Turk. J. Fish.& Aquat. Sci. 24(SI), TRJFAS27313
https://doi.org/10.4194/TRJFAS27313

RESEARCH PAPER

Turkish Journal of FISHERIES and AQUATIC SCIENCES

What is the Main Reason Why the Arctic Route is Developing Slower than Expected?

İshak Altinpinar[1,*]

[1]Department of Maritime Transportation and Management Engineering, Karadeniz Technical University, Trabzon, Türkiye.

How to Cite

Altinpinar, I. (2024). What is the Main Reason Why the Arctic Route is Developing Slower than Expected? *Turkish Journal of Fisheries and Aquatic Sciences*, *24(SI)*, *TRJFAS27313.* https://doi.org/10.4194/TRJFAS27313

Article History
Received 20 November 2024
Accepted 16 December 2024
First Online 19 December 2024

Corresponding Author
E-mail: ishakaltinpinar@ktu.edu.tr

Keywords
Northern Sea Route (NSR)
Arctic shipping challenges
Economic viability
Environmental Impact
Multi-criteria decision-making (MCDM)

Abstract

Arctic shipping routes attract increasing curiosity because of their potential to create profitable connections between East Asia and West Europe. However, there are many factors why this interest is not sufficiently reflected in the numbers. For this reason, in this article, the main obstacles to the development of the Northern Sea Route (NSR) as a significant shipping route covering Asia-Europe were evaluated using the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method (MCDM). The results indicate that economic viability (30.5%) is a critical challenge, with high operational costs and limited seasonal access undermining the NSR's competitiveness. Environmental and safety issues (29.6%) and ecological concerns (15.7%) also pose major risks due to unpredictable weather, insufficient search and rescue capabilities, reliance on icebreakers, and threats to fragile Arctic ecosystems. Infrastructure limitations (11.3%) and political and regulatory complexities (7.0%) further restrict usage, while limited international acceptance (5.9%) reflects the NSR's lack of integration into global supply chains. The financial nature of transportation is critical in terms of costs. Therefore, the economic viability barrier must be overcome first. It will require substantial investment, new regulations, and international cooperation to make NSR as a potential trade route.

Introduction

Maritime trade stands as one of the world's largest and oldest industries, playing a key role in global commerce by connecting economies across continents. The connection network of maritime trade and its function make it an incomparable pillar of international trade, pawing way to the movement of goods and resources on an unparalleled scale. There is an ongoing effort to explore new ways to improve maritime trade routes to make it more cost efficient. Melting of polar ice, driven by global climate change, has increased the interest in developing shipping routes through the Arctic region, specifically the Northern Sea Route (NSR) and the Northwest Passage (NWP). These Arctic passages, which located in the northernmost parts of Russia and Canada, offer comparatively shorter transit distances between major economic regions and reduce reduce voyage times and fuel consumption (See Figure 1). For instance, a journey from Japan to Europe through the NSR could be up to 40-50% shorter than traditional routes that goes through the Suez Canal (Liu & Kronbak, 2010; Xu et al., 2011). The retreat rate of ice mass in the last decade has exceeded 10%. Ice free summers are expected to be seen arctic region in the summer of 2050 (Gregory et al., 2002). Despite aforementioned advantages and the increased accessibility of the region, the development and use of Arctic routes remain notably limited (Schøyen & Bråthen, 2011).

Figure 1. Overview on the Northern Sea Route and the Existing Route.

The limited growth in Arctic transit points out the challenges that continue to hinder the region's integration into the global maritime network. Developing Arctic routes is challenging due to many factors including environmental, infrastructure, economic, regulatory, ecological, and social (Fedorov et al., 2020; Sun, 2018). These factors constrains the use of Arctic region as an alternative commercial shipping corridor for maritime trade. In this study, six key factors that play role in underdelopment of Arctic shipping routes are examined by using Analytical Hierarchy Process (AHP) methodology from the multi-criteria decision-making methods (MCDM). These key factors are i) environmental and safety challenges, ii) infrastructural limitations, iii) economic viability concerns, iv) political and regulatory complexities, v) ecological and social issues, and vi) limited international acceptance.

Environmental and Safety Challenges

Environmental and safety challenges are perhaps the biggest obstacles. Arctic region is known for extreme weather and water conditions, including low temperatures, frequent formation of fog, reduced visibility, and violent storms, which increases the risks associated with maritime operations (Schøyen & Bråthen, 2011; Liu & Kronbak, 2010). Although climate change has reduced the extent and duration of multiyear ice, the region remains dangerous, with drifting ice posing collision risks even during the summer months. These environmental risk factors are arisem from limited seasonal accessibility, as the ice-free period is unpredictable and varies year by year, creating uncertainties for navigational planning and operational reliability (Xu et al., 2011).

Furthermore, the remoteness of the Arctic increases the safety risks for vessels transiting these routes. Unlike more established shipping corridors around globe, search-and-rescue facilities and rapid-response infrastructures are limited which makes any emergency assistance attempt challenging in case of an incident (Benz et al., 2021). These difficulties increase safety risks for vessels and crews and also increase insurance costs as well. Among different factors that are at play in expanding Arctic trade routes, safety issues serve as a major deterrent (Fedorov et al., 2020).

Infrastructure Limitations

Infrastructural deficiencies along the NSR and NWP represent another major challenge for the commercial viability of Arctic shipping routes. Unlike traditional routes that benefit from well-equipped ports and ancillary services, the Arctic is comparatively way too underdeveloped in terms of maritime infrastructure (Fu et al., 2021; Inoue et al., 2015). Inadequate port infrastructure, maintenance and repair facilities, refueling stations, and navigational aid services, limits the region's capacity to support regular commercial shipping (Sun, 2018). Hence, vessels traveling through the Arctic are or will be unable to refuel, offload cargo, or obtain technical support in case of equipment failures or accidents, which ultemately increase operational risks and costs (Schøyen & Bråthen, 2011; Liu & Kronbak, 2010).

While Russia has made attempts in developing specific infrastructure along certain parts of the NSR, such efforts remain concentrated in select areas and largely been done for national strategic interests of Russia, rather than international commercial traffic (Katysheva, 2020). Additionally, the existing infrastructure is insufficient to handle large-scale traffic or unsuitable for different types of vessels, particularly those with higher draft requirements (Abe & Otsuka, 2019). The lack of infrastructural support restricts the attractiveness of the Arctic routes for large container liners, which rely on efficient, reliable port services to maintain operational schedules and customer commitments (Xu et al., 2011).

Economic Viability

The feasibility of Arctic shipping depends on costs. While the shorter travel distances provided by the NSR and NWP offer potential savings in fuel costs, the high operational costs in the Arctic often outweigh these savings. Icebreaker escort fees, the necessity for Polar-class vessels (ice-strengthened vessels), and increased insurance premiums increase the costs of Arctic transits, which makes the region less economically attractive than traditional routes (Faury & Cariou, 2016; Liu & Kronbak, 2010). The amount of fuel that polar-class ships consume to generate the power for their engines is considerably higher than that of other ship classes. Low sulfur fuel (IMO, 2023), which is used due to the environmental concerns for the region, is as an important cost item that is comparatively more expensive than high sulfur fuel (Dalaklis et al., 2023). Icebreaker services for navigating through the waters with thick ice cover increases fees that can exceed those associated with traversing the Suez Canal (Fedorov et al., 2020).

The shallow waterways prevent the passage of large-capacity vessels such as Very Large Crude Carriers (VLCCs) and capsize container ships, which are being used to optimize profitability on traditional shipping routes (Schøyen & Bråthen, 2011). Smaller vessels in the Arctic can transport fewer goods which will be reducing cost efficiency per unit (Xu et al., 2011). As a result, despite having shorter distance, the Arctic routes often fail to provide a compelling economic rationale for shipping companies focused on cost efficiency and scale.

Political and Regulatory Complexities

In terms of regulations, Arctic is characterized by a complex network of national, regional, and international frameworks that regulates maritime operations in the region. For instance, the NSR, which passes through territorial waters of Russia, is subject to Russia's jurisdiction, including specific requirements for icebreaker escorts, navigation permits, and compliance with Russian regulatory standards (Katysheva, 2020). This unique regulatory of the region necessitates coordination with Russian authorities and compliance to national policies, which may include tariffs and restrictions that do not normally apply to other maritime routes (Schøyen & Bråthen, 2011). Such complexities increase the administrative and operational burden for international shipping companies.

At the international level, the adoption of the Polar Code by the International Maritime Organization (IMO) has introduced strict safety and environmental standards for vessels operating in polar regions (IMO, 2023). The Polar Code is being applied to improve safety and environmental protection (Karahalil et al., 2021). However, complying with its requirements requires significant investment in specialized equipment and personnel training, which again increases the operational costs of Arctic shipping (Faury & Cariou, 2016). The geopolitical tensions in the Arctic region further worsen these regulatory challenges. Competing national interests in the region can lead to conflicts and legal uncertainties (Sun, 2018).

Ecological and Social Concerns

The Arctic is widely recognized as one of the world's most fragile ecosystems. Hence, there are environmental concerns for the ecological implications of increased maritime activity in this. Concerns include potential oil spills, black carbon emissions, and disruptions to marine life have led to calls for more strict regulations for Arctic shipping (Helle et al., 2020). Black carbon emissions, for example, can increase ice melt by reducing the albedo effect, thereby contributing to climate change impacts that directly affect Arctic ecosystems (Katysheva, 2020; Schøyen & Bråthen, 2011). Concerns over ecological impact have led environmental groups and local communities to call for careful and responsible Arctic shipping development, stressing the importance of balancing economic benefits with environmental protection. Global warming is expected to affect the spatial distribution of some fish species. Fishing activities have increased over the years in the region (See Figure 2). However, this warming may also reduce fish stocks over time due to new predators and invasive species (Ford et al., 2021; Hansel et al., 2020; Huntington et al., 2020). This may have negative consequences for local people who rely on fishing activities for a living.

In addition to environmental considerations, the potential social impacts on local communities who rely on the natural resources of the region for their cultural and economic well-being are on stake. Increased shipping activities raise concerns about potential interference with traditional practices, as well as the long-term sustainability of local resources (Fedorov et al., 2020; Sun, 2018). These social and ecological concerns have led to the imposition of regulatory

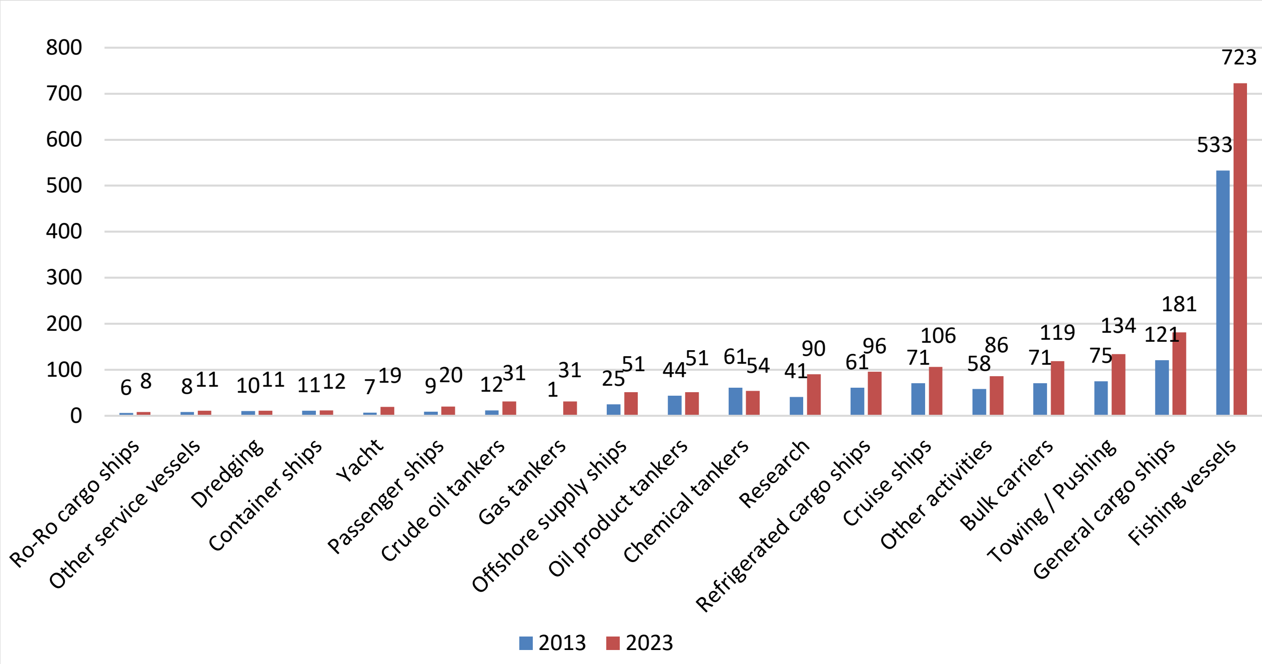

Figure 2. Change in the number of ships in the Arctic region over the years (PAME, 2024).

measures aimed at protecting the Arctic environment, which in turn impose additional constraints on the operational flexibility and economic feasibility of Arctic shipping. The current push to ban heavy fuel oil in the Arctic underscores that the risks of lighter oils should not be underestimated, as they have the potential to contaminate larger areas than heavier oils (Helle et al., 2020).

Limited International Acceptance

Despite the potential strategic advantages of Arctic routes, there is limited adoption of these routes within the international shipping industry. The preference for well-established routes, such as those that goes through the Suez and Panama Canal, reflects the industry's focus on reliability, predictability, and cost-efficiency (Zhang et al., 2016; Makarova et al., 2021). In contrast, Arctic routes are seen as high-risk and uncertain. This is mainly because of the seasonal nature of ice melt, the high costs of Arctic-class vessels, and the extensive regulatory requirements of the region (Schøyen & Bråthen, 2011). These factors collectively decrease the appeal of the Arctic as a commercial route, leading many shipping companies to view Arctic routes as niche or supplementary routes rather than primary alternatives.

The limited acceptance of Arctic routes is further influenced by the logistical and infrastructural advantages of established routes, which are integrated with global supply chains and supported by network of ports, refueling stations, and repair facilities (Xu et al., 2011). For the most of the shipping companies, the risks and uncertainties associated with Arctic transits outweigh the potential benefits, which results in low level of commercial interest in Arctic shipping.

Between 2013 and 2023, the number of ships entering the Arctic Polar Code area increased by 37%, reaching approximately 500 ships. Considering that approximately 200 of this increase are fishing vessels (See Figure 2), it is not seen as an increase independent of the growth rate in the world maritime merchant fleet (UNCTAD, 2024).

Material and Method

This study uses the Analytical Hierarchy Process (AHP), a multi-criteria decision-making system (MCDM), to assess and prioritize factors contributing to the underdevelopment of Arctic shipping routes. Developed by Thomas Saaty, AHP is a structured, mathematical decision-making method that allows expert judgments across multiple criteria to be quantified (Saaty, 2008). By making pairwise comparisons between criteria and sub-criteria, AHP enables qualitative expert opinions to be synthesized into quantitative rankings (Özdemir et al., 2018). Figure 3 shows the flow diagram of the steps involved in implementing AHP.

First, a literature review was conducted to find the criteria that hinder the development of the arctic route, and it was also evaluated by an expert team of 11 people, including experienced captains and academics working in the operations department. During this selection, experienced ship captains and members of the operations department who have completed at least 10 years in the profession, have detailed knowledge of the polar route, and have had the opportunity to ice navigation were selected, and expert opinions were also obtained from academics who study the poles. As a result of the research and interviews, it was determined that 6 main factors constitute obstacles to the development of the arctic route. It was also seen that each main criterion had three sub-criteria. (See Table 1).

In AHP, pairwise comparisons are used to evaluate the relative importance of each factor. For each pair of criteria (or sub-criteria), experts assign a relative importance score on a scale from 1 to 9, where 1 denotes equal importance, and 9 signifies extreme importance of one criterion over another (See Table 2).

The comparisons are organized into a pairwise comparison matrix A=[aij] where:

aij represents the relative importance of criterion i i over criterion j j.

If aij=k then aij=1/k to maintain matrix consistency.

For example, if the matrix is comparing six criteria C1, C2, C3, C4, C5, C6, the pairwise comparison matrix A would look like:

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & 1 & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & 1 & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & 1 & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 \end{bmatrix}$$

After this stage, the eigenvector calculation step is started.

Sum each column of the pairwise comparison matrix A.

Normalize each element by dividing it by the sum of its column.

Compute the average of each row in the normalized matrix to derive the priority vector

w= [w_1, w_2, w_3, w_4, w_5, w_6…, w_n] which gives the weights for each criterion.

For a matrix of size n, the formula for the priority of criterion i i is:

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right)$$

AHP performs a consistency check to ensure that the judgments in the pairwise comparison matrix are reasonably consistent. The Consistency Index (CI) is calculated as follows:

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1}$$

where λmax is the maximum eigenvalue of the matrix A, and n is the number of criteria. Testing the consistency degree of the pairwise comparison matrix (CR), the consistency ratio needs to be calculated as follows:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI}$$

RI and CI are the random index value and the consistency index value for the pairwise comparison matrix (Anxn), respectively. The random index value RI can be determined using the table of random index values or the following equation.

$$\mathrm{RI} = \frac{1.98(\mathrm{n} - 2)}{\mathrm{n}}$$

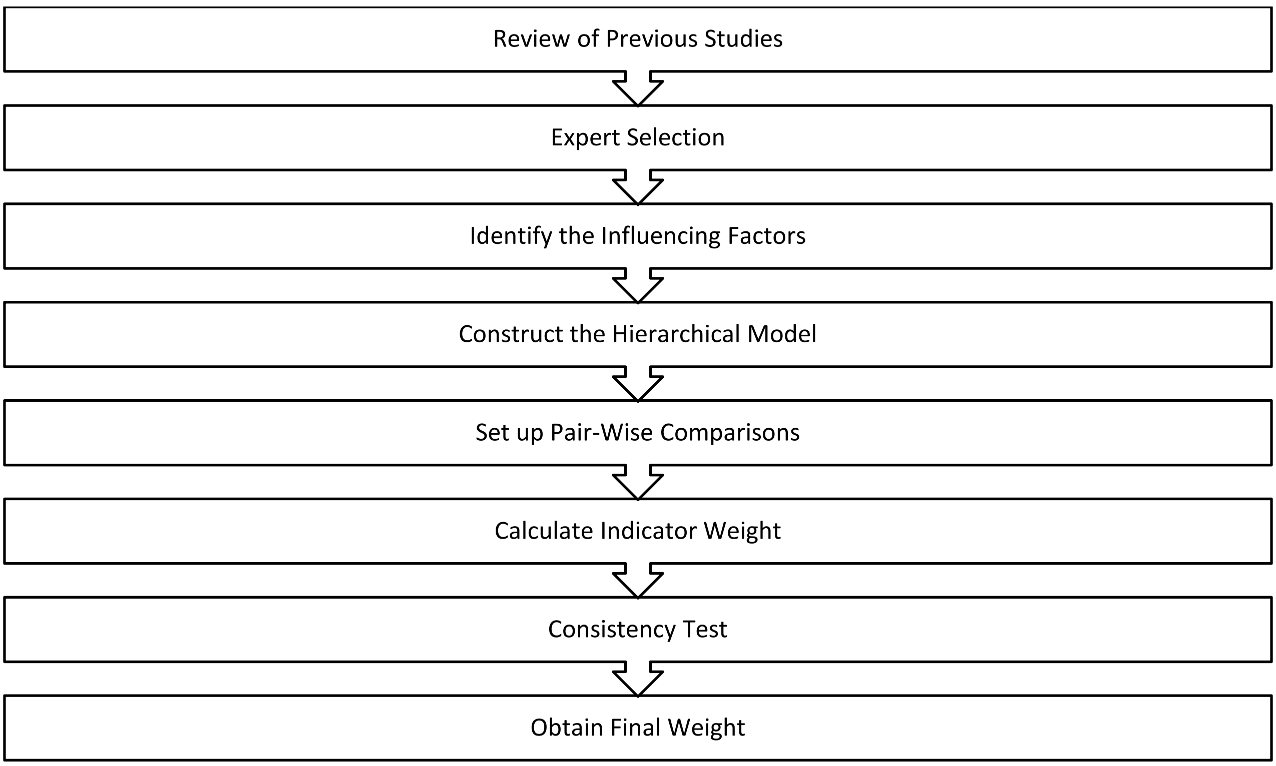

Figure 3. Flow diagram of steps involved in the implementation of AHP.

Table 1. Explanations of main and sub-criteria

C1.	Environmental and Safety Challenges
C1.1.	Unpredictable Ice and Weather Conditions
C1.2.	Inadequate Search and Rescue (SAR) Capabilities
C1.3.	Icebreaker Dependency
C2.	Infrastructure Limitations
C2.1.	Lack of Port Facilities
C2.2.	Insufficient Navigational Aids
C2.3.	Inadequate Communications Infrastructure
C3.	Economic Viability
C3.1.	High Operational Costs
C3.2.	Shallow Waters and Vessel Size Limitations
C3.3.	Seasonal Availability
C4.	Political and Regulatory Complexities
C4.1.	Jurisdictional and Sovereignty Issues
C4.2.	Compliance with the Polar Code
C4.3.	Russian Regulatory Oversight
C5.	Ecological and Social Concerns
C5.1.	Potential for Environmental Spills and Pollution
C5.2.	Impact on Indigenous Communities
C5.3.	Accelerated Ice Melt from Black Carbon
C6.	Limited International Acceptance
C6.1.	Perceived High Risk and Uncertainty
C6.2.	Lack of Inclusion in Global Supply Chains
C6.3.	Minimal Port and Supply Chain Connectivity

Table 2. Importance scale (Saaty, 2008)

Intensity of importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

If the CR value is less than 0.1, pairwise comparisons are consistent (Saaty, 2008). Otherwise, if necessary, the analysis should be reviewed and revised with different values.

Results

As a result of the comparisons made by each expert, normalized decision matrices were created and analyzed. Then, the weights-eigenvectors were created by the experts for each criterion and sub-criteria. The relative importance score of each criterion in the pairwise comparison matrix is determined by the experts' geometric means of the scores. Although these scores given by each expert are generally close to each other, there are also differences. The main criterion weights calculated according to the pairwise comparison matrices are shown in Table 3.

The study results reveal that Economic Viability (30.5%) and Environmental and Safety Challenges (29.6%) are the most significant factors contributing to the underdevelopment of Arctic shipping routes, with both factors closely competing in weight. Ecological and Social Concerns (15.7%) rank third, underscoring the importance of environmental considerations in the Arctic. Infrastructure Limitations (11.3%), Political and Regulatory Complexities (7.0%), and Limited International Acceptance (5.9%) carry relatively lower weights but still influence development decisions. Table 4 shows the weights of the sub-criteria of these criteria.

C1.1. Unpredictable Ice and Weather (14.81%): Found to be the highest weighted sub-criteria among all criteria, this sub-criterion highlights the extreme unpredictability of the Arctic. Variable ice cover and severe weather disrupt schedules, increase navigation risks, and create operational uncertainties, preventing consistent shipping operations.

C1.2. Inadequate Search and Rescue (SAR) Capabilities (3.76%): The Arctic's remote geography and limited SAR resources present significant safety risks. In emergency scenarios, response times can be long, elevating operator safety concerns.

C1.3. Icebreaker Dependency (11.03%): The sub-criterion with the fourth highest weight was found to be Icebreaker dependency. Reliance on icebreakers to ensure safe passage during long ice periods adds cost and logistical complexity. Icebreaker escorts are expensive and subject to availability restrictions, limiting the route's attractiveness for regular commercial use.

C2.1. Lack of Port Facilities (2.6%): Sparse port infrastructure limits refueling, repair, and maintenance capabilities, making the Arctic less attractive to commercial shipping. Existing ports are not equipped for large-scale operations, which can create logistical challenges for ships in transit.

C2.2. Insufficient Navigational Aids (1.9%): Navigation in the Arctic requires accurate and up-to-date aids, which are currently lacking. Without reliable navigational systems, vessels face increased risks, especially in conditions of poor visibility or rapidly changing weather.

C2.3. Inadequate Communications Infrastructure (6.78%): Communication challenges, including limited satellite and internet connectivity, affect the safety and coordination of Arctic operations. These limitations contribute to the overall risk, reducing the confidence of shipping companies in using Arctic routes.

C3.1. High Operating Costs (14.27%): High Operating Costs were found to be the second highest weighted sub-criterion after Unpredictable Ice and Weather Conditions. High operating costs (including icebreaker fees, special ship requirements, low-sulfur fuels required, and insurance premiums) weighed against environmental unpredictability, making Arctic crossings economically challenging. These costs are often prohibitive, preventing companies from considering Arctic routes as cost-effective alternatives.

C3.2. Shallow Waters and Ship Size Limitations (3.53%): The shallow depths of the Arctic route restrict the passage of larger vessels, reducing economies of scale. The inability to deploy high-capacity vessels limits profit margins, especially for container shipping.

C3.3. Seasonal Availability (12.66%): Seasonal availability was found to be the sub-criterion with the third highest weight. Due to the short and unpredictable ice-free season, the Arctic route cannot guarantee year-round accessibility, complicating long-term planning for shipping companies. This seasonality undermines the route’s viability for regular liner services that depend on consistent scheduling.

C4.1. Jurisdictional and Sovereignty Issues (1.51%): The Arctic is a region of competing territorial claims, particularly in the NSR where Russia asserts sovereignty. These disputes create legal uncertainties and potential conflicts, complicating operations for international shipping companies. However, this sub-criterion was the title with the least weight among all sub-criteria.

C4.2. Compliance with the Polar Code (3.69%): The Polar Code, established by the International Maritime Organization (IMO), imposes strict safety and environmental standards on vessels in polar waters.

Table 3. Experts' weights for the main criteria

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	FEW	PCT
C1	0.264	0.297	0.268	0.313	0.375	0.250	0.147	0.230	0.371	0.361	0.275	0.296	29.6%
C2	0.097	0.156	0.088	0.102	0.072	0.091	0.179	0.156	0.083	0.067	0.137	0.113	11.3%
C3	0.296	0.244	0.274	0.188	0.248	0.346	0.336	0.256	0.260	0.322	0.456	0.305	30.5%
C4	0.086	0.054	0.075	0.074	0.055	0.071	0.105	0.081	0.057	0.045	0.041	0.070	7.0%
C5	0.217	0.188	0.253	0.276	0.212	0.206	0.040	0.174	0.188	0.155	0.029	0.157	15.7%
C6	0.039	0.061	0.043	0.047	0.037	0.037	0.194	0.102	0.042	0.050	0.062	0.059	5.9%

*C: Criteria, E: Expert, FEW: Final Expert Weights

Tablo 4. Experts' weights on sub-criteria

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	FEW	PCT
C1.1	0.429	0.429	0.589	0.665	0.272	0.433	0.476	0.595	0.571	0.334	0.619	0.500	14.81%
C1.2.	0.143	0.143	0.252	0.104	0.120	0.101	0.072	0.129	0.143	0.098	0.096	0.127	3.76%
C1.3.	0.429	0.429	0.159	0.231	0.608	0.466	0.452	0.277	0.286	0.568	0.284	0.373	11.03%
C2.1.	0.106	0.126	0.192	0.192	0.168	0.129	0.137	0.595	0.458	0.343	0.292	0.231	2.60%
C2.2.	0.260	0.416	0.131	0.131	0.094	0.277	0.239	0.129	0.126	0.082	0.081	0.168	1.90%
C2.3.	0.633	0.458	0.677	0.677	0.738	0.595	0.623	0.277	0.416	0.575	0.627	0.601	6.78%
C3.1.	0.405	0.568	0.433	0.466	0.444	0.490	0.347	0.443	0.595	0.443	0.466	0.469	14.27%
C3.2.	0.115	0.098	0.101	0.101	0.084	0.198	0.058	0.170	0.129	0.170	0.101	0.116	3.53%
C3.3.	0.480	0.334	0.466	0.433	0.472	0.312	0.595	0.387	0.277	0.387	0.433	0.415	12.66%
C4.1.	0.106	0.113	0.122	0.104	0.241	0.400	0.328	0.443	0.241	0.411	0.088	0.218	1.51%
C4.2.	0.633	0.719	0.648	0.665	0.548	0.400	0.411	0.170	0.548	0.261	0.777	0.530	3.69%
C4.3.	0.260	0.168	0.230	0.231	0.211	0.200	0.261	0.387	0.211	0.328	0.135	0.252	1.75%
C5.1.	0.480	0.539	0.669	0.703	0.667	0.620	0.669	0.665	0.581	0.739	0.595	0.637	10.03%
C5.2.	0.115	0.164	0.088	0.182	0.111	0.156	0.088	0.104	0.110	0.082	0.129	0.119	1.87%
C5.3.	0.405	0.297	0.243	0.115	0.222	0.224	0.243	0.231	0.309	0.179	0.277	0.243	3.83%
C6.1.	0.400	0.333	0.490	0.539	0.198	0.589	0.500	0.600	0.490	0.250	0.643	0.449	2.68%
C6.2.	0.200	0.333	0.198	0.297	0.312	0.159	0.250	0.600	0.312	0.500	0.074	0.268	1.60%
C6.3.	0.400	0.333	0.312	0.164	0.490	0.252	0.250	0.200	0.198	0.250	0.283	0.282	1.68%

*C: Criteria, E: Expert, FEW: Final Expert Weights

While necessary for ecological protection, compliance with the code increases operating costs and impacts the financial burdens faced by operators.

C4.3. Russian Regulatory Oversight (1.75%): Russia's control over the NSR necessitates compliance with its regulations, including icebreaker escort fees and permit requirements. These conditions add complexity for foreign operators and can be viewed as restrictive, especially if political tensions influence regulatory practices.

C5.1. Potential for Environmental Spills and Pollution (10.03%): Environmental Spill and Pollution Potential was the sub-criterion with the fifth highest weight. With the Arctic's fragile ecosystem, environmental risks such as oil spills and black carbon emissions have heightened regulatory and public inspections. Pollution from shipping activities could have long-term ecological impacts, creating additional pressure for strict regulations.

C5.2. Impact on Indigenous Communities (1.87%): Increased shipping may disrupt traditional lifestyles and subsistence practices of Arctic Indigenous communities; concerns about cultural and environmental protections can influence policy decisions, increasing restrictions on large-scale shipping activities.

C5.3. Accelerated Ice Melt from Black Carbon (3.83%): Black carbon emissions from ships accelerate ice melt by reducing the albedo effect. This feedback loop contributes to climate change and can intensify environmental opposition to Arctic route developments.

C6.1. Perceived High Risk and Uncertainty (2.68%): The Arctic's route, affected by political situations, may encourage a perception of high uncertainty for most shipping companies. This may deter shipping companies from investing in Arctic-ready vessels or committing to the route as a reliable option.

C6.2. Lack of Inclusion in Global Supply Chains (1.6%): The Arctic's limited integration into global logistics networks means that it does not readily connect to major global supply chains. This isolation reduces the strategic value of Arctic routes for regular commercial shipping.

C6.3. Minimal Port and Supply Chain Connectivity (1.68%): The lack of developed port networks and distribution infrastructure further limits the attractiveness of the Arctic as a shipping route. Without efficient supply chain connectivity, the region cannot support the just-in-time delivery demands of modern trade.

The results of our study reveal that Economic Viability (30.5%) and Environmental and Safety Challenges (29.6%) are the most significant factors contributing to the underdevelopment of Arctic shipping routes, with both factors closely competing in weight. Ecological and Social Concerns (15.7%) rank third, underscoring the importance of environmental considerations in the Arctic. Infrastructure Limitations (11.3%), Political and Regulatory Complexities (7.0%), and Limited International Acceptance (5.9%) carry relatively lower weights but still influence development decisions.

Discussion

In this study, the Analytical Hierarchy Process (AHP) was used to assess key factors contributing to the slower-than-expected development of the Northern Sea Route (NSR) as a viable commercial maritime route. The six principal factors namely, Environmental and Safety Challenges, Infrastructure Limitations, Economic Viability, Political and Regulatory Complexities, Ecological and Social Concerns, and Limited International Acceptance Summarizes the challenges faced in Arctic route development. The results of the AHP analysis are in line with the barriers/factors identified in previous studies. This strengthens the conclusion that, despite its potential as a shorter route between Asia and Europe, the NSR remains an underdeveloped and costly option for international shipping.

Environmental and safety challenges are found as dominant factors delaying NSR development, with the second highest AHP weight (29.6%). Among its sub-factors, impacts of unpredictable ice and weather conditions (C1.1, 14.81%) are particularly significant, aligning with documented observations that variable ice conditions contribute to operational unpredictability. While ice coverage in the regions gets thinner every year due to climate change, its seasonal behaviour is inconsistent. Early freezes or sudden ice formations cause unexpected navigational challenges (Schøyen & Bråthen, 2011; Liu & Kronbak, 2010; Fedorov et al., 2020). Additionally, extreme Arctic weather, including formation of heavy fog and low temperatures, increases the complexity of year-round navigation, which limits the vessel options and inflates operational costs (Faury & Cariou, 2016; Fedorov et al., 2020).

Inadequate Search and Rescue (SAR) Capabilities (C1.2, 3.76%) is also found as an important factor that limits usage of SAR for commercial shipping route which also aligns with the previous studies (Fedorov et al., 2020; Schøyen & Bråthen, 2011). The absence of adequate emergency response facilities along the route, may cause delays in receiving assistance for vessels in distress.

Icebreaker Dependency (C1.3, 11.03%) is another critical factor. Icebreakers are crucial for safe passage through the NSR, yet their availability is limited (Faury & Cariou, 2016; Schøyen & Bråthen, 2011). Additionally, the requirement for icebreaker assistance often fails to satify the NSR's distance-related savings. In addition, icebreaker escorts can lead to slower-than-anticipated transit speeds (Liu & Kronbak, 2010).

The AHP analysis ranked Infrastructure Limitations (C2) as the fourth most significant factor. Among sub-factors, Inadequate Communications Infrastructure (C2.3, 6.78%) was identified as the most problematic.

Arctic communications remain largely outdated and unreliable, which restrains the real-time navigation and weather updates that are essential for safe operation (Xu et al., 2011; Fedorov et al., 2020; Schøyen & Bråthen, 2011). The absence of a stable communication network not only increases the risks of taking the NSR but also impacts schedule reliability.

Lack of Port Facilities (C2.1, 2.6%) and Insufficient Navigational Aids (C2.2, 1.9%) were additional factors identified by the AHP. Russia's Arctic ports capacities, such as Murmansk, in terms of repair, maintenance, and refueling capacities, are limited (Fedorov et al., 2020; Sun, 2018). The navigational aids, buoys, beacons, and radio signals that are essential in narrow or ice-covered straits are inadequate in the region which are extremely critical for safe passage (Xu et al., 2011; Schøyen & Bråthen, 2011). To avoid the risk of ships running aground, the presence of navigational aids and knowledge of the depths in the region is essential (Yildirim et al., 2017).

Economic viability is the highest-ranked factor. The High Operational Costs (C3.1, 14.27%) is the main causative sub-factor. Economic suitability is very important in maritime trade (Erol, 2023). Despite the shorter transit distance of the NSR, the route comes with unexpected operational costs, including fuel for ice-class vessels, icebreaker fees, and additional insurance premiums associated with risks of taking Arctic routes. Previous studies indicated that these costs often surpass the potential savings from shorter transit distance, especially given the limited vessel types that can profitably navigate the NSR (Faury & Cariou, 2016; Schøyen & Bråthen, 2011).

Seasonal Availability (C3.3, 12.66%) is another economic constraint. The NSR's limited navigable window, typically from July to November, restricts year-round accessibility compared to the Suez Canal (Xu et al., 2011; Liu & Kronbak, 2010). Inconsistent accessibility prevents the NSR from becoming a reliable route in global logistics, which prioritizes year-round and predictable operations.

The Shallow Waters and Vessel Size Limitations (C3.2, 3.53%) limit the economic viability of NSR. Shallow passages, particularly in the Sannikov Strait, prevent the enterance of larger container vessels to the region (Tezikov, & Ol'khovik, 2021). Consequently, the NSR primarily accommodates smaller, Arctic-class ships, that limits its capacity (Faury & Cariou, 2016; Xu et al., 2011).

Political and regulatory complexities present considerable hustle. Compliance with the Polar Code (C4.2, 3.69%) and Russian Regulations (C4.3, 1.75%) forms regulatory difficulties. The Polar Code's stricty safety and environmental standards requires specialized training and equipment, that increase operational expenses (Sun, 2018; Katysheva, 2020). Additionally, Russia's strict control over the NSR (imposing high fees and regulatory oversight) limits foreign operators, which adds uncertainty to route planning and inflating transit costs (Schøyen & Bråthen, 2011; Faury & Cariou, 2016).

Jurisdictional and Sovereignty Issues (C4.1, 1.51%) contribute to complex regulatory environment of NSR. Russia claims large portions of the route as national waters, leading to disputes over freedom of navigation and raising concerns among other countries who view parts of the NSR as international waters (Erol, 2024; Sun, 2018; Liu & Kronbak, 2010).

The results of AHP analysis highlight Ecological and Social Concerns (C5) as essential considerations. The Potential for Environmental Spills and Pollution (C5.1, 10.03%) being particularly significant. The fragile Arctic ecosystem is highly sensitive to pollution. Potential spills or black carbon emissions can cause detrimental long-term damage (Xu et al., 2011; Katysheva, 2020). Moreover, it is known that black carbon emissions not only impact Arctic ecosystems but also accelerate ice melt rate, which intensifies climate change effects (Schøyen & Bråthen, 2011; Katysheva, 2020).

Impact on Indigenous Communities (C5.2, 1.87%) and Accelerated Ice Melt from Black Carbon (C5.3, 3.83%) are other critical concerns. Indigenous communities rely on Arctic ecosystems for their livelihoods. Increased maritime activity threatens both ecological and cultural stability (Nuttal, 2007). Additionally, black carbon emissions from vessels hastens climate change, which in turn increases the risks of future Arctic operations (Xu et al., 2011; Katysheva, 2020).

Finally, Limited International Acceptance (C6) found as a relatively low weight, with Perceived High Risk and Uncertainty (C6.1, 2.68%) and Minimal Port and Supply Chain Connectivity (C6.3, 1.68%) subsections being significant. The NSR's limited infrastructure and unpredictable ice conditions increase risk, which discourage adoption of arctic routes by global shipping companies that are known to focus on efficiency and reliability (Faury & Cariou, 2016; Schøyen & Bråthen, 2011). Moreover, the NSR's limited connectivity to global supply chains further restricts its adoption as an alternative to the Suez Canal, as it cannot be easily integrated into established logistics networks (Sun, 2018).

Lack of Inclusion in Global Supply Chains (C6.2, 1.6%) also poses a barrier to the NSR's broader acceptance. With its seasonal accessibility of the region and high operational costs, the NSR struggles to gain traction among global logistics networks, which prioritize consistent, large-scale container transport (Schøyen & Bråthen, 2011; Katysheva, 2020).

Conclusion

The Northern Sea Route (NSR) is a promising but profoundly challenging option for traditional shipping routes, notably the Suez Canal. This study, using the Analytical Hierarchy Process (AHP), has systematically indicated that the NSR's development remains hindered by compound cooperation of environmental, infrastructural, economic, regulatory, ecological, and acceptance-related issues despite its potential to cut transit distances by up to 40% for Asia-Europe trade, natural and human-imposed constraints impeding the NSR's viability as a global transportation lane. Each criterion studied, from environmental challenges and safety concerns to political and ecological issues, provides a comprehensive perspective on why the NSR has not yet reached the expected level of evolution as a significant merchant maritime route.

Due to the melting ice caused by climate change, suitable opportunities for sea navigation in the Arctic region arise in the summer, but these opportunities still have some difficulties.

The ice melting did not eliminate the ice, large pieces of ice can still move at a level that will affect the voyages.

This situation makes the use of ice-class ships a necessity. In addition, the need for icebreakers in case of being trapped in ice still maintains its importance. The effect of icebreakers on voyage costs is undeniable. Countries in the region, especially Russia, are expanding their fleets day by day in order to meet this need. However, this expansion is not sufficient in the face of increasing demands.

The inadequacy of the SAR infrastructure for emergencies stands out as a very important safety risk for this route. It is understood that the capacity of the port facilities in the region is not sufficient for possible developments. Both the depths in the port, the narrow and shallow channels, and insufficient navigation aids limit the size of the ships that can come to the region. The limitation of the sizes directly affects efficiency and increases costs.

Additional costs, such as high insurance premiums and low-sulfur fuel consumption for voyages in the region, also reduce economic viability. Such deficiencies make it increasingly difficult for the route to compete with the stability offered by established routes such as the Suez Canal.

The polar code requires ships that can operate in the region to obtain a polar ship certificate. This certificate aims to increase both the structural and suitability of the vessel and the environmental awareness of the ship and its personnel. However, such positive efforts come with certain costs. In addition, the transit fees requested by the countries in the region are added to the costs as an additional item. When environmental factors are not taken into account, the impact on the local people in the region and the deterioration of the ecological balance of the region are seen as important issues to be prevented.

In conclusion, although the NSR has significant potential as a shorter and more attractive route between Asia, Europe, and America, realizing this potential requires a combined approach that addresses economic, environmental, logistical, and political challenges. Transforming the NSR into a reliable and essential shipping route will require international cooperation efforts, significant investments in Arctic infrastructure, unconditional compliance with environmental protection standards, and adjustments to regulatory frameworks. Until these innovations are implemented, it is anticipated that the NSR will remain a viable supplementary route for seasonal operations rather than large-scale commercial shipping. This study highlights that despite the distance advantages of the NSR, its multifaceted challenges make it a challenging alternative and underlines that both environmental impacts and infrastructure requirements must be carefully assessed for the NSR to fulfill its envisioned role in global trade. It also suggests that any strategy to facilitate Arctic route development must first ensure that environmental risks are reduced, economic sustainability is increased, and ecological concerns are addressed. In addition, improving SAR capabilities and developing port and communication infrastructure can create more favorable conditions for Arctic shipping and ultimately lead to wider adoption of these routes.

Ethical Statement

Not applicable.

Funding Information

This study did not receive any specific grant from public, commercial, or not-for-profit funding agencies.

Author Contribution

İshak ALTINPINAR: Conceptualization, Analysis, Investigation, Writing-Original Draft, Writing-Review & Editing Draft, Supervision, Visualization.

Conflict of Interest

The author declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

References

Abe, M., & OTSUKA, N. (2019). Northern Sea Route (NSR) as a Major Transport Route: Opportunities and Challenges. *Asian Transport Studies,* 5(4), 617-634. https://doi.org/10.11175/eastsats.5.617

Benz, L., Münch, C., & Hartmann, E. (2021). Development of a search and rescue framework for maritime freight shipping in the Arctic. *Transportation Research Part A: Policy and Practice,* 152, 54-69. https://doi.org/10.1016/j.tra.2021.07.006

Dalaklis, D., Drewniak, M., Christodoulou, A., Sheehan, R., Dalaklis, A., & Andreadakis, A. (2023). Future Arctic regulatory interventions: discussing the impact of banning the use of heavy fuel oil. *Polar Geography,* 46(2-3), 75-94.

https://doi.org/10.1080/1088937X.2023.2238794

Erol, S. (2023). Assessing the impact of the Covid-19 pandemic on the financial and economic structure performance of Turkish sea freight transport sector. *Regional Studies in Marine Science,* 57, 102749. https://doi.org/10.1016/j.rsma.2022.102749

Erol, S. (2024). The early impact of the Russia-Ukraine war on seaborne trade and transportation in the Black Sea. *Int. J. Shipping and Transport Logistics,* 18(3), 305. https://doi.org/10.1504/IJSTL.2024.139063

Faury, O., & Cariou, P. (2016). The Northern Sea Route competitiveness for oil tankers. *Maritime Economics & Logistics,* 18(2), 234–249. https://doi.org/10.1057/mel.2015.23

Fu, S., Goerlandt, F., & Xi, Y. (2021). Arctic shipping risk management: A bibliometric analysis and a systematic review of risk influencing factors of navigational accidents. *Safety Science, 139,* 105254. https://doi.org/10.1016/j.ssci.2021.105254

Fedorov, V., Katysheva, E. G., & Zaostrovskikh, E. A. (2020). The role of the Russian Arctic gas industry in the Northern Sea Route development. *IOP Conference Series: Earth and Environmental Science, 539,* 012075. https://doi.org/10.1088/1755-1315/539/1/012075

Ford, J. D., Pearce, T., Canosa, I. V., & Harper, S. (2021). The rapidly changing Arctic and its societal implications. *Wiley Interdisciplinary Reviews: Climate Change,* 12(6), e735. https://doi.org/10.1002/wcc.735

Gregory, J. M., Stott, P. A., Cresswell, D. J., Rayner, N. A., Gordon, C., & Sexton, D. M. H. (2002). Recent and future changes in Arctic sea ice simulated by the HadCM3 AOGCM. *Geophysical Research Letters,* 29(24), 28-1. https://doi.org/10.1029/2001GL014575

Hänsel, M. C., Schmidt, J. O., Stiasny, M. H., Stöven, M. T., Voss, R., & Quaas, M. F. (2020). Ocean warming and acidification may drag down the commercial Arctic cod fishery by 2100. *PLoS One,* 15(4), e0231589. https://doi.org/10.1371/journal.pone.0231589

Helle, I., Mäkinen, J., Nevalainen, M., Afenyo, M., & Vanhatalo, J. (2020). Impacts of oil spills on Arctic marine ecosystems: A quantitative and probabilistic risk assessment perspective. *Environmental Science & Technology,* 54(4), 2112-2121. https://doi.org/10.1021/acs.est.9b07086

Huntington, H. P., Danielson, S. L., Wiese, F. K., Baker, M., Boveng, P., Citta, J. J., De Robertis, A., Dickson, D. M. S., Farley, E., George, J. C., Iken, K., Kimmel, D. G., Kuletz, K., Ladd, C., Levine, R., Quakenbush, L., Stabeno, P., Stafford, K. M., Stockwell, D., & Wilson, C. (2020). Evidence suggests potential transformation of the Pacific Arctic ecosystem is underway. *Nature Climate Change,* 10. 342. https://doi.org/10.1038/s41558-020-0695-2

International Maritime Organization (IMO), IMO. (2023). 2020–cutting sulphur oxide emissions. Retrieved July 29, 2024, from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Polar-default.aspx.

Inoue, J., Yamazaki, A., Ono, J., Dethloff, K., Maturilli, M., Neuber, R., ... & Yamaguchi, H. (2015). Additional Arctic observations improve weather and sea-ice forecasts for the Northern Sea Route. *Scientific Reports,* 5(1), 16868. https://doi.org/10.1038/srep16868

Karahalil, M., Ozsoy, B., Basar, E., & Satır, T. (2021). The evaluation of the Polar Code by the survey conducted with those who have sailed in polar regions, and suggestions for further improvement. *Marine Policy,* 128, 104502. https://doi.org/10.1016/j.marpol.2021.104502

Katysheva, E. G. (2020). The role of the Russian Arctic gas industry in the Northern Sea Route development. *IOP Conference Series: Earth and Environmental Science, 539,* 012075. https://doi.org/10.1088/1755-1315/539/1/012075

Nuttall, M. (2007). An environment at risk: Arctic indigenous peoples, local livelihoods and climate change. *In Arctic alpine ecosystems and people in a changing environment* (pp. 19-35). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-48514-8_2

Liu, M., & Kronbak, J. (2010). The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe. *Journal of Transport Geography,* 18(3), 434–444. https://doi.org/10.1016/j.jtrangeo.2009.08.004

Makarova, I., Gubacheva, L., Makarov, D., & Buyvol, P. (2021). Economic and environmental aspects of the development possibilities for the northern sea route. *Transportation Research Procedia,* 57, 347-355. https://doi.org/10.1016/j.trpro.2021.09.060

Özdemir, Ü., Altinpinar, İ., & Demirel, F. B. (2018). A MCDM approach with fuzzy AHP method for occupational accidents on board. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation,* 12(1), 93-98. https://doi.org/10.12716/1001.12.01.10

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences,* 1(1), 83-98. https://doi.org/10.1504/IJSSCI.2008.017590

Schøyen, H., & Bråthen, S. (2011). The Northern Sea Route versus the Suez Canal: Cases from bulk shipping. *Journal of Transport Geography,* 19(5), 977–983. https://doi.org/10.1016/j.jtrangeo.2011.03.003

Sun, Y. (2018). The Northern Sea Route: The myth of Sino-Russian cooperation. *Stimson Center*. Retrieved from https://www.stimson.org

Tezikov, A., & Ol'khovik, E. (2021, June). Generalized model of maritime transport of the Northern Sea Route. In *Proceedings of the 26th International Conference on Port and Ocean Engineering under Arctic Conditions*.

United Nations Conference on Trade and Development (UNCTAD), UNCTAD (2024) Review of maritime transport. Retrieved November 01, 2024, from https://unctad.org/meeting/launch-review-maritime-transport-2024.

Xu, H., Yin, Z., Jia, D., Jin, F., & Ouyang, H. (2011). The potential seasonal alternative of Asia-Europe container service via Northern sea route under the Arctic sea ice retreat. *Maritime Policy & Management,* 38(5), 541-560. https://doi.org/10.1080/03088839.2011.597449

Yildirim, U., Ugurlu, O., Basar, E., & Yuksekyildiz, E. (2017). Human factor analysis of container vessel's grounding accidents. International Journal of Maritime Engineering, 159(A1). https://doi.org/10.5750/ijme.v159iA1.1012

Zhang, Y., Meng, Q., & Ng, S. H. (2016). Shipping efficiency comparison between Northern Sea Route and the conventional Asia-Europe shipping route via Suez Canal. *Journal of Transport Geography*, 57, 241-249. https://doi.org/10.1016/j.jtrangeo.2016.09.008