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Environmental Risk Analysis of Different Segments of The Arctic Northeast Route

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Abstract: There are huge differences in the sea ice conditions, climate and environment, geographical conditions and communication conditions in the Arctic waters, and the equipment and navigation requirements of ships are also different. In order to ensure the safety and success of the ships, through the route, this paper using fuzzy level analysis (Fuzzy Analytic Hierarchy Process, FAHP), build the northeast arctic route risk evaluation index system, targeted analysis of different segments, the results show that: (1) although the sea risk point is different but the natural environment risk has a significant impact on the arctic waters.(2) The risk coefficient of Arctic route is higher than that of traditional ordinary routes. Among the five sea areas in this study, Chukchi Sea is the highest, followed by East Belia Sea. The crew need to pay more attention when sailing.(3) The research in this paper can provide a reference for the navigation safety of the northeast Arctic shipping route.

Keywords: Arctic northeast route; Navigation environment analysis; Fuzzy level analysis; Fuzzy comprehensive evaluation.

1. Introduction

Global warming and the melting of sea ice are providing more opportunities for the development of international shipping and enhancing global attention to the Arctic routes. However, the harsh natural conditions, poor shipping infrastructure, and scarcity of ports along the Arctic routes currently exacerbate the risks of navigation. Therefore, a comprehensive and systematic analysis of the navigational environment of different segments of the Arctic Northeast Passage, and the identification of its risk factors, are of great importance for the safety of Arctic navigation.

Foreign scholars have conducted extensive research on the navigational environment of the Arctic routes, covering aspects such as channels, climate, ice conditions, and ships. As the importance of the Arctic region has become increasingly prominent, related research has also been further developed and improved. Li, ZF used the grey fuzzy comprehensive evaluation method to assess the navigational environment of the Arctic routes, concluding that hydrological factors, navigational aids, and information factors are the most crucial elements affecting the navigational environment of the Arctic routes, providing a reference for smooth navigation in the Arctic. Bi, WL, and others employed the Analytic Hierarchy Process to establish a navigational model for the Arctic routes, determining the weights of various indicators and concluding that the Arctic is unsafe but navigable. Wen-Hwa, Shyu used the fuzzy AHP based on the AHP expert questionnaire to analyze respondents' opinions, exploring their attitudes towards the construction of the Arctic routes. The results showed that "safety and risk" are the most significant aspects affecting the construction of the Arctic routes. Although China's research on the Arctic started relatively late, influenced by the Ice Silk Road, Chinese scholars have gradually increased their research on the Arctic region in the past decade. Domestic scholars' research is mainly focused on navigational feasibility, navigational environment analysis, and geopolitics. Li, Zhenfu evaluated the geopolitical security index of the Arctic routes from a geopolitical perspective, concluding that it is at a "third-level" standard. Ma, Xiaoxue evaluated the safety level of the Arctic routes based on resilience theory and used the Bayesian network method for quantitative assessment, further enhancing the safety and success of Arctic navigation. Cao, Yunfeng started from the rapid melting of sea ice, researching the changing pattern of navigational capacity of various Arctic routes in recent years, concluding that the navigational potential of the Arctic routes is continuously increasing. Li, Fengpeng focused on the Arctic navigational environment and, using a comprehensive evaluation method, assessed the navigational risks of the Arctic routes, concluding that the main risk factors affecting the navigation of ships in the Northeast Passage, in descending order, are the density of sea ice, temperature, and visibility, providing a reference for the navigation of the Arctic routes. As can be seen, both domestic and foreign scholars' analyses of the safety factors of the Arctic routes are more focused on exploring the safe navigation of the Arctic routes from a risk perspective.

The research of the aforementioned scholars provides important theoretical support for the safety of navigation on the Arctic routes. However, the analysis of the aforementioned studies shows that current academic research on the safety of the Arctic routes mostly starts from its entirety, lacking an analysis of the differences in risk between different segments. Compared to other routes, the Arctic routes are quite special, and a thorough analysis of the navigational environment of the Arctic routes is necessary. Therefore, it is necessary to analyze the navigational environment of different segments of the Northeast Passage from the perspective of conditional differences, study the impact of various risk factors on the safe navigation of ships, and conduct a comparative analysis. By analyzing the risks of different segments, it is possible to predict which route is safer, which risk factors of the chosen route are the most important factors affecting the safe navigation of ships, and allow shipping companies and crews to take safer protective measures.

This paper builds a risk assessment index system based on the safety risk characteristics of different segments of the Arctic Northeast Passage, attempting to identify several risk factors affecting the navigational environment of the Arctic

Northeast Passage and establish an evaluation index system. The Fuzzy Analytic Hierarchy Process (FAHP) and fuzzy comprehensive evaluation are used to assess the risks of different routes in the Arctic Northeast region, establishing a risk assessment model for different segments of the Arctic Northeast Passage, and ultimately measuring the risk levels of each segment. On this basis, it provides a decision-making reference for the safe navigation of the Northeast Passage.

2. Environmental and Risk Analysis of the 5 Major Segments of the Northeast Passage

2.1. Risk Analysis of the Arctic Northeast Passage by Segment

Navigational risk refers to the potential dangers and disasters that may occur during the navigation of ships. This paper summarizes the main factors of navigational risks of the Arctic Northeast Passage as natural environmental risks, geopolitical risks, dynamic navigational aids, and static navigational aids. Detailed analysis is shown in Figure 1.

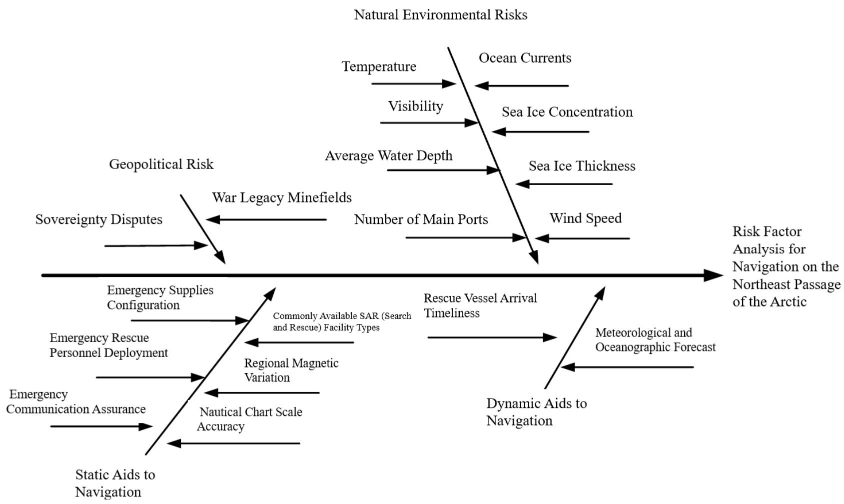

Figure 1. Fishbone chart of factors affecting navigation risk of Northeast Arctic route

The natural environment is a crucial factor affecting the navigation of the Arctic Northeast Passage, with the following main impacts: currents (ocean currents), sea ice, wind, temperature, visibility, channel depth, and the distribution of major ports. The natural environment of the Arctic Northeast Passage has a significant impact on both shipping safety and economic efficiency. It necessitates the reliance on high-tech means for ships and navigation equipment to strengthen monitoring, forecasting, and response measures to ensure the smooth and safe navigation of the route, as shown in Table 1, Table 2 and Table 3.

(1) Analysis of Natural Environmental Risk Factors

Table 1. Natural Environmental Risk Factors

Point of risk	Specific Diagnostic Results
Ocean current	The ocean currents around the Arctic consist of two main systems: the coastal gyre and the oceanic circulation. Coastal currents are significantly influenced by sea ice and land topography, while oceanic currents are influenced by global ocean circulation, playing an essential role in the climate and ecological environment of the Arctic region.
Sea ice	Sea ice is the most significant natural environmental factor affecting the navigability of the Arctic routes. When the sea ice is thick, it increases the resistance and friction for ships traveling through the ice, reducing the speed and efficiency of the vessels. When the sea ice is dense, it makes the ice harder to break or penetrate, increasing the risks and difficulties of navigation. Therefore, in Arctic navigation, it's crucial to adjust the ship's route and speed timely according to the thickness and density of the sea ice to ensure safe and smooth navigation.
The wind	The Arctic region is highly susceptible to weather changes due to its climate, so wind speeds often change rapidly. The Northeast Arctic waters often experience unique meteorological phenomena such as blizzards and uneven distribution of day and night time in winter, intensifying the variability of wind speed in the region. The high wind speeds generate correspondingly large waves, posing significant challenges to maritime transport, fishing, and seabed oil and gas exploration.
Temperature	Temperature is one of the important factors affecting the navigational environment of the Arctic Northeast Passage. High temperatures can lead to more storms and meteorological disasters in the Arctic region, increasing the risks of ship navigation at sea. Low temperatures causing ice layer thickening and expansion of ice-covered areas can affect ship maneuvering and crew living conditions.
Visibility	Visibility in the Northeast Arctic waters is affected by ice and snow coverage. Fog is a primary factor causing low visibility in Arctic waters.
Mean water depth	The average water depth of the Northeast Arctic waters plays an important role in the navigability of the Arctic Northeast Passage. If the average water depth in the Northeast Arctic waters is shallow, the difficulty of navigation will significantly increase, requiring more precise route planning and higher-tech ships to pass through. Additionally, the shallow water depth can also affect the ship's speed, leading to decreased transportation efficiency.
Supply port along the line	Supply ports along the Arctic include ports, islands, and cities located along the Arctic coast. Major supply ports include Murmansk, Dixon, Tiksi, Pevek, and Provideniya. It should be noted that these coastal ports face harsh weather and sea conditions throughout the year. Investments are required to continually improve and upgrade port infrastructure and equipment to ensure support, security, and services for various activities in the Arctic region.

(2) Analysis of Geopolitical Environmental Risk Characteristics

Table 2. Geopolitical Environmental Risk Factors

Point of risk	Specific Diagnostic Results
Minefields left over from war	During World War II, the Arctic Northeast Passage was an important route used by the Soviet Union for transporting materials and troops. Many ships from warring nations were sunk in this area, resulting in a large number of unexploded war remnants, such as mines, in the region. These unexploded ordnance and naval mines not only pose a threat to the safety of the shipping lanes in the area but can also impact the ecology and environment of the region. With the reduction of Arctic sea ice, the time these unexploded ordnance are covered by ice is decreasing, further intensifying the safety risks in the area.
Disputes over sovereignty	In terms of war remnant minefields, the Barents Sea is an important shipping area and was also a significant battleground for naval battles between the Soviet Union and Germany during World War II. Over time, a large number of unexploded bombs, shells, mines, and other war remnants have accumulated in the waters of the Barents Sea, forming war remnant minefields. These pose significant risks to activities such as ship anchoring and oil and gas exploration in the sea. The Chukchi Sea was also one of the battlegrounds where the Soviet Union and Germany conducted naval battles during World War II. In this area, a large number of unexploded shells, bombs, and other war remnants have accumulated, forming war remnant minefields.

(3) Analysis of the Completeness of Dynamic Navigational Aids

Table 3. Dynamic Navigational Equipment

Point of risk	Specific Diagnostic Results
Timeliness of arrival of rescue ships	The timeliness of the arrival of rescue ships refers to the period during which the action of rescue ships is valuable in the event of a maritime emergency, and this period of time is inversely proportional to the effectiveness of the response. The speed of the rescue directly impacts the timeliness of the rescue ships. In this paper, the overall distance is calculated based on the distances between the two ends of each sea area. Using the MarineTraffic software for measurement and statistics, the approximate distance for each sea area can be obtained, as shown in Figure 2.
Weather and sea state forecast	Weather and sea condition forecasts are based on meteorological conditions and changes in the marine environment to predict the weather and sea conditions of a certain sea area for a future period. Weather and sea condition forecasts in the Arctic region are primarily conducted through various remote sensing technologies, marine observation equipment, and numerical models. Among these five sea areas, the Barents Sea has the best meteorological and hydrological environment nearby, which is most conducive to the conduct of rescue activities. The Kara Sea has the worst meteorological and hydrological environment.

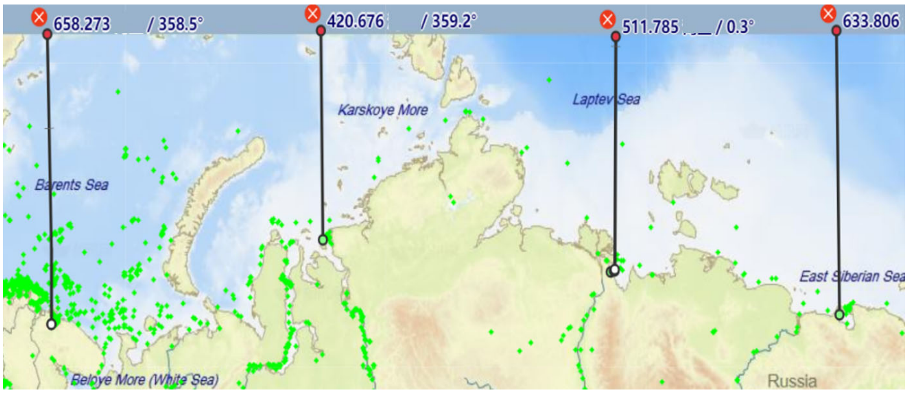

Figure 2. Distance Map of the 5 Major Arctic Northeast Seas

Based on the statistics of the "NSR" transits reported by the China National Oceanic Administration (https://arctic-lio.com/) from 2012 to 2020, arc4 ice-class ships have the highest frequency of transits through the NEP; therefore, Arc 4 is taken as the object of study. According to the document, the cruising speed of ARC4 is 22 knots. Therefore, the timeliness of rescue ships reaching each sea area can be roughly calculated based on time = distance ÷ speed, as shown in Table 4 and Table 5.

Table 4. Timeliness of Rescue Ship Arrival

	Murmansk	Dixon	Tiksi	Pevek	Provideniya
Distance/nautical mile	658	420	510	633	785
Speed/knot	22				
Time /h	30	19	23	29	36

(4) Analysis of the Completeness of Static Navigational Aids

Table 5. Static Navigational Equipment

Point of risk	Specific Diagnostic Results
Emergency supplies allocation	Medical resources are limited, making the treatment and transport of the injured challenging.
Emergency responders are working hard	The lack of infrastructure and high operating costs lead to insufficient search and rescue capabilities, making it difficult to conduct personnel rescues and resulting in less investment in rescue personnel.
Typically, the SAR device type is available	The search and rescue equipment types for the Arctic Northeast Passage include, but are not limited to: satellite communication devices, radar and sonar equipment, search and rescue aircraft and helicopters, lifeboats and life rafts, cold-weather clothing, and warming equipment.
Emergency communications support conditions	Communication equipment performance along the entire Northeast Passage is poor, with no signal reception for devices other than Iridium phones above 75°N latitude.
Regional magnetic difference	Near the Magnetic North Pole, the magnetic variation changes rapidly with geographical location, significantly impacting navigation. The Kara Sea is affected by magnetic storms, experiencing about ten days per month with a magnetic variation of 4°. In the Laptev Sea, severe magnetic storms occur no more than 4-5 days per month, but the number of days with a magnetic variation reaching 4° can also be about ten days. In the East Siberian Sea, the number of days with a magnetic variation of 4° can reach 10-12 days.
Accuracy of chart scale	Due to the remote geographical location and harsh climate of the region, there has been a long-term lack of support from ships and shore station data. Therefore, the update of nautical charts for this region lags behind, and the accuracy of the nautical charts is relatively low.

3. Data Collection and Model Building

3.1. Data Collection

3.1.1. Indicator Construction

Table 6. Risk Assessment System for Northeast Passage Navigation

		Barents Sea	Kara Sea	Laptev Sea	East Beria Sea	Chukchi Sea
Risks to natural environment	Ocean currents	＞3/4 knots	>1/2 knots	3/4 knots	>1/2 knots	＞1/4 knots
	Sea ice density	＜33%	About 50%	35%-50%	30%-40%	＞40%
	Sea ice thickness	0	10-40%	10-40%	60-90%	30-60%
	Wind speed	11-12 knots	8-9 knots	3-4 knots	4-5knots	13-15knots
	Temperature	Summer 0°C-10°C	Summer 1°C~6°C	Summer 0°C-4°C	0°C-10°C	Summer -2~5°C
	Visibility	×	×	×	15-20t	15-20t
	Average water depth (in meters)	229	118	519	45	88
	Number of major ports	3	6	2	2	2
Geopolitical risk	War remnant minefields	Yes	×	×	×	Yes
	Sovereignty disputes	Yes	×	×	×	Yes
Dynamic AIDS to navigation	Timeliness of rescue ship arrival	30	19	23	29	36
	Weather and sea condition forecasts	5	1.33	3.67	2.33	2.33
Static AIDS to navigation	Emergency supplies configuration	Model 1100 floating gate model 830 floating gate	Model 1100 floating gate model 830 floating gate	Type 600 floating gate desmi-250	Type 1100 floating gate type 830 floating gate National Bureau of Statistics	Type 830 floating gate National Bureau of Statistics
		Smith desmymini max Scepter	Smith desmymini max Scepter	Oil gathering system	valosep b2 adsorbent	valosep b1 type adsorbent
		Inflatable boat with suspension motor	Inflatable boat with suspension motor			
	Investment in emergency rescue personnel	4 people	4 people	3 people	3 people	3 people
	Typically available SAR (Search and Rescue) equipment types	RB/RV/LRG	RB/RV/LRG	RB/RV/LRG/SRG/HEL-L/HEL-M	RB/RV/LRG/SRG/HEL-L/HEL-M	RB/RV/LRG/SRG/HEL-L/HEL-M
	Emergency communication assurance conditions	79°N	82°N	81°13' N	72° 17′ N	69°N
	Regional magnetic variation	×	10t	10t	10-12t	×
	Nautical chart scale accuracy	＜1：1000000	＜1：1000000	＜1：1000000	＜1：1000000	＜1：1000000

Table 7. Data Sources for Bottom-Level Indicators of the Risk Assessment System for Arctic Northeast Passage Navigation

Metrics	Data Sources:
Ocean current	Liu Yiying and others, He Peilong and others, Arctic Navigation Guide, https://www.shipxy.com/
Sea ice density	Duan Chenglin and others, He Peilong and others, Arctic Navigation Guide
Sea ice thickness	Bai Xiangen and others, Liu Yiying and others
Wind speed	He Peilong and others, Yan Li and others, Arctic Navigation Guide, https://report.shipxy.com/
Temperature	Jiang Baode and others, https://www.liquisearch.com/laptev_sea/climate, https://seatemperature.net/seas/east-siberian-sea
Visibility	Bai Xiangen and others, Arctic Navigation Guide
Mean water depth	Arctic Navigation Guide
Number of major ports	https://www.worldatlas.com/seas/barents-sea.html
Minefields left over from war	He Peilong and others, Arctic Navigation Guide
Disputes over sovereignty	He Peilong and others, Arctic Navigation Guide
Timeliness of arrival of rescue ships	Yang Liu and others, https://www.shipxy.com/
Weather and sea state forecast	Liu Yiying and others
Emergency supplies allocation	http://www.nsra.ru/ru/pso.html
Emergency responders are working hard	http://www.nsra.ru/ru/pso.html
Usually the type of SAR facility is available	http://www.nsra.ru/ru/pso.html
Emergency communications support conditions	Fan Houming and others
Regional magnetic difference	Arctic Navigation Guide
Accuracy of chart scale	Overview of the British Admiralty Charts

3.2. Model Building

3.2.1. Quantification of Indicator Weights

The Analytic Hierarchy Process (AHP) is a multi-factor decision analysis method that transforms decision-making problems into hierarchical structures. Through quantitative and qualitative methods and expert opinions, the problems are analyzed and resolved to reach the optimal decision-making solution. This paper first divides the impact degree of fuzzy evaluation corresponding to the indicator into 5 levels, namely, very low safety (VL), low safety (L), medium safety (M), high risk, and very high risk (VH). By calculating, a risk degree evaluation set is formed, as shown in Table 6 and Table 7.

In quantifying the weights of the indicators, for each level, the importance of each indicator is determined. The trapezoidal fuzzy numbers of Gupta et al. are used to judge the impact degree of the main dimensions, objectives, and indicators of the judgment layer to form a judgment matrix, thereby determining the weights of each indicator. The trapezoidal fuzzy number is represented as A(a1, a2, a3, a4), and the 5 levels of impact degree correspond to 5 trapezoidal fuzzy numbers, as shown in Table 8 and Table 9.

Table 8. Risk Degree Scale Table

Vague comment	Trapezoidal fuzzy number
Safe navigation(VL)	(0,0,0.1,0.2)
Relatively safe(L)	(0.1,0.25,0.25,0.4)
Average(M)	(0.3,0.5,0.5,0.7)
Relatively dangerous(H)	(0.6,0.75,0.75,0.9)
Dangerous(VH)	(0.8,0.9,1,1)

3.2.2. Indicator Weight Measurement

Through the Fuzzy Analytic Hierarchy Process (FAHP), the weights of the indicators are determined. Assuming there are n sea areas, the risk degree of the mth sea area is $E\mathrm{m}\,(\mathrm{m},1,2,\cdots \mathrm{n})$, determined according to the trapezoidal fuzzy number corresponding to its risk degree scale, and the fuzzy evaluation set is $E\mathrm{m}\,(\mathrm{a}_1,\ \mathrm{a}_2,\ \mathrm{a}_3,\ \mathrm{a}_4)$. The specific process is shown below.

(1) Measure the binary consistency between evaluations of different sea areas in the Arctic Northeast Passage.

$$S_{UW}\left(\overline{E}_u,\overline{E}_w\right)=1-\frac{1}{4}\left|a_i-b_i\right| \quad i=1,2,3,4 \tag{1}$$

(2) Measure the average consistency of each sea area's evaluation. If the average consistency of the uth expert's evaluation is $AA\left(E_u\right)$, then its calculation formula is:

$$RA\left(E_u\right)=\frac{AA\left(E_u\right)}{\sum_{u=1}^{N}\left(\overline{E}_u,\overline{E}_w\right)} \tag{2}$$

Table 9. Diagnostic Results of the Navigational Risk of the Northeast Passage

Degree of risk	Barentsian Sea	Kara Sea	Laptev Sea	East Berea Sea	Chukchi Sea
Ocean current	VH	L	VH	L	VH
Sea ice concentration	VL	VH	VH	M	VH
Sea ice thickness	VL	L	L	VH	M
Wind speed	H	M	VL	VL	VH
Temperature	VL	VH	L	H	L
Visibility	H	H	H	H	H
Mean water depth	H	VH	VL	VH	VH
Number of major ports	VH	VL	VH	VH	VH
Minefields left over from war	VH	VL	VL	VL	VH
Disputes over sovereignty	VH	L	L	L	VH
Timeliness of arrival of rescue ships	H	VL	L	H	VH
Weather and sea state forecast	VL	VL	H	H	H
Emergency supplies allocation	VH	VL	VH	M	M
Emergency responders are working hard	L	L	M	M	M
Typically, the SAR device type is available	H	VH	VH	VL	VL
Emergency communications support conditions	H	H	L	L	L
Regional magnetic difference	H	H	H	H	H
Accuracy of chart scale	H	H	H	H	H

(3) Measure the relative consistency of each sea area's evaluation. If the relative consistency of the uth expert's evaluation is $RA\left(E_u\right)$, then its calculation is

$$RA\left(E_u\right)=\frac{AA\left(E_u\right)}{\sum_{u=1}^{N}AA\left(E_u\right)} \quad (3)$$

(4) Consistency coefficient test: Test the consistency coefficient of the feature vector to ensure the credibility of the assessment results.

$$CC\left(E_u\right)=\beta\cdot P\left(E_u\right)+(1-\beta)\cdot RA(E_u) \quad (4)$$

(5) Measure the cluster fuzzy number of the sea area's evaluation under this indicator.

$$\overline{R}_A=CC\otimes\overline{E}_1\oplus CC\otimes\overline{E}_2\oplus\cdots CC\,E_u\otimes\overline{E}_u \quad (5)$$

(6) Conduct fuzzy processing, measure the defuzzified indicator weights.

$$X=\frac{1}{3}\frac{(a_4+a_3)^2-(a_2+a_1)^2-a_4a_3+a_1a_2}{a_4+a_3-a_2-a_1} \quad (6)$$

(7) Normalize the results.

$$NX_q^i=\frac{X_q}{\sum_{q=1}^{n}X_q} \quad (7)$$

Table 10. Results of Indicator Weights

Risk Level	Index Weight	Uniformization
Sea Currents	1.1637	0.0631
Sea Ice Density	1.1145	0.0604
Sea Ice Thickness	1.2062	0.0654
Wind Speed	0.81089	0.044
Temperature	0.7463	0.0406
Visibility	1.3123	0.0711
Average Water Depth	1.3132	0.0712
Number of Major Ports	1.3834	0.075
War Legacy Minefields	0.7083	0.0384
Sovereignty Disputes	0.8828	0.0479
Response Time of Rescue Ships	0.9819	0.0532
Meteorological and Sea Conditions Forecast	0.867	0.047
Emergency Supplies Configuration	0.8534	0.0462
Intensity of Emergency Rescue Personnel Deployment	0.7021	0.0381
Types of Usually Available SAR Facilities	0.788	0.0427
Conditions for Emergency Communication Assurance	0.9882	0.0536
Regional Magnetic Variation	1.3123	0.0711
Accuracy of Nautical Chart Scale	1.3123	0.0711

3.2.3. Constructing the Evaluation Matrix

$$NX_q^i = \frac{X_q}{\sum_{q=1}^{n} X_q} \tag{7}$$

3.2.4. Fuzzy Synthesis

Fuzzy synthesis is a decision-making method that integrates multiple indicators, factors, or evaluation systems through mathematical model processing of various information. It is suitable for decision-making problems with many indicators, where the interactions and connections between indicators are complex and difficult to describe with precise numerical values. The fuzzy synthesis method adopts the idea of fuzzy mathematics and can effectively consider the impact of various factors, improving the scientific nature and accuracy of decision-making.

(1) Establish the evaluation model: In this paper, different rows in R reflect the membership degree of the five major sea areas based on different single indicators to the fuzzy subsets of each level. The fuzzy weight vector A is used to synthesize different rows, obtaining the overall membership degree of the evaluated sea area to the fuzzy subsets of each level, i.e., the fuzzy comprehensive evaluation result vector. Introduce a fuzzy subset B on V, called the fuzzy evaluation set, also known as the decision set. B(b1，b2，b3,⋯bn)

(2) Data processing: Use statistical methods and fuzzy mathematical theories to preprocess the evaluation factors, transforming and standardizing uncertain or fuzzy data. B=A*R (* as an operator symbol).

Synthetic operation method M=(Λ,⊕)

$$S_k = \min\left\{1, \sum \min(u,r)\right\}, k = 1, 2, ...$$

Judgment and decision-making: Based on the fuzzy synthesis model, calculate the comprehensive evaluation value of each factor, further establish the judgment matrix, and derive the final decision-making conclusion based on the judgment matrix.

$$B = (0.9112, 0.8806, 0.8915, 0.971, 0.9847)$$

4. Evaluation Results Analysis

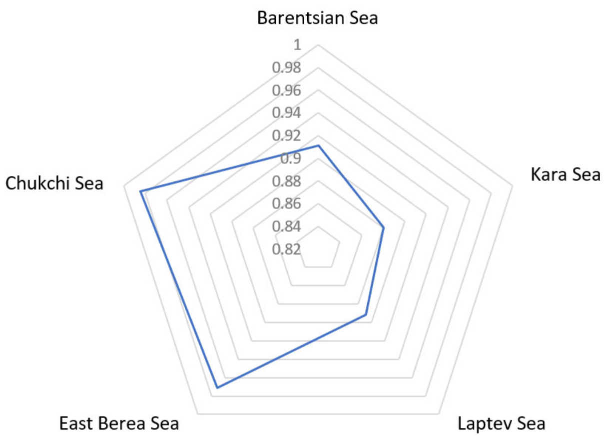

Figure 3. Risk Analysis of the Navigational Environment of Different Segments of the Arctic Northeast Passage

4.1. Evaluation of Influencing Factors

Based on statistical and measurement results, and referring to formulas (1)~(7), the binary consistency, average consistency, relative consistency, consistency coefficient, cluster fuzzy number are sequentially calculated, and then defuzzification is performed to obtain the defuzzified weight, normalized weight, and integrated weight of the indicators. The measurement results are shown in Table 10.

Based on the risk evaluation results, the following analysis is made:

Among the five major sea areas, the Chukchi Sea poses the highest navigational risk, followed by the East Siberian Sea. The Barents Sea, Kara Sea, and Laptev Sea have relatively lower navigational risks. For the five major sea areas, natural environmental factors have the most significant impact. Among them, sea ice, visibility, average water depth, and the number of major ports pose higher risks. In terms of geopolitical environmental risks, the Barents Sea and Chukchi Sea segments have higher risks. The completeness of dynamic and static navigational aids has a relatively smaller impact on the navigational risks of the five major sea areas, as shown in Figure 3.

5. Conclusion

The geographical environment of the Arctic region is complex. This paper analyzes and evaluates the navigational environment of the five major segments of the Arctic Northeast Passage, using methods such as Analytic Hierarchy Process and fault tree analysis to quantify its risk points and make a relatively objective evaluation of the results, thereby determining the risk levels of different segments.

Based on the specificity, differences, and complexity of the natural environmental conditions of the five major segments of the Northeast Passage and human intervention, extensive basic data for each segment are collected, indicators are quantified, an indicator evaluation system is constructed around risk causes, and a fuzzy analytic hierarchy model is used to determine the weight of indicators, ensuring the objectivity and credibility of the importance of indicators. This provides important navigational tips and references for polar sailors before heading to different waters.

The results of the Northeast Passage indicator weights determined by the fuzzy resolution model show that ocean currents, sea ice density, sea ice thickness, visibility, and the number of major ports are the five most important risk factors affecting the navigation risks of the Northeast Passage. The research results place greater emphasis on the attention and investment in the safe navigation of polar sailors, which significantly compensates for the uncertainty caused by excessive reliance on subjective judgment in the study.

Affected by temperature, compared to traditional routes, navigation in the Arctic Northeast is usually risky. This proves that risk identification for using the Northeast route is very necessary, and this result provides an important reference for polar sailors navigating in the Arctic.

In conclusion, the analysis and evaluation of the navigational environment of different segments of the Arctic Northeast Passage are very complex and require considering multiple factors. Ships should be equipped and respond specifically for different segments. The analysis in this paper can provide a scientific reference for the navigational safety of ships on this route.

References

[1] Ford J D, McDowell G, Jones J. An Evaluation of the Arctic Route's Navigation Environment. Environmental Research Letters, 2014, 9(10): 104005.

[2] Research on Model Establishment of Environment Evaluation of Arctic Route Navigation.

[3] Key Factors Influencing the Building of Arctic Shipping Routes.

[4] Li Zhenfu. Study on the Geopolitical Security Index of the Arctic Route. Computer Engineering and Applications, 2011, 47(35): 237-241.

[5] Ma Xiaoxue, Zhou Qun, Liu Yang. Research on the Safety Evaluation of the Arctic Route from the Perspective of Resilience Theory - Based on the Bayesian Network Method. Mathematics in Practice and Theory, 2020, 50(11): 299-308.

[6] Cao Yunfeng, Yu Meng, Hui Fengming, et al. Progress in Research on Navigation Capability Changes in the Arctic Ice Zone. Science Bulletin, 2021, 66(01): 21-33.

[7] Li Fengpeng, Cui Wei, Liu Zhenqiang. Multidimensional Index Evaluation of Navigation Risks in the Arctic Waterway Based on the DSR Model. Computer Simulation, 2022, 39(10): 138-142.

[8] Jia Zhizun. Research on Sino-Russian Cooperation in the Development of the Northern Sea Route. Jilin University, 2022.

[9] He Peilong, Ma Xiaoxue, Zhang Jingwen, et al. Risk Evaluation of Different Segments of the Arctic Northeast Route Based on Fuzzy Hierarchical Analysis - Multi-level Extension. Polar Research, 2021, 33(2): 279-293.

[10] Liu Yiyong. Economic Viability and Emergency Response to Marine Incidents on the Arctic Route: A Complex Network Study. Dalian Maritime University, 2016.

[11] Tian Jing, Zhang He, Wu Yue, Li Xuehua, Lu Hui. Application and Reflection of Remote Consultation in Arctic Medical Rescue. South China Journal of Defense Medicine, 2022, 36(05): 396-399.

[12] Xiao Yang. Arctic Air and Sea Search and Rescue Cooperation: Achievements, Problems, and Prospects. Journal of Ocean University of China (Social Science Edition), 2014, No.134(03): 8-13.

[13] Fan Houming, Zhao Qiqi, Liu Yiyong. Emergency Response Complex Network for Arctic Maritime Rescue. China Navigation, 2016, 39(02): 76-81+105.

[14] Fan Houming, Li Xiaoxuan, Liu Yiyong, et al. Evolutionary Game Simulation Study on Arctic Environmental Governance Response Complex Network. Management Review, 2017, 29(2): 26-34.

[15] Fan Houming, Zhao Qiqi, Liu Yiyong. Emergency Response Complex Network for Arctic Maritime Rescue. China Navigation, 2016, 39(2): 76-81+105.

[16] Christodoulou A, Dalaklis D, Raneri P, et al. An overview of the legal search and rescue framework and related infrastructure along the Arctic Northeast Passage. Marine Policy, 2022, 138: 104985.

[17] Warfield J N. Societal systems planning, policy and complexity. Cybernetics and System, 1978, 8(1): 113-115.

[18] Cai Changlin. Reachability Matrix and Structural Model of Systems. Journal of Systems Engineering, 1992(1): 145-152.

[19] Xiao Renbin, Fei Qi. Research on the Interpretive Structural Modeling Algorithm. Systems Engineering Theory and Practice, 1993(2): 28-32+57.

[20] Attri R, Dev N, Sharma V. Interpretive structural modelling (ISM) approach: an overview. Research journal of management sciences, 2013, 2319(2): 1171.

[21] Yu V F, Chiang F Y, Le T H A, et al. Using the ISM Method to Analyze the Relationships between Various Contractor Prequalification Criteria. Applied Sciences, 2022, 12(8): 3726.