and to try to completely prevent or minimize them.

In this article, we identified factors that negatively affect the ecological state of the Arctic territories and classified possible types of risks: by the object of influence (ecosystem, atmospheric air, water area of seas and rivers, etc.); by the type of impact of activities (production, transportation, tourism, etc.); and by the duration of exposure (seasonal and permanent). As an alternative, we proposed a classification of risks according to the stages of the life cycle of large systems, since the development of the Arctic involves the creation of large organizational and technical systems. However, it should be noted that a unified risk classification system has not yet been developed. In this regard, the latest research needs to overcome the current limitation of the study: to analyze the literature devoted not only to environmental risks and to develop a multiclassifier of risks for strategic projects for the Arctic territories' development.

Understanding the causes of risk situations, as well as the severity of the likely consequences of their occurrence, will make it possible to foresee possible ways to prevent such situations, as well as to minimize negative consequences in order to reduce possible damage. Therefore, it is important to perform strategic planning and forecasting when developing programs and infrastructure projects, taking into account the risks and consequences in the short and long term. In this regard, we developed and described in this paper a conceptual model of the risk management system, which can be useful in the practical implementation of the strategy for the Russian Arctic development until 2035. In the future, it is necessary to expand the concept of risk management in order to move from a conceptual one to a real system of risk analysis and management in the implementation of strategic projects. It is necessary to formalize ways to identify risks, identify the most critical ones, taking into account external factors, and then select the most effective management methods for each case. In addition, further research should be directed to the development of the composition of key performance indicators within the framework of a balanced scorecard and the determination of their minimum and maximum standard values.

Author Contributions: Conceptualization, I.M. and D.M.; methodology, I.M. and D.M.; formal analysis, I.M. and A.B.; investigation, I.M., P.B., L.G., E.M. and V.M.; resources, I.M., A.B., E.M. and V.M.; writing—original draft preparation, I.M.; writing—review and editing, I.M., D.M., P.B., A.B., L.G., E.M. and V.M.; visualization, I.M.; project administration, P.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhou, X.; Min, C.; Yang, Y.; Landy, J.C.; Mu, L.; Yang, Q. Revisiting Trans-Arctic Maritime Navigability in 2011–2016 from the Perspective of Sea Ice Thickness. *Remote Sens.* **2021**, *13*, 2766. [CrossRef]
2. Savard, C.; Nikulina, A.; Mécemmène, C.; Mokhova, E. The Electrification of Ships Using the Northern Sea Route: An Approach. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 13. [CrossRef]
3. Makarova, I.; Gubacheva, L.; Makarov, D.; Buyvol, P. Economic and environmental aspects of the development possibilities for the northern sea route. *Transp. Res. Procedia* **2021**, *57*, 347–355. [CrossRef]
4. Gritsenko, A.; Shepelev, V.; Salimonenko, G.; Cherkassov, Y.; Buyvol, P. Environmental Control and Test Dynamic Control of the Engine Output Parameters. *FME Trans.* **2020**, *48*, 889–898. [CrossRef]
5. Makarova, I.; Mavrin, V.; Magdin, K.; Barinov, A. Reducing Black Carbon Emissions in the Arctic Territories. *Transp. Res. Procedia* **2021**, *57*, 356–362. [CrossRef]
6. Gabrielyan, M.; Tretyakov, O. Classification of risks in investment and construction activities. *Univ. Bull.* **2016**, *5*, 60–67.
7. Watch Out for These 5 Types of Environmental Hazards. Available online: https://safestart.com/news/watch-out-for-these-5-types-of-environmental-hazards/ (accessed on 19 September 2022).
8. Sluser, B.M.; Caliman, F.A.; Betianu, C.; Gavrilescu, M. Methods and procedures for environmental risk assessment. *Environ. Eng. Manag. J.* **2007**, *6*, 573–592.
9. Hillson, D.; Rafele, C.; Grimaldi, S. Managing Project Risks Using a Cross Risk Breakdown Matrix. *Risk Manag.* **2006**, *8*, 61–76. [CrossRef]
10. Barchukov, A.; Sokolov, D. Multitasking risk classification. *Bull. Sib. Inst. Bus. Inf. Technol.* **2015**, *3*, 17–26.
11. CMA CGM ANTOINE DE ST EXUPERY. Available online: https://www.marinetraffic.com/en/ais/details/ships/shipid:5336324/mmsi:229270000/imo:9776418/vessel:CMA_CGM_ANTOINE_DE_ST_EXUPERY (accessed on 19 September 2022).
12. Norway Unveils World's First Autonomous Electric Container Ship. Available online: https://3dnews.ru/1054153/v-norvegii-predstavili-perviy-v-mire-avtonomniy-elektricheskiy-konteynerovoz (accessed on 19 September 2022).
13. Aleinikova, A.; Byashkin, M.; Gaivoron, T.; Mainasheva, G.; Marsheva, N. The role of specially protected natural areas in solving environmental problems of the Russian arctic (using the example of Vaygach Island). *E3S Web Conf.* **2020**, *169*, 02019. [CrossRef]
14. Chekmareva, A.C.; Dobrynin, D.V.; Kirilov, A.G.; Byzova, N.M. Monitoring of anthropogenic load, recreational safety of the Arctic tourism objects in Russian Arctic National Park. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *263*, 012024. [CrossRef]
15. Sevastyanov, D.V.; Grigoryev, A.A.; Paranina, A.N.; Obyazov, V.A.; Kiseleva, M.V. Arctic tourism in the Barents Sea Region: Current status and boundaries of the possible. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *625*, 012008. [CrossRef]
16. Qiao, W.; Ma, X.; Liu, Y.; Lan, H. Resilience Assessment for the Northern Sea Route Based on a Fuzzy Bayesian Network. *Appl. Sci.* **2021**, *11*, 3619. [CrossRef]
17. Tsukerman, V.A.; Ivanov, S.V.; Goryachevskaya, E.S. Management of the Ecological-Economic System of the Russian Arctic Zone. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *753*, 06201. [CrossRef]
18. Batova, T.; Lazareva, E.; Pavlova, E. Sustainable use of natural resources in the Arctic region (the example of China's cooperation with Western countries). *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *110*, 02064. [CrossRef]
19. Katansky, A.A.; Minchenok, E.E.; Zhuravleva, N.G.; Aleksandrova, Y.Y.; Trotsenko, A.A. Industrial and ecological safety analysis for modeling oil and petroleum products spills in the Arctic waters of the Kola Bay. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *862*, 062007. [CrossRef]
20. Pavlov, V.; Aguiar, V.C.M.; Hole, L.R.; Pongrácz, E. A 30-Year Probability Map for Oil Spill Trajectories in the Barents Sea to Assess Potential Environmental and Socio-Economic Threats. *Resources* **2022**, *11*, 1. [CrossRef]
21. Romasheva, N.; Dmitrieva, D. Energy Resources Exploitation in the Russian Arctic: Challenges and Prospects for the Sustainable Development of the Ecosystem. *Energies* **2021**, *14*, 8300. [CrossRef]
22. Alekseeva, M.N.; Svarovskaya, L.I.; Yashchenko, I.G. Ecological Risks of Oil Contamination in the Arctic Zone. *Chem. Sustain. Dev.* **2020**, *28*, 213–218. [CrossRef]

23. Yakovlev, S.; Putilov, V.; Masloboev, A. Information and analytical support for the industrial and ecological safety management of Arctic communications. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *302*, 012032. [CrossRef]
24. Varotsos, C.A.; Krapivin, V.F. Pollution of Arctic Waters Has Reached a Critical Point: An Innovative Approach to This Problem. *Water Air Soil Pollut.* **2018**, *229*, 343. [CrossRef]
25. Mavrin, V.; Magdin, K.; Shepelev, V.; Danilov, I. Reduction of environmental impact from road transport using analysis and simulation methods. *Transp. Res. Procedia* **2020**, *50*, 451–457. [CrossRef]
26. Wu, D.; Zhang, F.; Lou, W.; Li, D.; Chen, J. Chemical characterization and toxicity assessment of fine particulate matters emitted from the combustion of petrol and diesel fuels. *Sci. Total Environ.* **2017**, *605*, 172–179. [CrossRef] [PubMed]
27. Corbin, J.C.; Czech, H.; Massabò, D.; de Mongeot, F.B.; Jakobi, G.; Liu, F.; Lobo, P.; Mennucci, C.; Mensah, A.A.; Orasche, J.; et al. Infrared-absorbing carbonaceous tar can dominate light absorption by marine-engine exhaust. *NPJ Clim. Atmos. Sci.* **2019**, *2*, 12. [CrossRef]
28. Corbin, J.C.; Pieber, S.M.; Czech, H.; Zanatta, M.; Jakobi, G.; Massabò, D.; Orasche, J.; El Haddad, I.; Mensah, A.A.; Stengel, B.; et al. Brown and black carbon emitted by a marine engine operated on heavy fuel oil and distillate fuels: Optical properties, size distributions, and emission factors. *J. Geophys. Res. Atmos.* **2018**, *123*, 6175–6195. [CrossRef]
29. Jiang, Y.; Yang, J.; Gagné, S.; Chan, T.W.; Thomson, K.; Fofie, E.; Cary, R.A.; Rutherford, D.; Comer, B.; Swanson, J.; et al. Sources of variance in BC mass measurements from a small marine engine: Influence of the instruments, fuels and loads. *Atmos. Environ.* **2018**, *182*, 128–137. [CrossRef]
30. Choi, I.; Lee, C. Numerical Study on Nitrogen Oxide and Black Carbon Reduction of Marine Diesel Engines Using Emulsified Marine Diesel Oil. *Sustainability* **2019**, *11*, 6347. [CrossRef]
31. Choi, I.; Lee, C. Feasibility Study of Emission Reduction on Marine Engine with Variation of Emulsified Water Concentration and Turbocharger Compression Ratio. *Appl. Sci.* **2020**, *10*, 1215. [CrossRef]
32. Choi, J.H.; Kim, D.Y.; Lee, W.J.; Kang, J. Conversion of Black Carbon Emitted from Diesel-Powered Merchant Ships to Novel Conductive Carbon Black as Anodic Material for Lithium Ion Batteries. *Nanomaterials* **2019**, *9*, 1280. [CrossRef]
33. Corbin, J.C.; Peng, W.; Yang, J.; Sommer, D.E.; Trivanovic, U.; Kirchen, P.; Miller, J.W.; Rogak, S.; Cocker, D.R.; Smallwood, G.J.; et al. Characterization of particulate matter emitted by a marine engine operated with liquefied natural gas and diesel fuels. *Atmos. Environ.* **2020**, *220*, 117030. [CrossRef]
34. Park, J.; Choi, I.; Oh, J.; Lee, C. Preliminary Numerical Study on Exhaust Emission Characteristics of Particulate Matters and Nitrogen Oxide in a Marine Engine for Marine Diesel Oil and Dimethyl Ether Fuel. *J. Mar. Sci. Eng.* **2020**, *8*, 316. [CrossRef]
35. Schøyen, H.; Steger-Jensen, K. Nuclear propulsion in ocean merchant shipping: The role of historical experiments to gain insight into possible future applications. *J. Clean. Prod.* **2017**, *169*, 152–160. [CrossRef]
36. Lindstad, H.E.; Eskeland, G.S.; Rialland, A. Batteries in offshore support vessels—Pollution, climate impact and economics. *Transp. Res. Part D Transp. Environ.* **2017**, *50*, 409–417. [CrossRef]
37. Kim, M.; Oh, J.; Lee, C. Study on Combustion and Emission Characteristics of Marine Diesel Oil and Water-In-Oil Emulsified Marine Diesel Oil. *Energies* **2018**, *11*, 1830. [CrossRef]
38. Zetterdahl, M.; Moldanová, J.; Pei, X.; Pathak, R.K.; Demirdjian, B. Impact of the 0.1% fuel sulfur content limit in SECA on particle and gaseous emissions from marine vessels. *Atmos. Environ.* **2016**, *145*, 338–345. [CrossRef]
39. Winnes, H.; Fridell, E.; Moldanová, J. Effects of Marine Exhaust Gas Scrubbers on Gas and Particle Emissions. *J. Mar. Sci. Eng.* **2020**, *8*, 299. [CrossRef]
40. Zhao, J.; Zhang, Y.; Yang, Z.; Liu, Y.; Peng, S.; Hong, N.; Hu, J.; Wang, T.; Mao, H. A comprehensive study of particulate and gaseous emissions characterization from an ocean-going cargo vessel under different operating conditions. *Atmos. Environ.* **2020**, *223*, 117286. [CrossRef]
41. Xu, L.; Jiao, L.; Hong, Z.; Zhang, Y.; Du, W.; Wu, X.; Chen, Y.; Deng, J.; Hong, Y.; Chen, J. Source identification of PM2.5 at a port and an adjacent urban site in a coastal city of China: Impact of ship emissions and port activities. *Sci. Total Environ.* **2018**, *634*, 1205–1213. [CrossRef]
42. Wan, Z.; Zhang, Q.; Xu, Z.; Chen, J.; Wang, Q. Impact of emission control areas on atmospheric pollutant emissions from major ocean-going ships entering the Shanghai Port. *China Mar. Pollut. Bull.* **2019**, *142*, 525–532. [CrossRef]
43. Sorte, S.; Arunachalam, S.; Naess, B.; Seppanen, C.; Rodrigues, V.; Valencia, A.; Borrego, C.; Monteiro, A. Assessment of source contribution to air quality in an urban area close to a harbor: Case-study in Porto. *Port. Sci. Total Environ.* **2019**, *662*, 347–360. [CrossRef]
44. López-Aparicio, S.; Tønnesen, D.; Thanh, N.; Neilson, H. Shipping emissions in a Nordic port: Assessment of mitigation strategies. *Transp. Res. Part D Transp. Environ.* **2017**, *53*, 205–216. [CrossRef]
45. Kozmovskiy, D.V.; Sineschuk, Y.I.; Artamonov, V.S. The method of operational control of the use functionality of resources and services of the automated information and control system in the Unified State System for the Prevention and Response of Emergency Situations. *Bull. St. Petersburg Univ. State Fire Serv. Russ. Minist. Emerg. Situat.* **2014**, *2*, 51–59.
46. Bakharev, T.S.; Gadyshev, V.A.; Plotnikov, Y.A. Application of geographic information systems for solving applied problems of emergency prevention. *Bull. St. Petersburg Univ. State Fire Serv. EMERCOM Russ.* **2010**, *6*, 2–17.
47. Kashka, M.M.; Irlitsa, L.A.; Efanskaya, E.A.; Matviishina, K.A.; Golovinsky, S.A. The role of the nuclear icebreaker fleet in achieving the national goal of increasing in fright traffic in the water area of the Northern Sea Route. *Arkt. Ekol. Ekon.* **2021**, *1*, 101–110. [CrossRef]

48. Kashka, M.M.; Smirnov, A.A.; Golovinsky, S.A.; Vorobyev, V.M.; Ryzhkov, A.V.; Babich, E.M. Prospects for the development of the nuclear icebreaker fleet. *Arkt. Ekol. Ekon.* **2016**, *3*, 98–107.
49. *Transport Strategy of the Russian Federation for the Period Up To 2030*; Order of the Russian Federation Government, November 22, 2008, No. 1734-p; Russian Federation Government: Moscow, Russia, 2008.
50. *Strategy for the Development of Inland Waterway Transport of the Russian Federation for the Period Up To 2030*; Order of the Russian Federation Government, February 29, 2016, No. 327-p; Russian Federation Government: Moscow, Russia, 2016.