Technical Economic Analysis of Container Ship Transportation on the Arctic Northern Sea Route

Jiayu Dai [a], Ming Yin [b]

School of Shanghai Maritime University, College of Transport & Communications, Shanghai International Shipping Institute, Shanghai 201306, China

[a]15001867191@163.com, [b]yinm@shmtu.edu.com

Abstract

Taking the actual situation of M.V. V, a full container vessel of a shipping company, navigated the Arctic Northern Sea Route (NSR) as an example. Based on the cost analysis, the economic comparison between the NSR and the traditional Suez route is carried out. The relevant questionnaires are designed and the experts are invited to score each factors. The weight of each factor is determined by the Fuzzy Analytic Hierarchy Process (FAHP). The quantitative characterization of some indicators is combined with the expert's scores to determine the comprehensive evaluation scores of the two routes. Data processing is performed with MATLAB.. The research results show that the freight unit cost of the NSR is about 53.2% higher than that of the traditional route. And the NSR does not have a direct economic advantage. However, according to the experts' comprehensive evaluation of factors such as turnover, safety and environmental protection and combining with the actual situation of the routes, the data are revised and finally the score of the NSR is 7.0, which is higher than the 6.7 of the traditional route, indicating that the NSR still has certain expansion potential compared with the traditional route.

Keywords

Arctic route, container ship, technical economy, FAHP.

1. Introduction

With global warming and melting of Arctic glaciers, some frozen areas may become seasonal or permanently navigable. The Arctic Northern Sea Route (NSR) has reduced the fuel consumption by nearly 40% of the distance between Asia and Europe and nearly 20 days of sailing time compared to the traditional Suez Canal route. However, the navigation period of the NSR is generally 3 to 5 months, and the seaworthy vessel must meet the Ice Class level. The exhaust gas generated by the navigation of the ship will affect the Arctic environment. Therefore, whether the NSR has economic benefits is a research hotspot in recent years. The literature [1] improved the GTAP model and studied the economic impact of the northeast arctic route on different countries and regions. And the literature [2] studied Arctic shipping lines and seaworthy ships through GIS and route operation data.

The Arctic route is generally composed of the NSR and the Northwest Passage (NWP). This paper mainly studies the NSR. Previously, many scholars have studied the navigation of ships on the NSR: Reference [3] studied the navigation of bulk carriers on the NSR, the Suez Canal and the Cape of Good Hope. This study compared the fuel consumption, CO2 emissions, navigation fees and supply chain transportation risks. In [4], descriptive statistics and multiple regression analysis was used to analyze the fixed cost, fuel cost and cargo volume of dry bulk vessels and liquid bulk carriers of ice and non-ice grades, and also evaluated the profit potential. In [5], the entropy weight method and principal component analysis method was used to compare the economic benefits of LNG ships of different ship types in the navigation of the NSR and the Suez Canal. Reference [6] compared the

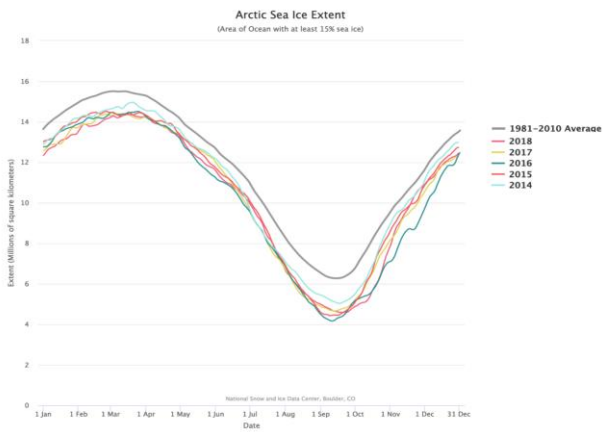
NSR with the traditional route for the ARC6 ice class tanker for route mileage, unit voyage cost and necessary freight rate. Reference [7] verified the technical and economic feasibility of container liner transportation along the NSR through several modes of transportation, such as the NSR, the traditional Suez route and the railway crossing Siberia. Literature [8] used the cost analysis method to compare the NSR with the traditional route for container transportation from Shanghai to Rotterdam. Reference [9] considered the size of the liner and the anti-ice charter and idle cost. The feasibility of transporting the liner on the NSR was judged by comparing the NSR with the traditional route.

According to the research of literature [10], the main seaworthy ships in the NSR are liquid bulk carriers, dry bulk carriers and general cargo ships. Container shipping routes in NSR has certain limitations: First, the NSR is currently restricted to container ships carrying 4500TEU. Second, due to seasonal factors in the NSR, container ships need to change their navigation plan within one year. Third, the environment of the NSR has high requirements for ship design and crew quality.

To sum up, most of the existing literatures only carry out qualitative or quantitative analysis on the economic characteristics of ships sailing the NSR. Scholars' researches on the NSR mainly focus on bulk carriers, general cargo ships and oil carriers, while few researches on container ships are supported by practical cases. The innovative explorations of this paper mainly include: 1) Supplementing and updating the relevant indicators and data based on the existing ship economy research results; 2) Combine quantitative analysis and qualitative analysis, conduct comprehensive analysis of shipping line routes from the aspects of turnover, safety, economy and environmental protection, design questionnaires and score each factor by experts, and use Fuzzy Analytic Hierarchy Process (FAHP) to process expert evaluation; 3) The comprehensive evaluation scores of the NSR and traditional Suez routes are determined by combining the quantitative characterization of route turnover and economy with the scoring results of safety and environmental protection by experts.

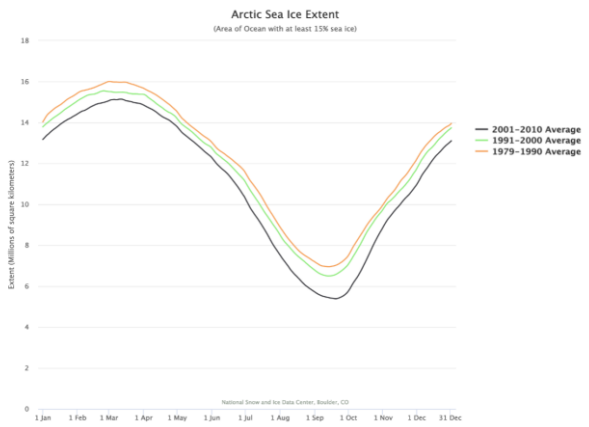
2. Overall navigation of the NSR

Since 1978, the arctic sea ice area has decreased and the sea ice coverage has decreased[11]. The Arctic sea ice range has a natural seasonality. Sea ice coverage in the Arctic from 1981 to 2018 was obtained through the National Snow and Ice Data Center website. Sea ice usually reaches its maximum extent at the end of winter in March and its minimum extent at the end of summer in September. It can be seen from Fig.1 that the sea ice coverage in 2014-2016 showed a downward trend, with a slight increase in 2017-2018. The average coverage of sea ice decreased significantly in the past five years compared with 1981-2010. In Fig.2, the Arctic sea ice area has declined in all months, with the sea ice area decreasing the most in September and the least in winter.



Source: National Snow and Ice Data Center

Fig.1 The value of the Arctic sea ice range in 2014-2018 and the average of the Arctic sea ice range from 1981 to 2010



Source: National Snow and Ice Data Center

Fig.2 Average range of Arctic sea ice in 1979-1990, 1991-2000 and 2001-2010

As the concentration of carbon dioxide and other greenhouse gases in the atmosphere increases, the Arctic sea ice melts rapidly. It is predicted that the NSR will be navigable all year in 2030. The NSR begins in the northwest of Europe near the north cape of Norway, passes through Eurasia and the northern coast of Siberia, and crosses the bering strait to the Pacific Ocean[12]. The NSR is the shortest route between Asia and Europe. Compared with the traditional Suez route, it has great advantages in navigation distance and navigation time.

According to the statistics released by the Northern Sea Route Information Office, from 2014 to 2018, the NSR began roughly in July and ended in December, with an average of approximately 125 days of aerospace. The total number of five-year navigation vessels was 144. The average sailing time on the NSR is 12 days. The specific data is shown in Table 1.

Table 1 NSR navigation details from 2014 to 2018

Year	Start date	End date	Total days	Total number of ship	Average sailing time
2014	6.28	11.16	141	54	15.5
2015	7.3	12.1	133	18	10.6
2016	7.27	11.17	113	18	14.3
2017	8.15	12.6	113	27	10.2
2018	7.24	12.3	132	27	10.6
Source: Northern Sea Route Information Office					

3. Cost-based Economic Research on the NSR

On August 23, 2018, a shipping company with a container capacity of 3,600 TEU, the M.V. V, a full container vessel of a shipping company, departed from Vladivostok, Russia[13], entered the NSR through the Bering Strait, and arrived in St. Petersburg on September 28. It is the first container ship of the world to explore the NSR. This paper will choose Vladivostok as the departure port and St. Petersburg as the destination port, and take the NSR and the traditional Suez route as the navigation routes. It will analyze and compare the two routes in terms of route mileage, navigation time and voyage cost. The specific route trajectory is shown in Fig.3.

Souce: MailOnline

Fig.3 Schematic diagram of NSR and traditional Suez route

3.1 Route Comparison

The NSR is set to Vladivostok - Bering Strait - Northeast Passage - Bremerhaven - St. Petersburg, the traditional Suez route is set to Vladivostok - the Straits of Malacca - Suez Canal - St. Petersburg. The NSR is linked to 5 ports, and the traditional Suez route is linked to 7 ports.

Route mileage: See Table 2 for comparison of route mileage between the NSR and traditional channel. As can be seen from the table, the NSR saves 31.4% of the voyage compared to the traditional route.

Table 2 Comparison of NSR and traditional Suez route voyages

Departure port	Destination poat	NSR/n mile	Suez/n mile	Voyage difference/n mile	Save mileage/%
Vladivostok	St. Petersburg	7200	10500	3300	31.4%

(2) Ship type: The NSR is a 3600 TEU ice class container ship with a load of 42,000 tons. The traditional route is a 3600 TEU Panamax container ship with a load of 42,000 tons.

Sailing time: The voyage time from Vladivostok to St. Petersburg through the NSR is 37 days, the sailing time is 23 days. The voyage time from Vladivostok to St. Petersburg through the traditional route is 52 days, and the sailing time is 34 days.

3.2 Cost Comparison

The main cost components of container shipping include capital cost, operating cost and voyage cost. The capital cost of a ship mainly consists of depreciation and interest expense. The operating cost consists of crew fee, insurance fee, maintenance fee, lubricant fee, management fee and other operating fees. The voyage cost mainly consists of fuel, port, canal and other voyage costs.

3.2.1 Capital Cost

Ship depreciation: The V vessel was delivered in July 2018. According to the monthly data of the global shipbuilding industry in July 2018, a new ordinary ship’s cost of the 3600 TEU container ship was 37.5 million USD, and the ice class ship’s cost twice as many as the ordinary ship. Referring to the current demolition market, the price of the ship is about 450 USD/net ton. The depreciation charge is calculated according to the annual average method. The daily depreciation charge for the ice class container ship is 4100 USD, and the daily depreciation fee for the Panama container ship is 2100 USD.

Interest expense: The interest generated by a shipping company for the construction of a ship to a bank or other financial institution.

3.2.2 Operating Cost

(1) Crew fee: The V vessel is equipped with 26 specially trained crew members, whose wages are 20% higher than those on traditional routes[8]. Panamax container ships generally have 20 crew members. According to the estimate of the ship staff's market released in September 2018, the first-month ship staff of the NSR is 90,000 USD, and the traditional route has a monthly salary of 60,000 USD.

(2) Insurance fee: Including ship insurance, freight insurance, crew insurance, etc., accounting for 5% of the total cost. The insurance fee for container ships on NSR is 50% higher than that on traditional routes[8]. In addition, due to the presence of pirates in the Somali waters of traditional route, the required piracy insurance fee is 0.2% of the total cost[14].

(3) Maintenance fee: The annual maintenance cost of the ship is 0.2% of the total cost[8].

(4) Lubricant fee: 5% of fuel costs[8].

(5) Management fee: The shipping enterprise needs to carry out management work, including dispatching business, ship maintenance, safety supervision. And this part of the expenses is apportioned according to the ship, accounting for about 30% of the total cost.

(6) Other operating fees: Including fresh water supply, postal electricity and nautical books, accounting for 2% of management fee[8].

3.2.3 Voyage Cost

(1) Fuel cost: Refer to Singapore Fuel Price, from August to September in 2018, the average value of 380CST is 468 USD/ton, and the average value of MDO is 680 USD/ton. The V vessel used low-sulfur oil on the NSR. The current price difference between low-sulfur oil and heavy oil is 200

USD/ton, that is, the price of low-sulfur oil is 668 USD/ton. The daily fuel consumption during the voyage is 92 tons, and the daily fuel consumption when berthing at the port is 10 tons.

(2) Port cost: Berthing ports mainly consider ship tonnage tax, parking fees, garbage fees and loading and unloading fees. According to the current relevant fee collection standards for mainstream ports in Western Europe, the vessel tonnage tax includes fixed fees, tonnage fees and liner shipping tariffs, of which the fixed fee is about 20.28 USD, the tonnage fee is about 1.74 USD/GT, and the liner shipping tariff is about 0.33 USD/GT. The parking fee is approximately 0.20 USD/GT; the garbage fee consists of a fixed fee and a variable fee, of which the fixed fee is 123.45 USD and the variable fee is 0.006 USD/GT. According to data released by the Atlantic Contaier Line (ACL), the loading and unloading cost of the port is about 72.75 USD/TEU.

(3) Canal fee: Calculate the cost of a single canal through the Suez Canal according to the data published by the Suez Canal Authority (SCA) in Table 3. The 1 SDR is equivalent to 1.392 USD. The calculated canal fee is approximately 240,400 USD.

Table 3 Suez Canal tolls at full load (SDR/SCNT)

Type	SC Net Tonnage				
	First 5000	Next 5000	Next 10000	Next 20000	Next 30000
Container ship	7.88	5.41	4.2	2.94	2.73

(4) Escort Fee: Since 2013, the Russian government has adjusted the navigation system of mandatory use of icebreakers in the NSR, but the V vessel still used the Russian icebreaker to open the way for navigation of the NSR. The icebreaker charges 14 USD per ton[14], which means the cost of using the icebreaker is about 588,000 USD. In 2008, NATO began to maintain military escort in Somali waters. Currently, participating countries include the United States, Russia, China, Japan, India and the European Union. Vessels can receive armed protection after submitting escort applications. Therefore, the cost of armed escort in Somali waters on traditional Suez route is not considered here.

3.2.4 Comparing Results

Calculation of voyage cost according to various data sorted out from 3.2.1-3.2.3 is shown in table 4. Inside:

Total transportation cost = capital cost + operating cost + voyage cost

Freight unit cost = voyage cost / freight turnover

Freight turnover = freight tonnage × sailing distance

Table 4 Comparison of route transportation costs (unit: 10,000 USD)

Cost		NSR	Suez
Capital Cost	Ship depreciation	15.17	10.92
	Interest expense	/	/
Operating Cost	Crew fee	11.1	10.4
	Insurance fee	39.58	33.88
	Maintenance fee	1.52	1.07
	Lubricant fee	7.54	7.93
	Management fee	166.35	158.30
	Other operating fees	3.33	3.17
Voyage Cost	Fuel cost	150.87	158.63
	Port cost	100.24	119.33
	Canal fee	0	24.04
	Escort Fee	58.8	0
Total transportation cost		554.49	527.67
Freight unit cost（USD/1000tons·n mile）		18.34	11.97

As can be seen from Table 4, the total transportation cost of NSR is higher than that of the traditional Suez route, and the freight unit cost of NSR is about 53.2% higher than that of the traditional route.

The proportion of capital cost, operating cost and voyage cost to the total cost is analyzed respectively. According to the results shown in Fig. 4 and 5, it can be seen that the cost of each part of the two routes accounts for a similar proportion of the total cost. The higher freight unit cost of the NSR than the traditional route may be caused by higher management fee and escort fee.

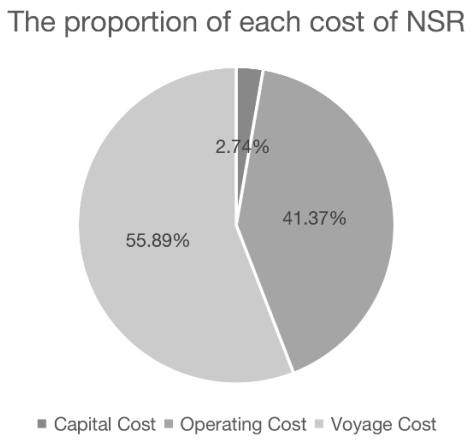


Fig.4 The proportion of each cost of NSR

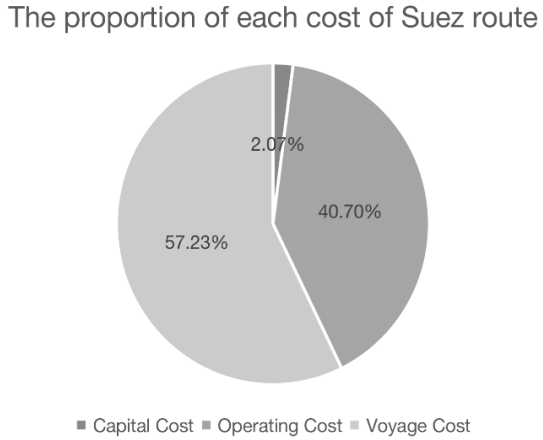


Fig.5 The proportion of each cost of Suez route

4. Evaluation of Technical Economic Factors of NSR by FAHP

When doing a technical economic analysis of a specific route, in addition to considering the economy purely based on the cost, the overall consideration should be given to the turnover of the vessel navigation (Refers to the number of times a vessel makes a round trip within the navigation time range due to the influence of navigation distance and speed), as well as safety. With the implementation of the 2020 Sulfur Limit, environmental factor will also be an important component of route selection.

Because the Analytic Hierarchy Process (AHP) can't guarantee the consistency of thinking when there are many evaluation indicators, it needs to conduct consistency test. In order to simplify the steps and improve the accuracy of decision making, the Fuzzy Analytic Hierarchy Process (FAHP) is selected for analysis and evaluation in this paper.

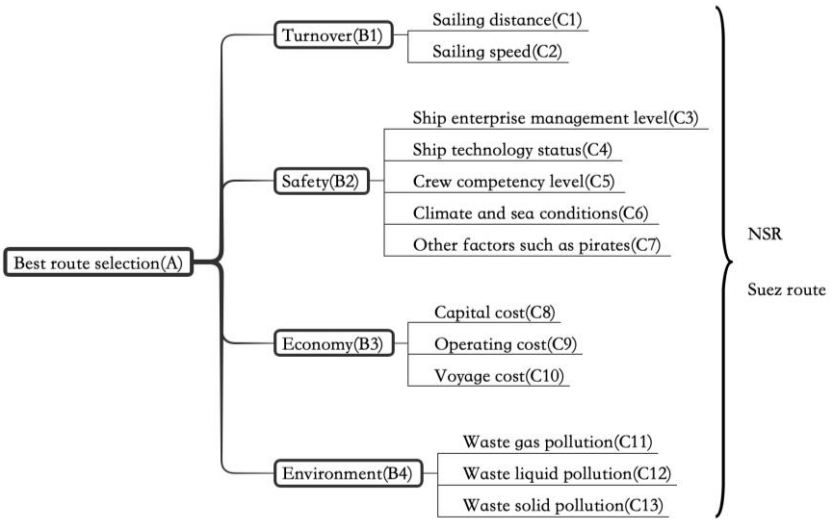


Fig. 6 Route selection feature hierarchy

In order to select route with higher comprehensive efficiency, the first factor of turnover, safety, economy and environmental protection is established. And a multi-level hierarchical structure model that decomposes each factor again on the basis of the first layer of factors. The specific hierarchy is shown in Fig. 6.

The main steps for selecting best route through FAHP are: 1) Identify the factors that affect route selection and establish a multi-level hierarchical structure model. 2) The experts scored the same layer of factors in pairs and established a fuzzy judgment matrix. 3) Determine the relative importance of the factors through calculation. 4) Calculate the comprehensive evaluation score of routes and judge the two routes.

Model Establishment

(1) Establishment of fuzzy complementary judgment matrix

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

Inside, $a_{ii}=0.5, i=1,2,\cdots,n;\ a_{ij}+a_{ji}=1, i,\ j=1,2,\cdots,n;$

$a_{ij}=0.5$ means that two factors are equally important. If $a_{ij}\in[0.1,0.5)$, factor x_j is more important than x_i. If $a_{ij}\in(0.5,0.9]$,factor x_i is more important than x_j.

(2) Construct a fuzzy uniform matrix $R=(r_{ij})_{n\times n}$

$$r_i=\sum_{k=1}^{n} r_{ik}, i=1,2,\cdots,n \tag{2}$$

$$f_{ij}=\frac{r_i+r_j}{2n}+0.5 \tag{3}$$

(3) Calculating Single Ranking of Layers

$$\overline{s_i}=\frac{s_i}{\sum_{j=1}^{n} s_i}, i=1,2,\cdots,n \tag{4}$$

$$w_0=(\overline{s_1},\overline{s_2},\cdots,\overline{s_n}) \tag{5}$$

Inside, $s_i=(\prod_{j=1}^{n} r_{ij})^{\frac{1}{n}}$

(4) Hierarchical total ordering

$$w_n^{(1)}=\prod_{k=2}^{k=n} w_k^{(k-1)}=w_n^{(n-1)}w_{n-1}^{(n-2)}\cdots w_3^{(2)}w_2^{(1)} \tag{6}$$

$$w_k^{(k-1)}=(w_1^{(k)},w_2^{(k)},\cdots w_{k-1}^{(k)}) \tag{7}$$

4.1 Fuzzy Judgment Matrix(FJM)

The data of the fuzzy judgment matrix of each layer is obtained by means of expert questionnaire survey. The content of the questionnaire is mainly composed of the relative importance of the factors and the scores of the two routes. A total of 30 questionnaires were distributed and collected, of which 4 came from government departments, 18 from port and shipping enterprises and 8 from research institutions. All the interviewees had rich management, practice or research experience.

By processing the data obtained from experts' judgment on the relative importance of factors, fuzzy judgment matrices between layers A and B and between layers B and C are obtained. Specific data are shown in Table 5-9.

Table 5 A-B FJM

A	B1	B2	B3	B4
B1	0.5	0.65	0.67	0.59
B2	0.35	0.5	0.75	0.63
B3	0.33	0.25	0.5	0.62
B4	0.41	0.37	0.38	0.5

Table 6 B1-C FJM

B1	C1	C2
C1	0.5	0.72
C2	0.28	0.5

Table7 B2-C FJM

B2	C3	C4	C5	C6	C7
C3	0.5	0.69	0.7	0.65	0.64
C4	0.31	0.5	0.68	0.66	0.43
C5	0.3	0.32	0.5	0.69	0.65
C6	0.35	0.34	0.31	0.5	0.6
C7	0.36	0.57	0.35	0.4	0.5

Table 8 B3-C FJM

B3	C8	C9	C10
C8	0.5	0.67	0.66
C9	0.33	0.5	0.63
C10	0.34	0.37	0.5

Table 9 B4-C FJM

B4	C11	C12	C13
C11	0.5	0.7	0.68
C12	0.3	0.5	0.66
C13	0.32	0.34	0.5

4.2 Each factor allocates weight

The weights of each factor in FAHP were calculated by MATLAB, and the results are shown in Table 10. According to the ranking of various factors, experts generally believe that turnover has the greatest impact on route selection.

Table 10 Weight and ranking of route factors

B layer factor	B layer weight	C layer factor	C layer weight	Total weight	Rank
Turnover	0.2758	Sailing distance	0.5557	0.1533	1
		Sailing speed	0.4443	0.1225	2
Safety	0.2645	Ship enterprise management level	0.2274	0.0601	9
		Ship technology status	0.2032	0.0537	10
		Crew competency level	0.1984	0.0525	11
		Climate and sea conditions	0.1839	0.0486	13
		Other factors such as pirates	0.1871	0.0495	12
Economy	0.2311	Capital cost	0.3703	0.0856	4
		Operating cost	0.3289	0.0760	5
		Voyage cost	0.3009	0.0695	7
Environment	0.2286	Waste gas pollution	0.3760	0.0860	3
		Waste liquid pollution	0.3289	0.0752	6
		Waste solid pollution	0.2952	0.0675	8

4.3 Route Comprehensive Evaluation Score

In the second part of the 30 questionnaires, experts processed the data obtained by scoring each index 1-10 of the two routes to obtain the average score of each factor of the two routes. And then, combined with the total weight of each factor in Table 10, the comprehensive score of routes was calculated. Specific data are shown in Table 11.

Table 11 Comprehensive evaluation scores of NSR and Suez route under various factors

factor	B1		B2					B3			B4			Comprehensive
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	

NSR	8.4	6.3	8.1	8.1	8.2	7.7	6.1	7.1	7.2	7.8	7.1	7.4	7.1	7.4
Suez	7.1	7.6	7.4	7.4	7.5	7.3	6.6	6.7	7.2	7.2	7.0	7.0	6.9	7.1

Although relevant indicators can be quantitatively characterized to a certain extent (quantitative characterization of turnover and economy is relatively easier), experts are still required to make subjective judgments based on their cognition and experience when comparing their mutual importance. Correspondingly, it is necessary to revise the score in combination with the economic research on NSR and traditional route in the second part of this paper. The data of turnover and economic factors are shown in Table 12, and the revised scores are shown in Table 13.

Table 12 Specific data of turnover and economic factors

factor	Sailing diatance (n mile)	Sailing speed (knot)	Capital cost (Ten thousand USD)	Operating cost (Ten thousand USD)	Voyage cost (Ten thousand USD)
NSR	7200	13.04	15.17	229.41	309.91
Suez	10500	12.87	10.92	214.75	302.00

Table 13 Comprehensive evaluation scores of NSR and Suez route under the revised factors

factor	B1		B2					B3			B4			Comprehensive
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	
NSR	6.7	7.7	8.1	8.1	8.2	7.7	6.1	4.6	6.8	6.6	7.1	7.4	7.1	7.0
Suez	4.6	7.6	7.4	7.4	7.5	7.3	6.6	6.4	7.3	6.8	7.0	7.0	6.9	6.7

Comparing the revised comprehensive scores of the NSR and the traditional Suez route, it can be concluded that the NSR have a slight advantage over the traditional route after considering the turnover, safety, economy and environmental protection.

5. Conclusion

Based on the actual situation of the V vessel navigation the NSR, this paper compares the economic cost with the traditional Suez route, and its freight unit cost is about 53.2% higher than the traditional route. In order to further compare the technical economic characteristics of the two routes, this paper considers the factors of turnover, safety, economy and environmental protection. By means of questionnaire, experts scored each factor, and FAHP model was adopted to determine the weight of each factor. Finally, the quantitative representation of turnover and economy was combined with the scoring results of experts on the two routes to determine the comprehensive evaluation score of the two routes. The results show that the NSR has a slight advantage over the traditional route.

The NSR is the shortest shipping route between Asia and Europe. In this comparison, the distance is 31.4% shorter than the traditional route, the sailing time is 11 days shorter, and the fuel consumption is reduced. Since the V vessel used low sulfur oil on the NSR while the ship on the traditional route is still heavy oil, the difference in fuel costs is not significant. However, with the implementation of the sulfur restriction in 2020 and carbon emission reduction in 2050, the fuel cost gap between the two routes will continue to increase, and the economic advantages of ships on traditional route will gradually decrease.

With global warming, the coverage of Arctic sea ice is gradually shrinking. Some experts predict that there will be no ice on NSR and their coasts in 2030, or it will be able to achieve annual navigation. The limitations imposed by the current seasonal navigation of the NSR will be disintegrated in the future, that is, container ships can achieve liner shipping on the NSR. The opening of this route can not only speed up the turnover of ships, but also reduce the cargo damage caused by pirates, because it avoids the region where Somali pirates are located.

Due to the special requirements of the ship's structure and function of the hull in the Arctic, and the crew also need special training, the NSR has no direct economic advantage. However, combining

turnover, safety and environmental protection factors to score the two routes, the comprehensive evaluation score of the NSR is slightly higher than that of the traditional route, indicating that the NSR has certain potential for expansion.

References

[1] X.N. Cong, M.Wang: CGE Analysis of Potential Influence of the Arctic Northeast Passage on Global Economics and Its Strategic Implications, China Soft Science, vol. 8 (2017), p. 21-33.
[2] L. Guan, B. Yan, N. Wang: Spatio-Temporal Pattern of China-Europe Arctic Shipping Routes and Seaworthy Ship, Navigation of China, vol. 41(2018), p. 128-133.
[3] H. Schøyen, S. Bråthen: The Northern Sea Route versus the Suez Canal: cases from bulk shipping, Journal of Transport Geography, vol. 19(2011), p. 977-983.
[4] T. Solakivi, T. Kiiski, L. Ojala: The impact of ice class on the economics of wet and dry bulk shipping in the Arctic waters, Maritime Policy & Management, vol. 45(2018), p. 1-13.
[5] T. Yu, Y. Ding, G.L. Lin: Economic benefit evaluation of LNG ship through the Northeast Passage based on entropy weight method, Journal of Dalian Maritime University, vol. 43(2017), p. 50-57.
[6] J. Gao, C.F. Deng, J. Fu, et al. Economic Analysis of Crude Oil Tanker Using Arctic Northeast Sea Route, Navigation of China, vol. 41(2018), p.127-130.
[7] J. Verny, C. Grigentin: Container shipping on the Northern Sea Route, International Journal of Production Economics, vol. 122(2009), p.107-117.
[8] Z.F. Li, X. You, W.Y. Wang, et al. Economic Analysis of the Container Shipping on the Arctic Northeast Route, Journal of Jimei University(Philosophy and Social Sciences), vol. 18(2015), p. 34-40.
[9] Z.F. Li: Liner transportation in northeast Arctic, feasible or not, China Ship Survey, vol. 9(2017), p. 25-28.
[10] Y. Zhang, Q. Meng and L. Zhang: Is Northern Sea Route attractive to shipping companies? Some insights from recent ship traffic data, Marine Policy, vol. 73(2016), p. 53-60.
[11] M.C. Serreze, W.N. Meier: The Arctic's sea ice cover: trends, variability, predictability, and comparisons to the Antarctic, Annals of the New York Academy of Sciences, vol. 1436(2018), p. 36-53.
[12] B. Ellis, L. Brigham: Arctic marine shipping assessment 2009 report, Arctic Council.
[13] J.Y. Zheng: Maersk "breaking ice" first test water Arctic channel, Tianjin Navigation, vol. 148(2018), p. 82.
[14] Z.Q. Qian, L. Xu, X.P. Yan, et al. Navigation strategy and economic research of the northeast passage in the Arctic, Chinese Journal of Polar Research, vol. 27(2015), p. 203-211.