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## Fuzzy-based decision analysis on Arctic transportation: A guidance for freight shipping companies

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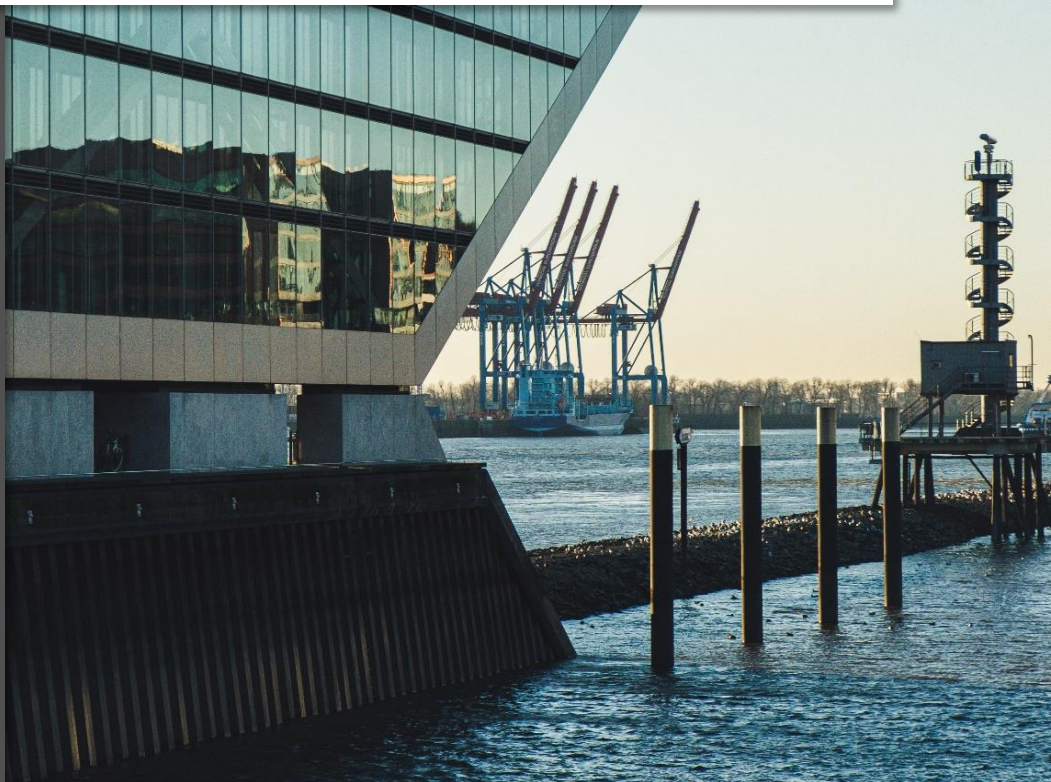
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Lukas Benz, Christopher Münch, and Evi Hartmann

# Fuzzy-based decision analysis on Arctic transportation: A guidance for freight shipping companies



# Fuzzy-based decision analysis on Arctic transportation: A guidance for freight shipping companies

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**Purpose:** Due to climate change the Arctic ice is melting, opening new possibilities for the economical use of the Arctic Ocean. However, the decision for shipping companies to transport freight through Arctic waters is based on many factors. The aim of the research is to develop a decision-supporting guidance for shipping companies.

**Methodology:** Based on a literature review and subsequent validation through expert interviews, influencing factors are identified and classified using a framework covering Benefits, Opportunities, Costs, and Risks. A fuzzy set theory to structure multi-criteria decision problems is applied afterward.

**Findings:** The results show that equipment, insurance, and inadequate port infrastructure are the factors with the highest influence in the Costs category and are the most influential factors overall. Security and market potential, the factors with the greatest impact on the Opportunities category, also rank highly as influential overall factors. The strongest Risk factors are weather conditions, delay, and collisions / accidents. The highest influence in the Benefits category are reduced costs.

**Originality:** The influencing factors for Arctic freight shipping have so far only been considered in part with risks focus or other specific aspects, but not in the overall context. To consider multiple perspectives, 24 experts from different domains were involved.

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## 1 Introduction

Due to various reasons, the Arctic is recently receiving more and more attention. Arctic sea ice is melting continuously due to global warming, and it is assumed that this development will continue or even accelerate in the next decades. This opens new possibilities for the economical use of the Arctic Ocean (Wang, Silberman and Corbett, 2020). The Arctic routes are significantly shorter and could reduce distances up to 40 % compared to the Suez Canal (Furuichi and Otsaka, 2013), which would lead to cost savings from reduced transit time and lower fuel consumption (Hong, 2012; Lasserre, 2014). Additionally, the most commonly used maritime sea routes like the Suez Canal, Strait of Malacca, or the Panama Canal are reaching their carrying capacity (Schneider, 2018). As the need for new shipping lines emerges, novel routes through the Arctic offer a solution to capacity constraints (Buixadé Farré, et al., 2014). Considering the Arctic routes, transit traffic through Arctic waters remains low, especially when compared to common routes. However, an upward trend is emerging, which could lead shipping companies to establish and evaluate their own business cases for freight transport through the Arctic.

As a result of these developments, trans-Arctic shipping is an arising research topic in the field of maritime transportation, which is reflected in an exponential growth of publications in the past decades (Theocharis, et al., 2019). For example, Lasserre (2014) identified 26 studies dealing with the feasibility of Arctic sea routes compared to traditional routes. Among others, Faury and Cariou (2016) took ice thickness, total transit costs, and transit time into account, whereas Wang, Zhang and Meng (2018) focus on navigation risk, shipping profits / costs, and shipping time as route-specific factors.

There are already research studies that provide an overview of these factors, which were previously considered in detail. For example, Tseng and Cullinane (2018) identified influencing criteria affecting the choice for Arctic shipping, Milaković, et al. (2018) collated challenges related to the use of the northern sea route (NSR). Fu, et al. (2018) identified risk influencing factors for Arctic maritime transportation systems. In addition, the topic of maritime freight transportation through the Arctic was dealt with by numerous authors.

Existing studies being conducted in recent years therefore either deal with a comparison of the profitability of Arctic routes with existing routes or consider a limited number of factors. However, there is as yet no study providing a comprehensive overview of potential factors for assessing Arctic freight shipping. Therefore, the aim of the research is to identify and evaluate criteria for the decision of shipping companies to transport freight through the Arctic. This paper contributes to existing research by conducting a literature review for the identification of influencing factors, and factor classification into a framework afterwards. Based on this, two-round semi-structured interviews for factor discussion and evaluation are conducted. After that, a fuzzy set theory (FST) is applied, followed by a sensitivity analysis. The article is organized as follows. After presenting the theoretical background, factors for Arctic maritime transportation, an overview of the methodological approach is given. The identified factors are placed in a Benefits, Opportunities, Costs and Risks (BOCR) model and are judged and refined through an expert survey afterwards. Subsequently, FST is applied. Afterwards, a sensitivity analysis is conducted, followed by the presentation of the results. After that, a discussion is held and a conclusion is presented in the last section.

## 2 Theoretical foundation

As already stated in the introduction, a considerable number of research studies have been conducted on influencing factors for Arctic freight shipping.

An overview of the existing studies is given in Table 1, whereby the focus is on the most recent publications with the highest thematic relevance. Furthermore, the research gap of this study is derived.

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Table 1: Overview of existing studies

Author (Year)	Title	B	O	C	R
Schøyen and Bråthen (2011)	The northern sea route versus the suez canal: cases from bulk shipping	x		x	x
Furuichi and Otsaka (2013)	Cost analysis of the NSR and the conventional route shipping			x	
Lasserre (2014)	Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector	x		x	
Faury and Cariou (2016)	The Northern Sea Route competitiveness for oil tankers	x		x	
Wang, Zhang and Meng (2018)	How will the opening of the Northern Sea Route influence the Suez Canal Route? An empirical analysis with discrete choice models	x		x	
Tseng and Cullinane (2018)	Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model			x	x
Fu, et al. (2018)	Risk influencing factors analysis of Arctic maritime transportation systems: a Chinese perspective				x
Milaković, et al. (2018)	Current status and future operational models for transit shipping along the Northern Sea Route			x	x
Marchenko, et al. (2018)	Arctic shipping and risks: emergency categories and response capacities				x

Author (Year)	Title	B	O	C	R
Khan, et al. (2018)	An operational risk analysis tool to analyze marine transportation in Arctic waters				x
Christensen, Georgati and Arsanjani (2019)	A risk-based approach for determining the future potential of commercial shipping in the Arctic	x		x	x
Theocharis, et al. (2019)	Feasibility of the Northern Sea Route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker market	x		x	
Zhang, Huisingh and Song (2019)	Exploitation of trans-Arctic maritime transportation			x	x
Lin and Chang (2018)	Ship routing and freight assignment problem for liner shipping: Application to the Northern Sea Route planning problem			x	
Wang, et al. (2020)	Feasibility of the Northern Sea Route for oil shipping from the economic and environmental perspective and its influence on China's oil imports			x	
<i>This study</i>	<i>Fuzzy-based decision analysis on Arctic maritime transportation: A guidance for shipping companies</i>	x	x	x	x

As can be concluded, there is as yet no study providing a comprehensive overview of potential factors for assessing Arctic freight shipping.

In the area of negative influencing factors, quantitative research already exists, but an evaluation of the positive factors, Benefits and Opportunities, has not yet been carried out comprehensively.

### 3 Methodology

As several papers have shown, the operation of freight ships on Arctic maritime routes is linked to the assessment and evaluation of numerous influencing criteria (Fu, et al., 2018; Tseng and Cullinane, 2018). Therefore, FST was selected as a suitable technique for analyzing the viability of Arctic freight transportation. FST is a systematic method for structuring and evaluating MCDPs (multi criteria decision problems) in which complex decisions have to be made in a setting where there are several objectives and several criteria that affect the decision (Zadeh, 1965). The proposed two-stage methodology approach is illustrated in Figure 1.

#### 3.1 Phase 1: Factor identification and judgment

Initially, the influencing factors for the MCDP were identified. This procedure is a challenging problem due to the limited data and the uncertainty of the available information (Fu, et al., 2018). Thus, the factors were identified in a two-step approach to ensure a comprehensive and reliable register of factors for the development and assessment of the framework. The first step was to determine the factors based on a review of the relevant literature, and to classify them systematically within a framework. We used the BOCR based on Saaty (2004), which allows decisions in MCDP to be treated from four different perspectives: the Benefits (B), positive aspects which could be linked with the decision; the Opportunities (O), potentially positive aspects which might result from the decision in the future; Costs (C), distress and disappointment which would be connected with the decision made; and Risks (R), potential distress and disappointment which might be caused by the decision. To improve the practical validity of the BOCRs found in the literature review, in a second step experts were invited to review the factors identified. The following two criteria for inclusion of participants for the interview and the subsequent questionnaire were defined: extensive practical or research experience in the Arctic area and knowledge in the field of freight shipping. Before the actual survey was conducted, the completed questionnaire was piloted with five experienced researchers.



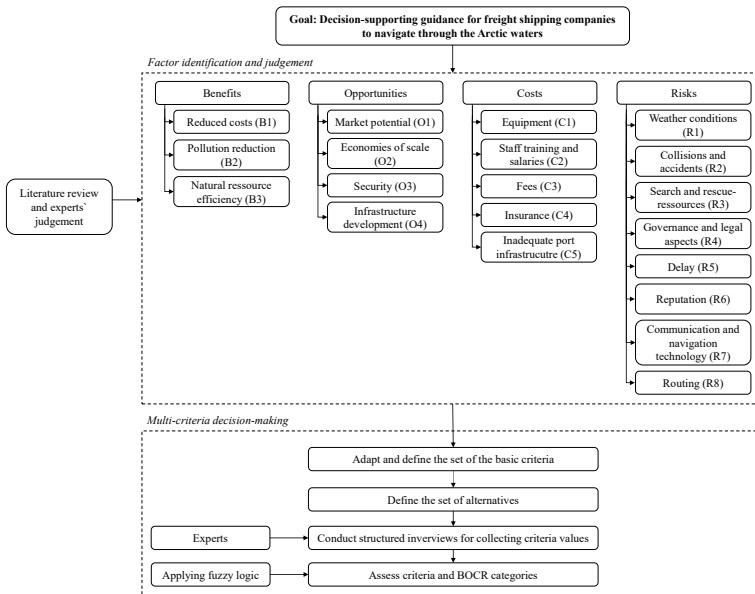


Figure 1: Methodological approach

### 3.2 Phase 2: Fuzzy synthetic evaluation method

The first step in the FST process was to determine the key criteria. This study established the identified factors for each category of the BOCR framework as the essential criteria. This was followed by the definition of the alternatives as the second step of the FST process. In this model, the set of alternatives represent the possible values of the probability of occurrence ( $P$ ) and impact ( $I$ ). For each criterion of the BOCR framework, the values of  $P$  and  $I$  were surveyed using a questionnaire. Experts were asked to independently assess the impact level and probability of BOCRs in numerical order with the following question: 'Please assess the probability of occurrence and the impact of the

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respective criterion'. The following five-point language scale was used based on the number of potential values for  $P$  and  $I$ , with the appropriate definitions of the possible values for  $P$  and  $I$  (Kiani Mavi and Standing, 2018): very low (1), low (2), moderate (3), high (4), and very high (5). This approach goes beyond the decision-makers' subjectivity - the underlying linguistic variables truly represent the experts' assessments (Bozbura and Beskese, 2007). Afterward the fuzzy synthetic evaluation method for criteria assessment by Andrić, Wang and Zhong (2019) was utilized. It consists of three steps, which are shown in the following:

### 3.2.1 Step 1: Assessment of each criterion

The membership function  $F$  of each criterion is generated with the collected values of  $P$ . In the matrix  $F$ , the element  $f_{ij}$  of the matrix reflects the level to which the variable  $a_j$  represents the criterion  $i$ .

$$(F_i^P)_{1 \times 5} = (f_{i1}^P, f_{i2}^P, f_{i3}^P, f_{i4}^P, f_{i5}^P), i = 1, 2, \dots, n \quad (1)$$

In a similar way, the impact of criteria assessed, and membership function  $F$  for  $I$  is specified:

$$(F_i^I)_{1 \times 5} = (f_{i1}^I, f_{i2}^I, f_{i3}^I, f_{i4}^I, f_{i5}^I), i = 1, 2, \dots, n \quad (2)$$

For each of the alternatives in the set, an appropriate weighting is given:  $v_j = \{1, 2, 3, 4, 5\}$ . Furthermore,  $P$  and  $I$  of each criterion are calculated with the equation as follows:

$$P_i = \sum_{j=1}^5 v_j \times f_{ij}^P \quad (3)$$

$$I_i = \sum_{j=1}^5 v_j \times f_{ij}^I \quad (4)$$

To rank the criteria, the score ( $SC$ ) is calculated as the product of  $P$  and  $I$  using to the equation below:

$$SC_i = \sqrt{P_i \times I_i}, i = 1, 2, \dots, n \quad (5)$$

### 3.2.2 Step 2: Assessment of the categories

Once  $P$ ,  $I$ , and  $SC$  have been calculated for each criterion, the next step is to calculate the  $SC$  for each of the four categories. First, the weights of all criteria in each category are evaluated. The weights of  $P$  of criterion  $i$  are calculated as:

$$w_i^p = \frac{P_i}{\sum_{i=1}^a P_i}, i = 1, 2, \dots, a \quad (6)$$

where  $a$  is defined as the number of criteria in a category.

Likewise, the weights for  $I$  are calculated for each criterion. The evaluation matrix  $C$  for each category is the product of the fuzzy combination of the weight vector  $W$  and the membership function  $F$ . Furthermore, the membership functions of category  $t$  for  $P$  are determined with the following equation:

$$c_{t,j}^p = \sum_{i=1}^a w_i^p \times f_{ij}^p \quad (7)$$

$$(C_t^p)_{1 \times 5} = (W_t^p)_{1 \times a} \times (F_t^p)_{a \times 5} = (c_{t1}^p, c_{t2}^p, c_{t3}^p, c_{t4}^p, c_{t5}^p) \quad (8)$$

The membership function for  $I$  of category  $t$  and matrix  $C$  is calculated, respectively. Similar to the calculation of criteria,  $P$ ,  $I$ , and  $SC$  of each category are determined:

$$P_t = \sum_{j=1}^5 v_j \times c_{tj}^p \quad (9)$$

$$I_t = \sum_{j=1}^5 v_j \times c_{tj}^l \quad (10)$$

$$SC_t = \sqrt{P_t \times I_t}, t = 1, 2, \dots, n \quad (11)$$

### 3.2.3 Step 3: Assessment of positive and negative dimensions

The next step is to calculate the  $SC$  for overall positive (B and O) and overall negative (C and R) dimensions. Again,  $P$ ,  $I$ , and  $SC$  of these two dimensions were evaluated as the product of the weighting vector of respective categories and the evaluation matrix. The weightings of  $P$  for each category are then estimated by the equations below:

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$$w_t^p = \frac{P_t}{\sum_{t=1}^l P_t}, t = 1, 2, \dots, l \quad (12)$$

where  $l$  is the number of categories within the dimension and  $(\sum_{i=1}^a P_i)_t$  is the total of  $P$  for every criterion in the category  $C_t$ .

The weightings of  $I$  for each category are calculated in the same way. Next, the membership functions of  $P$  and  $I$  for the positive and negative dimensions respectively are determined using these equations:

$$d_{l,j}^p = \sum_{t=1}^k w_t^p \times c_{tj}^p \quad (13)$$

$$(D_l^p)_{1 \times 5} = (W_l^p)_{1 \times k} \times (D_l^p)_{k \times 5} = (d_{11}^p, d_{12}^p, d_{13}^p, d_{14}^p, d_{15}^p) \quad (14)$$

This is calculated under the assumption that the membership functions of  $P$ ,  $I$ , and  $SC$  for the positive and negative categories are evaluated according to the equations following:

$$P_l = \sum_{j=1}^5 v_j \times d_{lj}^p \quad (15)$$

$$I_l = \sum_{j=1}^5 v_j \times d_{lj}^l \quad (16)$$

$$SC_l = \sqrt{P_l \times I_l}, l = 1, 2, \dots, n \quad (17)$$

### 3.2.4 Step 4: Sensitivity analysis

In order to achieve stability and compatibility of analysis, sensitivity analysis is performed. Sensitivity analysis is a systematic method for identifying the most serious criteria and aims to guide the decision-making process to obtain the right decision alternatives and develop an appropriate strategy. To determine the criteria that have the most influence, the probability of occurrence and the impact for each criterion were increased by the value  $\delta$  ( $\delta > 0$ ), and the overall rating was estimated using equations (18) and (19) (Phillis, et al., 2018).

$$\Delta_{BO} = \frac{SC(P_{B1}, I_{B1}, \dots, P_n + \delta, I_n + \delta, \dots, P_{O4}, I_{O4}) - SC(P_{B1}, P_{B1}, \dots, P_{O4}, I_{O4})}{\delta} \quad (18)$$

$$\Delta_{CR} = \frac{SC(P_{C1}, I_{C1}, \dots, P_n + \delta, I_n + \delta, \dots, P_{RB}, I_{RB}) - SC(P_{C1}, P_{C1}, \dots, P_{RB}, I_{RB})}{\delta} \quad (19)$$

## 4 Case study

As mentioned earlier in the paper, the identification and assignment of specific factors to each of the four dimensions is based in a first step on the results of a comprehensive literature review, which leads to a factor catalog comprising a total of 20 factors. Second, the factors were evaluated by 25 experts, whereupon one factor was deleted. In total, a final criteria register was created containing 19 criteria. The descriptions of the various criteria and the sources justifying their potential relevance (and thus inclusion in the analysis) are presented for the positive factors (reduced costs, pollution reduction, natural resource efficiency, market potential, economies of scale, security and infrastructure development) in Table 2 and the negative factors (equipment, staff training and salaries, fees, insurance, inadequate port infrastructure, weather conditions, collisions and accidents, search and rescue resources, governance and legal aspects, delay, reputation and routing) in Table 3.

Table 2: Positive influencing criteria - Benefits and Opportunities

Category	Code	Criteria / Definition	Author(s)
Benefits	B1	Reduced costs (Lower costs due to reduced transit times)	Furuichi and Otsaka (2013), Lasserre (2014)
	B2	Pollution reduction (Reduction of the total amount of air pollution)	Humpert and Raspotnik (2012), Furuichi and Otsaka (2013)

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Category	Code	Criteria / Definition	Author(s)
Opportunities	B3	Natural resource efficiency (Reduced fuel consumption due to lower speed)	Schøyen and Bråthen (2011)
	O1	Market potential (Great potential in inter- and intra-arctic transports, especially due to large oil and gas reserves)	Buixadé Farré, et al. (2014), Eliasson, et al. (2017)
	O2	Economies of Scale (No restrictions in size and capacity of tankers)	Arctic Council (2009)
	O3	Security (Increased security, amongst other things due to pirate incidents)	Hong (2012)
	O4	Infrastructure development (Well-developed infrastructure expected in the future)	Buixadé Farré, et al. (2014)

Table 3: Negative influencing criteria - Costs and Risks

Category	Code	Criteria / Definition	Author(s)
Costs	C1	Equipment (High investment costs for expanding the fleet, upgrading existing vessels or ship leasing, and the uncertainty around the operational cost)	Hong (2012), IMO (2014), Tseng and Cullinane (2018)
	C2	Staff training and salaries (Hiring of a suitable crew comes along with higher salary costs)	Furuichi and Otsaka (2013), Lasserre (2014), Pruyn (2016)
	C3	Fees (Transit fees for passing the routes, depending on many factors)	Lasserre (2014)

Category	Code	Criteria / Definition	Author(s)
Risks	C4	Insurance (Level of insurance required, no insurer yet has offered rates because of missing data for calculating and many influencing factors)	Milaković, et al. (2018), Wang, Zhang and Meng (2018)
	C5	Inadequate port infrastructure (Insufficiently developed infrastructure, also along the NSR)	Milaković, et al. (2018)
	R1	Weather Conditions (Polar air temperatures, heavy wind, low visibility due to fog and snow, big waves and hardly predictable ice conditions, depending on the season)	Fu, et al. (2018), Khan, et al. (2018)
	R2	Collisions and Accidents (Collision or accidents caused by external or internal factors)	Afenyo, et al. (2017), Khan, et al. (2018)
	R3	Search and rescue - resources (Inadequate search and rescue resources, equipment is not sufficient to guarantee common SAR standards)	Schmied, et al. (2017), Dalaklis, Drewniak and Schröder-Hinrichs (2018), Benz, et al. (2021)
	R4	Governance and legal aspects (Legal issues that pose obstacles for shipping companies)	Eliasson, et al. (2017), Milaković, et al. (2018)
	R5	Delay (Delay in transit)	Marken, Ehlers and Khan (2015)

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Category	Code	Criteria / Definition	Author(s)
	R6	Reputation (Negative reputation due to social and environmental reasons as impact on culture / economic activities of indigenous people)	Brubaker and Ragner (2010), Afenyo, et al. (2017)
	R7	Routing (Selection of the route and Route deviation of ships due to external factors)	Eliasson, et al. (2017), Meng, Zhang and Xu (2017), Tseng and Cullinane (2018)

The method presented in the third section is used to calculate  $P$ ,  $I$ , and  $SC$  for criteria given by equations (1) - (5). The results for the criteria are presented in Table 4.

The procedure was exemplified for the cost factor equipment (C1). In case of equipment (C1), 0 respondents (0%) evaluated  $P$  as very low, 2 respondents (0.08%) as low, 5 respondents (0.20%) as a moderate, 13 respondents (0.52%) as high, and 5 respondents (0.20%) as very high. Based on the data collected, the membership function of  $P$  for equipment is as follows:

$$(F_{C1}^P)_{1 \times 5} = (0, 0.08, 0.20, 0.52, 0.20)$$

Therefore, the following membership function results for  $I$ :

$$(F_{C1}^I)_{1 \times 5} = (0, 0.08, 0.20, 0.48, 0.24)$$

With use of equations (3) and (4)  $P$  and  $I$  are calculated:

$$\begin{aligned}
 P_{C1} &= \sum_{i=1}^5 s_j \times f_{ij}^P = 1 \times 0 + 2 \times 0.08 + 3 \times 0.20 + 4 \times 0.52 \\
 &\quad + 5 \times 0.20 = 3.84
 \end{aligned}$$



$$I_{C1} = \sum_{i=1}^5 s_j \times f_{ij}^l = 1 \times 0 + 2 \times 0.08 + 3 \times 0.20 + 4 \times 0.48 + 5 \times 0.24 = 3.88$$

Finally, the factor score ( $SC$ ) is evaluated using equation (5):

$$SC_{C1} = \sqrt{P_{C1} \times I_{C1}} = \sqrt{3.84 \times 3.88} = 3.86$$

Table 4: Results for probability, impact, weight, and score of influencing criteria

Code	Probability		Impact		Score
	Value	Weight	Value	Weight	
B1	3.68	0.37	3.68	0.38	3.62
B2	3.04	0.32	3.04	0.32	3.04
B3	2.84	0.31	2.84	0.30	2.88
O1	3.76	0.26	3.76	0.26	3.60
O2	3.12	0.22	3.12	0.22	.98
O3	3.68	0.29	3.68	0.25	3.74
O4	3.88	0.23	3.88	0.27	3.41
C1	3.84	0.20	3.88	0.21	3.86
C2	3.64	0.19	3.52	0.19	3.58
C3	4.08	0.21	3.63	0.20	3.85
C4	3.88	0.20	3.68	0.20	3.78
C5	3.68	0.19	3.52	0.19	3.60

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Code	Probability		Impact		Score
	Value	Weight	Value	Weight	
R1	4.28	0.18	3.92	0.15	4.10
R2	2.68	0.11	3.72	0.14	3.16
R3	3.76	0.16	3.80	0.15	3.78
R4	3.32	0.14	3.64	0.14	3.48
R5	3.68	0.15	3.52	0.14	3.60
R6	3.32	0.14	3.88	0.15	3.59
R7	3.12	0.13	3.24	0.13	3.18

Furthermore,  $P$ ,  $I$ , and  $SC$  were calculated for each category of the BOCR framework using equations (6) - (11). The results are shown in Table 5.

Table 5: Results for probability, impact, weight, and score of categories

Code	Probability		Impact		Score
	Value	Weight	Value	Weight	
B	3.20	0.49	3.22	0.47	3.21
O	3.31	0.51	3.63	0.53	3.47
C	3.79	0.52	3.62	0.50	3.71
R	3.55	0.48	3.68	0.50	3.62

To assess the overall positive or negative dimension, the weights of the respective categories (Benefits and Opportunities for the positive dimension; Costs and Risks for the negative dimension) are determined by using equations (12)-(17). The calculation results

in an overall score of 3.35 for the positive criteria (Benefits and Opportunities) and an overall score of 3.66 for the negative criteria (Costs and Risks). The overall results differ only slightly. This highlights that there is no clear tendency for a decision pro or contra the use of the Arctic routes for freight shipping. The results for both positive and negative criteria lie between the linguistic terms “moderate” and “high”. For the positive criteria, the value is closer to 3.00 than to 4.00, which is why they are regarded as moderate. For the negative criteria, the value is closer to 4.00 than to 3.00 and is therefore considered high. A sensitivity analysis is also carried out (equations (18) and (19)), the result of which is the differences in the assessment before and after the increase in probability and impact for each criterion is shown in Table 6.

Table 6: Sensitivity analysis

Category	Criteria	Code	$\Delta i$	Rank
Benefits	Reduced costs	B1	0.0315	12
	Pollution reduction	B2	0.0094	13
	Natural resource efficiency*	B3	0.0000	14
Opportunities	Market potential	O1	0.1105	5
	Economies of scale*	O2	0.0000	14
	Security	O3	0.1188	4
	Infrastructure development	O4	0.0806	11
Costs	Equipment	C1	0.1970	1
	Staff training and salaries	C2	0.0872	9
	Fees	C3	0.1080	6
	Insurance	C4	0.1925	2

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Category	Criteria	Code	$\Delta i$	Rank
	Inadequate port infrastructure	C5	0.1855	3
	Weather conditions	R1	0.1012	7
	Collisions and accidents	R2	0.0962	8
	Search and rescue resources*	R3	0.0000	14
Risks	Governance and legal aspects*	R4	0.0000	14
	Delay	R5	0.0851	10
	Reputation*	R6	0.0000	14
	Routing*	R7	0.0000	14

\*The marked criteria all ranked fourteenth, as they were rated identically in the sensitivity analysis.

## 5 Discussion

In terms of the sensitivity analysis, the critical criteria contribute to the highest increase in the overall rating (a criterion with the highest  $\Delta$  in Table 6). From the data, it can be deduced that the three most critical criteria are (in descending order) equipment ( $\Delta = 0.1970$ ), insurance ( $\Delta = 0.1925$ ), and inadequate port infrastructure ( $\Delta = 0.1855$ ), all of which are part of the category of Costs. This fact is also reflected in the literature. Several studies dealt with the calculation and creation of scenarios for the use of Arctic sea routes in terms of costs (Hong, 2012; Furuichi and Otsaka, 2013; Lasserre, 2014; Pruyn, 2016; Fedi, Faury and Gritsenko, 2018). In general, the investment for equipment a firm has to take into account, once it decides to operate in the polar areas, is mainly the acquisition of ice-classed vessels (Theocharis, et al., 2019). Further costs arise mainly from the additional safety-relevant, technical equipment of the ships, e.g., redundancy of equipment and a larger stock of spare parts (Budzik, 2009; Hong, 2012), the supply of

medicine, food, and water (Liu and Kronbak, 2010), and specially designed equipment to withstand the temperatures and weather requirements (Budzik, 2009; Liu and Kronbak, 2010). Additional costs occur due to vessel inspections (Pruyn, 2016) and increasing maintenance intervals (Xu, et al., 2011; Furuichi and Otsaka, 2013). For insurance ( $\Delta = 0.1925$ ), the findings of the present study also match existing research. The use of Arctic sea routes is associated with high insurance premiums (Xu, et al., 2011; Hong, 2012; Theocharis, et al., 2019; Wang, et al., 2020), as regular insurance does not cover areas in latitudes above 70° north (“excluded trading areas”), special arrangements with the insurer are required, including additional hull premiums (Milaković, et al., 2018). High insurance premiums also result from the limited availability of information on Arctic shipping and lack of transparency (Liu and Kronbak, 2010; Furuichi and Otsaka, 2013; Theocharis, et al., 2019).

Inadequate port infrastructure ( $\Delta = 0.1855$ ) is the third highest on the list. There is a consensus in the literature that all Arctic routes are insufficiently equipped with port structures (Hong, 2012; Lasserre, 2014). There are two main conclusions to be drawn from the lack of port infrastructure. Firstly, a lack of port infrastructure is accompanied by a lack of search and rescue infrastructure. Secondly, commercial interest is also reduced, because there are no ports equipped to receive the containers to be loaded and unloaded during possible rotations (Lasserre, 2014).

One unanticipated finding was that the criterion security ( $\Delta = 0.1188$ ) follows as rank four and is the first criterion of the positive dimension and a criterion of the category possibilities. It has received very little attention in the literature so far. Only Hong (2012) mentions security as an influencing factor and compares it with the safety on other routes. The Arctic region is not characterized by sea piracy (Hong, 2012). Furthermore, there are no politically unstable waters in the Arctic and provocations by individual countries are less threatening there (Hong, 2012).

The criterion market potential ( $\Delta = 0.1105$ ) is ranked second within the positive dimension and fifth in the overall assessment. So far, there are no interesting intermediate markets along the Arctic routes. However, this could change for two reasons: First, the economic development of local communities offers new market potential (Lasserre, 2014); second, these communities are striving to significantly reduce

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the cost of their consumer goods, which are usually delivered by air, and thus represent a target group. Moreover, the exploration and exploitation of natural resources is booming with the prospect of decreasing ice cover and rising world market prices (Faury, Cheaitou and Givry, 2020).

With a sixth rank in the overall assessment and a fourth rank in the assessment of negative criteria, fees ( $\Delta = 0.1080$ ) are a criterion not to be neglected in Arctic shipping. Fees are payable for icebreaker support (Furuichi and Otsaka, 2013), the inspection required by the Russian authorities before passing the route (Liu and Kronbak, 2010) and the pilotage is a mandatory requirement (Liu and Kronbak, 2010; Furuichi and Otsaka, 2013; Pruyn, 2016). It should be mentioned here that only along the NSR fees are due and the other routes are not associated with fees (Lasserre, 2014). Furthermore, the fees vary depending on various factors (Liu and Kronbak, 2010; Furuichi and Otsaka, 2013; Lasserre, 2014; 2015).

With a seventh place in the overall evaluation and a fifth place within the negative dimension, weather conditions ( $\Delta = 0.1012$ ) is the first criterion from the Risk category. The findings are directly in line with previous findings which described the harsh environmental conditions in the Arctic region (Hong, 2012; Meng, Zhang and Xu, 2017). Especially polar air temperatures, strong winds, visibility, fog and darkness (in the winter months) are characteristic for the Arctic (Khan, et al., 2018; Tseng and Cullinane, 2018). In addition to the weather conditions described, ice also plays an important role and increase the risk for a shipping company (Fu, et al., 2018; Khan, et al., 2018).

## 6 Conclusion

The freight shipping in maritime Arctic waters is an emerging topic in recent years. Due to the significantly shorter routes, cost savings are likely. A lot of research has focused on the feasibility of shipping through the Arctic. Furthermore, there are also studies dealing exclusively with the costs and risks of Arctic freight shipping. However, in order to provide a holistic decision model, both positive and negative factors should be considered. The aim of this research is to create a comprehensive decision model for Arctic freight shipping by identifying and evaluating relevant criteria. The results of the review are

structured using the BOCR method. The identified factors are judged through an expert survey and refined afterwards. Subsequently, FST is applied, and a sensitivity analysis is conducted. The results of this study show that equipment, insurance and inadequate port infrastructure are the main influencing criteria in Costs (C), and also the most influential factors overall. They are followed by the criteria security and market potential (Opportunities (O) category). Weather conditions, delay, and collisions / accident also have a high impact, being the strongest criteria in Risks (R). Reduced costs have the highest influence in Benefits (B), but with comparatively little influence.

With this result, the study offers a contribution both from a theoretical and a practical point of view. From a theoretical perspective, the research creates a quantitative, aggregated overview of influencing criteria. Furthermore, the level of influence is considered and thus supplements the existing theory, especially for the positive criteria. From a practical point of view, the results provide guidance for the assessment of influencing criteria for shipping companies when considering freight transportation through Arctic waters.

Serving as a starting point for further research, there are some limitations to be considered. A general constraint is the continuous development of political and ecological framework conditions in the Arctic. In addition, the technical capabilities are also evolving. Therefore, the results of this study are a snapshot and should be repeated at regular intervals, also with a focus on individual thematic priorities such as technical aspects. Furthermore, the special features of cruise ships are not included. At the same time, it is also possible to select different individual types of cargo ships within the freight shipping industry as a level of consideration or to focus on intra-Arctic transports.

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### References

- Afenyo, M., Khan, F., Veitch, B. and Yang, M., 2017. Arctic shipping accident scenario analysis using Bayesian Network approach. *Ocean Engineering*, [e-journal] 133, pp. 224–230. <http://dx.doi.org/10.1016/j.oceaneng.2017.02.002>.
- Andrić, J. M., Wang, J. and Zhong, R., 2019. Identifying the Critical Risks in Railway Projects Based on Fuzzy and Sensitivity Analysis: A Case Study of Belt and Road Projects. *Sustainability*, [e-journal] 11(5), pp. 1302–1319. <http://dx.doi.org/10.3390/su11051302>.
- Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report.
- 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*, [e-journal] 152, pp. 54–69. <https://doi.org/10.1016/j.tra.2021.07.006>
- Bozbura, F. T. and Beskese, A., 2007. Prioritization of organizational capital measurement indicators using fuzzy AHP. *International Journal of Approximate Reasoning*, [e-journal] 44(2), pp. 124–147. <http://dx.doi.org/10.1016/j.ijar.2006.07.005>.
- Brubaker, R. D. and Ragner, C. L., 2010. A review of the International Northern Sea Route Program (INSROP) – 10 years on. *Polar Geography*, [e-journal] 33(1-2), pp. 15–38. <http://dx.doi.org/10.1080/1088937X.2010.493308>.
- Budzik, P., 2009. Arctic Oil and Natural Gas Potential.
- Buixadé Farré, A., Stephenson, S. R., Chen, L., Czub, M., Dai, Y., Demchev, D., Efimov, Y., Graczyk, P., Grythe, H., Keil, K., Kivekäs, N., Kumar, N., Liu, N., Matelenok, I., Myksvoll, M., O'Leary, D., Olsen, J., Pavithran.A.P., S., Petersen, E., Raspotnik, A., Ryzhov, I., Solski, J., Suo, L., Troein, C., Valeeva, V., van Rijckevorsel, J. and Wighting, J., 2014. Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure. *Polar Geography*, [e-journal] 37(4), pp. 298–324. <http://dx.doi.org/10.1080/1088937X.2014.965769>.
- Christensen, M., Georgati, M. and Arsanjani, J. J., 2019. A risk-based approach for determining the future potential of commercial shipping in the Arctic. *Journal of*



- Marine Engineering & Technology, [e-journal] 44, pp. 1–18.  
<http://dx.doi.org/10.1080/20464177.2019.1672419>.
- Dalaklis, D., Drewniak, M. L. and Schröder-Hinrichs, J.-U., 2018. Shipping operations support in the “High North”: examining availability of icebreakers along the Northern Sea Route. *WMU Journal of Maritime Affairs*, [e-journal] 17(2), pp. 129–147. <http://dx.doi.org/10.1007/s13437-018-0142-7>.
- Eliasson, K., Ulfarsson, G. F., Valsson, T. and Gardarsson, S. M., 2017. Identification of development areas in a warming Arctic with respect to natural resources, transportation, protected areas, and geography. *Futures*, [e-journal] 85, pp. 14–29. <http://dx.doi.org/10.1016/j.futures.2016.11.005>.
- Faury, O. and Cariou, P., 2016. The Northern Sea Route competitiveness for oil tankers. *Transportation Research Part A: Policy and Practice*, [e-journal] 94, pp. 461–469. <http://dx.doi.org/10.1016/j.tra.2016.09.026>.
- Faury, O., Cheaitou, A. and Givry, P., 2020. Best maritime transportation option for the Arctic crude oil: A profit decision model. *Transportation Research Part E: Logistics and Transportation Review*, [e-journal] 136, p. 101865–101865. <http://dx.doi.org/10.1016/j.tre.2020.101865>.
- Fedi, L., Faury, O. and Gritsenko, D., 2018. The impact of the Polar Code on risk mitigation in Arctic waters: a “toolbox” for underwriters? *Maritime Policy & Management*, [e-journal] 45(4), pp. 478–494. <http://dx.doi.org/10.1080/03088839.2018.1443227>.
- Fu, S., Yan, X., Di Zhang and Zhang, M., 2018. Risk influencing factors analysis of Arctic maritime transportation systems: a Chinese perspective. *Maritime Policy & Management*, [e-journal] 45(4), pp. 439–455. <http://dx.doi.org/10.1080/03088839.2018.1448477>.
- Furuichi, M. and Otsaka, N., 2013. Cost Analysis of the Northern Sea Route (NSR) and the Conventional Route Shipping. *Proceedings of the IAME 2013 Conference, Marseille, France*, 3-5.
- Hong, N., 2012. The melting Arctic and its impact on China’s maritime transport. *Research in Transportation Economics*, [e-journal] 35(1), pp. 50–57. <http://dx.doi.org/10.1016/j.retrec.2011.11.003>.

## Fuzzy-based decision analysis on Arctic transportation

- Humpert, M. and Raspotnik, A., 2012. The future of Arctic shipping. *Port Technology International*, (55), pp. 10–11.
- IMO, 2014. Resolution MSC 385(94) of 21 November 2014 and Resolution MEPC 264(68) of 15 May 2015: International Code for Ships Operating in Polar Waters (Polar Code).  
<<http://www.imo.org/en/MediaCentre/HotTopics/polar/Documents/POLAR%20CODE%20TEXT%20AS%20ADOPTED.pdf>> [Accessed 23 August 2020].
- Khan, B., Khan, F., Veitch, B. and Yang, M., 2018. An operational risk analysis tool to analyze marine transportation in Arctic waters. *Reliability Engineering & System Safety*, [e-journal] 169, pp. 485–502.  
<http://dx.doi.org/10.1016/j.ress.2017.09.014>.
- Kiani Mavi, R. and Standing, C., 2018. Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach. *Journal of Cleaner Production*, [e-journal] 194, pp. 751–765.  
<http://dx.doi.org/10.1016/j.jclepro.2018.05.120>.
- Lasserre, F., 2014. Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector. *Transportation Research Part A: Policy and Practice*, [e-journal] 66, pp. 144–161.  
<http://dx.doi.org/10.1016/j.tra.2014.05.005>.
- Lasserre, F., 2015. Simulations of shipping along Arctic routes: comparison, analysis and economic perspectives. *Polar Record*, [e-journal] 51(3), pp. 239–259.  
<http://dx.doi.org/10.1017/S0032247413000958>.
- Lin, D.-Y. and Chang, Y.-T., 2018. Ship routing and freight assignment problem for liner shipping: Application to the Northern Sea Route planning problem. *Transportation Research Part E: Logistics and Transportation Review*, [e-journal] 110, pp. 47–70. <http://dx.doi.org/10.1016/j.tre.2017.12.003>.
- Liu, M. and 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*, [e-journal] 18(3), pp. 434–444.  
<http://dx.doi.org/10.1016/j.jtrangeo.2009.08.004>.
- Marchenko, N., Andreassen, N., Borch, O. J., Kuznetsova, S., Ingimundarson, V. and Jakobsen, U., 2018. Arctic Shipping and Risks: Emergency Categories and

- Response Capacities. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, [e-journal] 12(1), pp.107–114. <http://dx.doi.org/10.12716/1001.12.01.12>.
- Marken, V. B., Ehlers, S. and Khan, F., 2015. Delay risk analysis of ship sailing the northern sea route. *Ship Technology Research*, [e-journal] 62(1), pp.26–35. <http://dx.doi.org/10.1179/0937725515Z.0000000007>.
- Meng, Q., Zhang, Y. and Xu, M., 2017. Viability of transarctic shipping routes: a literature review from the navigational and commercial perspectives. *Maritime Policy & Management*, [e-journal] 44(1), pp.16–41. <http://dx.doi.org/10.1080/03088839.2016.1231428>.
- Milaković, A.-S., Gunnarsson, B., Balmasov, S., Hong, S., Kim, K., Schütz, P. and Ehlers, S., 2018. Current status and future operational models for transit shipping along the Northern Sea Route. *Marine Policy*, [e-journal] 94, pp.53–60. <http://dx.doi.org/10.1016/j.marpol.2018.04.027>.
- Phillis, Y. A., Chairetis, N., Grigoroudis, E., Kanellos, F. D. and Kouikoglou, V. S., 2018. Climate security assessment of countries. *Climatic Change*, 148(1-2), pp.25–43.
- Pruyn, J. F., 2016. Will the Northern Sea Route ever be a viable alternative? *Maritime Policy & Management*, [e-journal] 43(6), pp.661–675. <http://dx.doi.org/10.1080/03088839.2015.1131864>.
- Saaty, T. L., 2004. Fundamentals of the analytic network process — multiple networks with benefits, costs, opportunities and risks. *Journal of Systems Science and Systems Engineering*, [e-journal] 13(3), pp.348–379. <http://dx.doi.org/10.1007/s11518-006-0171-1>.
- Schmied, J., Borch, O. J., Roud, E. K. P., Berg, T. E., Fjørtoft, K., Selvik, Ø. and Parsons, J. R., 2017. Maritime Operations and Emergency Preparedness in the Arctic—Competence Standards for Search and Rescue Operations Contingencies in Polar Waters. In: K. Latola, and H. Savela, eds. 2017. *The Interconnected Arctic — UArctic Congress 2016*. Cham: Springer International Publishing, pp. 245–255.
- Schneider, A., 2018. Northern Sea Route. *Problems of Economic Transition*, 60(1-3), pp.195–202.

## Fuzzy-based decision analysis on Arctic transportation

- Schøyen, H. and Bråthen, S., 2011. The Northern Sea Route versus the Suez Canal: cases from bulk shipping. *Journal of Transport Geography*, [e-journal] 19(4), pp. 977–983. <http://dx.doi.org/10.1016/j.jtrangeo.2011.03.003>.
- Theocharis, D., Rodrigues, V. S., Pettit, S. and Haider, J., 2019. Feasibility of the Northern Sea Route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker market. *Transportation Research Part E: Logistics and Transportation Review*, [e-journal] 129, pp. 111–135. <http://dx.doi.org/10.1016/j.tre.2019.07.003>.
- Tseng, P.-H. and Cullinane, K., 2018. Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model. *Maritime Policy & Management*, [e-journal] 45(4), pp. 422–438. <http://dx.doi.org/10.1080/03088839.2018.1443225>.
- Wang, D., Ding, R., Gong, Y., Wang, R., Wang, J. and Huang, X., 2020. Feasibility of the Northern Sea Route for oil shipping from the economic and environmental perspective and its influence on China's oil imports. *Marine Policy*, [e-journal] 118, p. 104006–104006. <http://dx.doi.org/10.1016/j.marpol.2020.104006>.
- Wang, H., Zhang, Y. and Meng, Q., 2018. How will the opening of the Northern Sea Route influence the Suez Canal Route? An empirical analysis with discrete choice models. *Transportation Research Part A: Policy and Practice*, 107, pp. 75–89.
- Wang, Z., Silberman, J. A. and Corbett, J. J., 2020. Container vessels diversion pattern to trans-Arctic shipping routes and GHG emission abatement potential. *Maritime Policy & Management*, [e-journal] 33(2), pp. 1–20. <http://dx.doi.org/10.1080/03088839.2020.1795288>.
- Xu, H., Yin, Z., Jia, D., Jin, F. and 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*, [e-journal] 38(5), pp. 541–560. <http://dx.doi.org/10.1080/03088839.2011.597449>.
- Zadeh, L. A., 1965. Fuzzy Sets. *Information and Control*, [e-journal] 8(3), pp. 338–353. [http://dx.doi.org/10.1016/S0019-9958\(65\)90241-X](http://dx.doi.org/10.1016/S0019-9958(65)90241-X).
- Zhang, Z., Huisingh, D. and Song, M., 2019. Exploitation of trans-Arctic maritime transportation. *Journal of Cleaner Production*, [e-journal] 212, pp. 960–973. <http://dx.doi.org/10.1016/j.jclepro.2018.12.070>.