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Exploring the Economic Significance of Arctic Routes in the Supply Chain Field by Contrasting with Traditional Route

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Abstract: With global climate warming, the reduction of Arctic ice and the opening of shipping routes during the summer season, the Arctic route has gradually become an important choice in the field of supply chains as it connects Asia, Europe, and North America. It offers the advantages of reducing shipping time, lowering transportation costs, expanding trade opportunities, and diversifying supply chain routes. This article collected data from websites such as the Clarksons and the Shanghai Shipping Exchange to investigate the current number of voyages along the Arctic route and various factors that impact the cost of navigation. By comparing the navigation costs between the Arctic route and the traditional Suez Canal route, it was found that the Arctic region has higher voyage transportation costs compared to the Suez route, indicating that the Suez route still holds an economic advantage. However, choosing the Arctic route can shorten the delivery lead time and reduce certain supply chain costs.

Keywords: Arctic shipping route, supply chain, delivery lead time, economic analysis, logistics costs

1. Introduction

On March 23, 2021, the vessel "Ever Given," operated by Taiwan-based shipping company Evergreen Marine Corp, ran aground near the entrance of the Suez Canal while traveling from south to north. This incident caused a significant disruption in the supply chain between Europe and Asia. As a direct consequence, there was a partial interruption in the global supply chain in the short term, and the overall cost of the supply chain increased in the long term due to delays and increased logistics costs caused by the congestion of ships. This led to higher shipping rates and an increase in the prices of bulk commodities. Consequently, diversifying transportation methods and establishing more supply chains may become the next development trend. Building a more robust industrial supply chain and a more comprehensive and diversified logistics supply chain service network are important directions for future industrial and trade development [1].

In the entire supply chain, it is evident that logistics plays a crucial role. Not only does it connect various links within the supply chain, but it also facilitates the effective division of labor and collaboration among different enterprises. Therefore, strengthening the core of supply chain management, which is efficient logistics process management, is crucial for achieving value chain appreciation and value addition [2]. Optimizing logistics management within the supply chain can be reflected in the optimization of logistics transportation routes. The main focus of this article is to

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explore the significant implications of Arctic routes in the field of supply chain. By investigating the current navigation data of Arctic routes and various factors influencing navigation costs, the study aims to compare the navigation costs of Arctic routes with the traditional Suez Canal route. This exploration seeks to determine whether the current Arctic routes can achieve diversification and a more diverse logistics supply chain service network.

2. Determining Voyage Costs

2.1. Setting Voyage Parameters

Due to the location of the Northeast Passage in the vicinity of Kotelny Island in the Sannikov Strait, which spans approximately 402 km with a narrowest width of 57 km and a shallowest depth of 14 meters, it is not advisable to choose ships with a draft exceeding 14 meters for cost analysis. Referring to the "General Plan Design Specifications for Harbors," this article selects a 50,000-ton (40,001-65,000 tons) tonnage 4,000 TEU container ship with a draft of 13 meters and a 61,000-ton bulk carrier as the subjects for the Suez route. Correspondingly, ice-strengthened vessels are selected for navigation on the Arctic route.

Referring to the 4,000 TEU Panama-type container vessel "YM KAOHSIUNG," its cruising speed ranges from 23.8 to 24.1 knots. However, for the purpose of economical navigation, this study assumes that the 4,000 TEU container ship will sail at a speed of 24 knots. Similarly, based on the cruising speed of 13.2 knots for the 60,400-ton Panama-type bulk carrier "HAKATA QUEEN," this study sets the 61,000-ton bulk carrier to sail at a speed of 14 knots.

In the three segments of the Arctic route, the first and third segments have respective navigational distances of approximately 3,055 nautical miles and 1,621 nautical miles, which are considered normal open waters. The cruising speed of the 4,000 TEU container vessel is 24 knots, and the cruising speed of the 61,000-ton bulk carrier is 14 knots. The second segment involves passing through ice zones and has a distance of about 3,003 nautical miles. This segment belongs to the Northeast Passage of the Arctic and carries a higher risk. Based on the actual voyages of the "Yongsheng" vessel in 2013 and 2015, the average cruising speed for both the 4,000 TEU container vessel and the 61,000-ton bulk carrier in this segment is approximately 12.0 knots due to ice restrictions.

By traversing the Northeast Passage of the Arctic, from Shanghai Port in China to Rotterdam Port in the Netherlands, the total distance covered is 7,679 nautical miles. The voyage passes through five ports, with 1-day stops at both Shanghai Port and Rotterdam Port, and 0.5-day stops at Busan Port, Providence Bay Port, and Murmansk Port for refueling and resupplying, resulting in a total of 3.5 days of stay. Through the calculation of the above content, the time of each stage of the Arctic route is shown in Table 1 [3].

Table1: Time of each stage of the Arctic route.

Time (Days)	4000TEU container ship	61000 tons bulk carrier
First Sector	5.3	9.1
Second Sector	10.4	10.4
Third Sector	2.8	4.8
Berthing	3.5	3.5
Total	22.0	27.8

As a result, the total duration of a single voyage for a 4,000 TEU container ship on the Arctic route is 22 days, while for a 61,000-ton bulk carrier, it is 27.8 days.

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On the Suez route, there are no ice conditions, and the vessels sail normally throughout the journey, covering approximately 10,749 nautical miles. The 4,000 TEU container ship has a speed of 24 knots, requiring 18.7 days of travel time. The 61,000-ton bulk carrier has a speed of 12 knots, requiring approximately 32 days of travel time. The vessels depart from Shanghai Port, make stops at seven ports along the traditional Suez Canal route, and finally reach Rotterdam Port. Both Shanghai Port and Rotterdam Port require a one-day stop, while during the passage through the Suez Canal, the vessel needs to stop for one day due to queueing and refueling. The remaining ports require a stop of 0.5 days each for refueling and supplies. The total time spent on port stops amounts to 5.5 days [4].

Therefore, the total duration of a single voyage for a 4,000 TEU container ship on the Suez route is 24.2 days, while for a 61,000-ton bulk carrier, it is 37.5 days.

2.2. Factors Affecting Navigation Costs

Since the 1970s, due to changes in various cost structures and in order to align cost accounting with different operating forms of ships for capital, cost, and profit analysis, a new classification method has been adopted, dividing the total navigation cost of ships into capital costs, operating costs, and voyage costs [5].

Capital costs include the construction cost or rent of the ship, as well as ship depreciation.

In general, compared to ordinary ships of the same tonnage or type, ice-class reinforced ships in ice zones have a higher cost or rent and weight, typically about 20% to 50% higher than ordinary ships. In this study, the ARC6-type ship is used as a benchmark, with an increase of 30% over the base cost of an ordinary ship [6].

Referring to the "Regulations for the Management of Old Transport Ships," this study assumes a lifespan of 20 years for both container ships and bulk carriers. According to the Global Ship Recycling Market Report of September 16, 2022, published by the Shanghai International Maritime Information Center, the average price for scrapping bulk carriers is \$565/Ldt, while for scrapping container ships it is \$585/Ldt, based on the average of Bangladesh and India, two major ship scrapping countries. Referring to the 4,000 TEU Panama-type container ship "YM KAOHSIUNG," this study sets the empty displacement of a 4,000 TEU vessel at approximately 17,000 tons, while the corresponding ice-class reinforced ship has an empty displacement of approximately 22,100 tons. Referring to the 60,400-ton Panama-type bulk carrier "HAKATA QUEEN," this study sets the empty displacement of a 61,000-ton bulk carrier at approximately 20,000 tons, while the empty displacement of the ice-class reinforced ship is approximately 26,000 tons.

Since the international shipping market commonly uses long tons (Ldt) as a unit of measurement for scrapping ships, the calculated weight of a scrapped ordinary 4,000 TEU container ship is approximately 16,700 Ldt, while the empty displacement of the ice-class reinforced ship is approximately 21,800 Ldt. The empty displacement of a 61,000-ton ordinary bulk carrier is approximately 19,700 Ldt, while the empty displacement of the ice-class reinforced ship is approximately 25,600 Ldt.

Since ships need to consider their depreciation costs during usage, this study uses the straight-line method for depreciation. The annual average depreciation cost C is calculated as:

$$C = (S - V)/n \tag{1}$$

C: Annual average depreciation cost of the vessel;S: Vessel cost;V: Scrap ship recycling price;n: Vessel lifespan

Let's define the number of days in a year as 365 days. Therefore, the capital cost of a single voyage for a vessel (CC) is calculated as follows:

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$$CC = C \cdot d/365 \quad (2)$$

Using the formula for scrap ship price, V = s · M (where V is the scrap ship recycling price, s is the recycling unit price, and M is the light displacement of the scrap ship), and referring to Table 2 of Clarkson's official website for newbuilding prices data, the Table 3 about the scrap recycling price can be calculated.

Table 2: Newbuilding prices from 2018 to 2022.

Date	3,500/4,000 TEU container ship $m	61-63K DWT bulk carrier $m
2018	39.00	26.00
2019	41.50	25.50
2020	40.25	24.00
2021	50.00	32.50
2022	54.00	30.50
Average	44.95	27.70
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Table 3: Scrap recycling price statistics.

Ship Types	Cost($m)	Recycling Price($m)	Annual Depreciation($m)	Average Daily Depreciation($m)
4000TEU container ship	44.95	9.77	1.76	0.0048
Ice-reinforced 4000TEU container ship	58.44	12.75	2.28	0.0062
61000 tons bulk carrier	27.70	11.13	0.83	0.0023
Ice reinforced 61000 tons bulk carrier	36.01	14.46	1.08	0.0030

Operating costs refer to the regular maintenance expenses incurred by a shipping company to ensure the normal operation of its vessels. These costs include crew wages, essential materials on board, insurance, vessel repair and maintenance expenses, lubricant costs, as well as related management expenses.

Crew Wages: Referring to the "China (Shanghai) International Seafarer Salary Table" released by the Shanghai Shipping Exchange in June 2023 and based on the Drewry market analysis report, this article assumes that a 4000 TEU container vessel is equipped with 22 crew members, and a 61,000-ton bulk carrier is equipped with 19 crew members. Table 4 provides information on the crew complement and corresponding wage costs for the 4000 TEU general container vessel and the 61,000-ton general bulk carrier. Due to the special nature of the Arctic route, crew members must undergo specialized training to overcome harsh environmental conditions. Therefore, the wages for crew members on Arctic route vessels should be 20% higher than those for crew members on regular vessels. Consequently, the total monthly crew wages for the 4000 TEU ice-strengthened container vessel and the 61,000-ton ice-strengthened bulk carrier amount to 113,835.6 US dollars and 101,521.2 US dollars, respectively.

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Table 4: The crew payroll of suez route.

Occupation	4000TEU Container Ship		61000-tons Bulk Carrier	
	Wages ($/1 month)	Headcount	Wages ($/1 month)	Headcount
Captain	9929	1	9762	1
First Mate	8138	1	7913	1
Second Mate	5196	1	4998	1
Third Mate	4816	1	4624	1
Chief Engineer	9534	1	9281	1
Second Engineer	8120	1	7903	1
Third Engineer	5196	1	5004	1
Fourth Engineer	4794	1	4616	1
Electrical Engineer	5177	3	4935	3
Boatswain	2496	1	2307	1
Sailor	2028	5	1781	4
Chief Motorman	2496	1	2307	1
Motorman	2028	3	1781	1
Chef	2393	1	2176	1
Total	94863	22	84601	19

Marine Insurance Costs: Due to the harsh climate and high navigation risks of the Arctic route, the insurance costs are expected to be approximately 50% higher than those of traditional common routes. For a 4,000 TEU container ship and a 61,000-ton bulk carrier on the traditional Suez route, the annual maritime insurance premiums are generally $170,000 and $140,000 respectively. Therefore, the estimated insurance costs for ice-strengthened vessels in the polar region would be around $255,000 and $210,000 respectively.

Ship Maintenance and Repair Costs: Ship maintenance and repair costs are incurred to ensure the safe navigation and proper functioning of all equipment on board. These costs are usually determined as a percentage of the ship's construction cost, typically around 2‰. However, for ice-strengthened vessels, the ship maintenance and repair costs are expected to be approximately 30% higher than the original 2‰.

Management Costs: In this article, the management costs are calculated based on 50% of the crew's wages. Therefore, the monthly management costs for ice-strengthened vessels, namely a 4,000 TEU container ship and a 61,000-ton bulk carrier, would amount to approximately $56,917.8 and $50,760.6 respectively.

Voyage costs refer to the expenses directly attributed to a specific voyage undertaken by a vessel for transporting specific cargo. These costs primarily include fuel costs, port charges, canal fees, ice-breaking and pilotage fees, armed security and piracy insurance, and other voyage expenses [7].

Fuel Costs: Assuming a regular 4,000 TEU container vessel consumes approximately 100 tons of fuel per day at sea and 10 tons of fuel per day while in port, and a regular 61,000-ton bulk carrier consumes around 40 tons of fuel per day at sea and 4 tons of fuel per day in port. The fuel consumption for an enhanced 4,000 TEU container vessel and a 61,000-ton bulk carrier is estimated to be 110 and 44 tons per nautical mile, respectively, while the fuel consumption in port remains the same as that of regular vessels. Based on this, the total fuel consumption for a single voyage for a 4,000 TEU container vessel and a 61,000-ton bulk carrier is calculated to be 1,925 tons and 1,302 tons, respectively, while for the corresponding enhanced vessels, it is 2,070 tons and 1,083.2 tons. In this article, the designed route is from Shanghai, China to Rotterdam, the Netherlands, for an ocean voyage. The fuel price used is based on the 380CST fuel oil price published by CBI (http://www.100ppi.com) on July 11, 2023, with a fuel benchmark price of $500 per ton. Therefore,

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the fuel costs for a single voyage for a 4,000 TEU container vessel and a 61,000-ton bulk carrier are $963,000 and $651,000, respectively, while for the corresponding enhanced vessels, they are $1,035,000 and $519,000.

Canal Fees: When a vessel passes through the Suez Canal, it is required to pay an additional fee known as the Suez Canal toll. Taking a 4,000 TEU container ship and a 57,000-ton bulk carrier as examples, the one-time canal fees for passage through the Suez Canal are approximately $273,000 and $189,000 respectively [8]. Therefore, in this article, the canal fees for a 61,000-ton bulk carrier are estimated to be around $200,000.

Port Fees: Here, assuming the cost of each port in a single voyage is around $20,000, and considering that the Arctic route has 5 ports of call while the traditional Suez route requires passing through 7 ports, the port fees for each route would be $100,000 and $140,000 respectively.

Icebreaking Pilotage Fees: Icebreaking pilotage fees refer to mandatory charges imposed by Russian authorities when a vessel needs to navigate in icy waters. According to information provided by the Russian Northern Sea Route Administration, the fee for each standard 20-foot container with a maximum load weight of 14 tons should be $15 per ton.

Armed Security and Piracy Insurance: Due to the proximity of the Suez Canal route to the waters near Somalia, it is necessary to purchase piracy insurance, typically around 0.125% to 0.2% of the ship's value, using 0.15% as the average [9]. High-risk piracy areas employ armed security personnel, and according to shipping company statistics, the average cost for a 7-day armed security escort is $30,000.

2.3. Calculation and Analysis

Based on the above analysis, the formula for calculating the total economic cost of a single voyage on a route is as follows:

$$TC = CC + CW + IE + MC + AC + OC + FC + PC + IC + SC \tag{3}$$

TC: Total economic cost of a single voyage on the route;CC: Capital cost of the vessel;CW: Crew wages;IE: Insurance expenses;MC: Vessel maintenance and upkeep costs;AC: Administrative costs;OC: Fuel expenses;FC: Canal fees;PC: Port charges;IC: Pilotage fees;SC: Armed security and insurance expenses

Therefore, the economic cost of a single voyage on the Arctic route is:

$$TC = CC + CW + IE + MC + AC + OC + PC + IC \tag{4}$$

And the economic cost of a single voyage on the traditional Suez Canal route is:

$$TC = CC + CW + IE + MC + AC + OC + FC + PC + SC \tag{5}$$

The calculation data of the total cost per single voyage, the calculation data of each cost and their proportion can be obtained in Table 5.

Table 5: Total cost per single voyage and the proportion of each cost parameter(continue).

Parameter Types	4000TEU container ship	Ice-reinforced 4000TEU container ship	61000 tons bulk carrier	Ice reinforced 61000 tons bulk carrier

Table 5: (continued).

Hours Underway (Days)		24.2	22.0	37.5	27.8
Capital Costs (10000$)	Depreciation	11.6(6.7%)	13.6(6.9%)	8.6(6.5%)	8.3(4.7%)
Operating Costs (10000$)	Crew Wages	7.7(4.5%)	8.3(4.2%)	10.6(8.0%)	9.4(5.3%)
	Marine Insurance Costs	1.1(0.6%)	1.5(0.8%)	1.4(1.1%)	1.6(0.9%)
	Maintenance Cost	0.6(0.3%)	0.9(0.5%)	0.6(0.5%)	0.5(0.3%)
	Management Costs	3.8(2.2%)	4.2(2.1%)	5.3(4.0%)	4.7(2.6%)
Voyage Costs (10000$)	Fuel Costs	96.3(56.0%)	75.7(38.2%)	65.1(49.0%)	51.9(29.2%)
	Canal Fees	27.3(15.9%)	-	20(15.1%)	-
	Port Fees	14(8.1%)	10(5.0%)	14(10.5%)	10(5.6%)
	Icebreaking Pilotage Fees	-	84(42.4%)	-	91.5(51.4%)
	Security Insurance Costs	9.7(5.6%)	-	7.2(5.4%)	-
Total		172.1	198.2	132.8	177.9

3. Time Compression Resulting from the Arctic Shipping Route

3.1. Relationship Between Time Compression and Total Supply Chain Cost

The supply chain functions as a single entity to efficiently meet the demands of the end consumers. Time compression strategies aim to gain a competitive advantage by reducing non-value-added time in the supply chain through various means. Time compression plays a crucial role in achieving low costs, just-in-time delivery, and effectively mitigating or eliminating the bullwhip effect [10]. According to Liu Gaofeng's research paper "Supply Chain Management Based on Time Compression Strategy" (pages 20-22), there exists a direct and mutually beneficial relationship between time compression and total supply chain cost, rather than a purely trade-off relationship [11].

3.2. Computational Analysis

Since transportation and production times determine the delivery cycle, the Arctic shipping route offers shorter transit times compared to the traditional Suez Canal route. Based on the calculations from the charts, the time difference for container ships is 2.2 days, while for bulk carriers, it is 9.7 days. Referring to the article "Supplier Selection Considering the Impact of Delivery Cycle on Total Supply Chain Cost" by the Modern Logistics Center of Xiamen University, it is assumed that the ordering cycle equals the delivery cycle, and the lead time for ordering equals the delivery cycle. Additionally, the daily demand of the company follows a normal distribution with an expectation of μ and a variance of $\sigma 2$. The relationship between the total supply cost and each parameter can be obtained through the formula (6-11) that is formula (12).

$$Q = \mu T \tag{6}$$

$$Q_0 = \sigma S \sqrt{T} \tag{7}$$

$$Z = Z_I + Z_P + Z_M \tag{8}$$

$$Z_I = C_I (Q_0 + Q/2) T \tag{9}$$

$$Z_P = Z_0 + pQ \tag{10}$$

$$Z_M = r(Z_P + Z_I) \tag{11}$$

$$Z = (1+r)\left(Z_0 + \mu p T + \sigma C_I S \sqrt[2]{T^3} + \mu C_I\, T^2/2\right) \tag{12}$$

T: Delivery cycle; Q: Order quantity per cycle; Q0: Enterprise safety stock; p: Unit purchase price of goods; S: Safety factor; CT: Unit transportation cost of goods; CI: Unit inventory holding cost over time; r: Interest rate per unit of funds over time; Z0: Fixed purchase cost; ZI: Inventory holding cost; ZT: Transportation cost; Zp: Purchase cost ; ZM: Cost of capital occupation; Z: Total supply cost; C: Unit supply cost [12]

Z is a power function of the delivery cycle T. According to the first partial derivative of Z with respect to the delivery cycle T, the change in total supply cost for a unit change in the delivery cycle can be determined:

$$\frac{\partial Z}{\partial T} = (1+r)\left(\mu p + \frac{3}{2}\sigma C_I S\sqrt{T} + \mu C_I T\right) \tag{13}$$

To find the second partial derivative of Z with respect to the delivery cycle T:

$$\frac{\partial^2 Z}{\partial T^2} = (1+r)\left(\frac{3}{4}\sigma C_I S\frac{\sqrt{T}}{T} + C_I R\right) \tag{14}$$

Since both equations are greater than 0, the total supply cost will increase as the delivery cycle increases, and the rate of increase will also become faster. Therefore, reducing the navigation time means reducing the transportation time. If we divide the delivery cycle into pre-order lead time (arrival and delivery time) and information lead time (ordering time), then the reduction of transportation time, i.e., delivery time, will result in a decrease in the delivery cycle. This also means that the overall supply chain cost will decrease [13].

Therefore, by substituting ∂T=2.2 and ∂T=9.7, the reduced supply chain costs for container ships and bulk carriers can be obtained as follows:

$$\partial Z = 2.2(1+r)(\mu p + 7.38\sigma C_I S + 24.2\mu C_I) \tag{15}$$

$$\partial Z = 9.7(1+r)(\mu p + 9.19\sigma C_I S + 37.5\mu C_I) \tag{16}$$

The specific decrease in total supply chain costs is related to the volume of goods transported, which includes the daily demand for goods and their prices for the enterprises involved, as well as the cost of holding inventory per unit of goods per unit of time.

4. Economic Analysis

Based on the data calculations shown in Table 5, it can be concluded that using the Arctic route for voyages results in shorter travel time compared to the traditional Suez Canal route, thus achieving time compression. In terms of costs, although the Arctic route has lower port fees and fuel costs per voyage, the total cost for completing a single voyage is higher than that of the Suez Canal route. Taking a 4,000 TEU container ship and a 61,000-ton bulk carrier as examples, the total costs are higher by 15.17% and 33.96%, respectively.

In the Suez route, fuel costs account for the highest proportion of the single voyage cost, followed by canal fees. In the Arctic route, the highest proportion of the single voyage cost is icebreaking and pilotage fees, followed by fuel costs. However, as the Arctic ice gradually melts and shipbuilding technology improves, the feasibility of the Arctic route will increase. Icebreaking and related shipping insurance and vessel fraud costs will gradually decrease, opening up new opportunities for the development of Arctic neighboring countries.

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5. Conclusion

In conclusion, taking the example of the Shanghai Port in China to the Port of Rotterdam in the Netherlands, the Suez route still has an advantage in terms of logistics costs. Choosing the Arctic route as a logistics transportation route without careful consideration would impose additional burdens on logistics costs in the supply chain. In the calculation analysis in section 3.2, it was found that choosing the Arctic route could shorten the delivery cycle and reduce certain supply chain costs. When the reduced supply chain costs and increased logistics costs balance each other out, the Arctic route offers the benefit of shorter transportation time compared to traditional routes. Therefore, under the premise of suitable navigation and cargo, whether a company chooses the Arctic route as a path for supply chain logistics transportation needs to consider the daily demand for goods, the price of goods, and the holding cost of goods in terms of time, in order to determine the relationship between the cost reduction from the shortened delivery cycle offered by the Arctic route and the increased logistics costs associated with choosing it.

It should be noted that this study assumes that the daily demand of companies follows a normal distribution, whereas, in reality, daily demand fluctuates randomly. As a result, inventory levels also vary with demand fluctuations, and once safety stock is depleted, stockouts occur, leading to additional negative costs.

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