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Developing a resilience index for safer and more resilient arctic shipping

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ABSTRACT
The growth of Arctic shipping requires effective tools to assess the appropriateness of existing practices on safety and resilience levels, especially in the enforcement of the Polar Code. Understanding such, in this study, we develop a resilience index using the Fuzzy Analytical Hierarchy Process (FAHP). Data collection for the index's implementation started during a research voyage along the Northwest Passage in Canada. It resulted in 61 valid responses, upon which the relative importance and the level of satisfaction of resilience builders were investigated. The findings indicate that factors that rank high on importance are, in many cases, not that high on satisfaction. This presents dilemmas regarding the effectiveness of the current practices in promoting safe and resilient Arctic shipping management practices. This study fills an important gap in the monitoring of safety and resilience practices in Arctic shipping. In turn, this affects the future actions and research of researchers, stakeholders, and right-holders in the Arctic area.

KEYWORDS
Risk management; resilience; arctic shipping; Fuzzy Analytical Hierarchy Process (FAHP); shipping safety

1. Introduction

Shipping traffic in the Arctic has grown considerably over the last decades in mainly because of the rate of ice melting as supported by the navigability data of the Arctic routes (Aksenov et al. 2017). The shipping traffic in the Arctic region so far can be divided into 'destinational' and 'trans-Arctic' shipping. The former is expected to increase primarily because of hydrocarbon extraction activities, re-supply to remote Arctic communities, fishing, research voyages, and tourism (Melia, Haines, and Hawkins 2017). For trans-Arctic shipping, it is currently mainly performed along two main routes: Northern Sea Route (NSR) along Russia's northern coastlines, and Northwest Passage (NWP) through the Canadian Archipelago. The Transpolar Sea Route (TSR)—a mid-Arctic Ocean route compared to the two mentioned coastal routes is less explored due to extreme ice conditions (Ng et al. 2018) illustrates the minimum sea ice extent for September 1999–2019 (Lindsey and Scott 2019) (Figure 1).[1]

As illustrated in Figure 1, the traffic was significantly higher along NSR compared to the NWP. Similarly, projected navigability of the routes suggests that the condition along the NSR is currently the most advantageous. This conditions may apply to the NWP and TSR in about ten and 30 years, respectively (Aksenov et al. 2017). In this regard, a report published by the Protection of the Arctic Marine Environment (PAME), a working group of the Arctic Council Monitoring traffic above 58 degrees north,[2] shows that there were 1,628 unique ships in the Arctic area in 2019, among which

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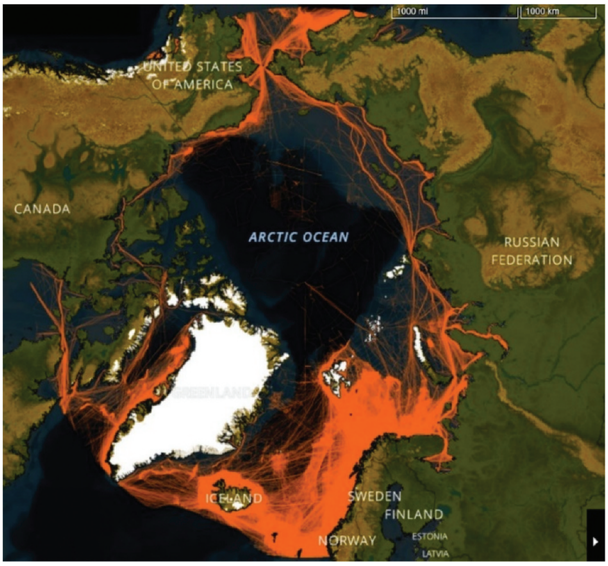

Figure 1. A map of Arctic shipping (Source: Authors elaboration using WWF Arctic Geographical Information System (wwfarcticmaps.org)).

over 40% were fishing vessels, followed by ships classified as 'others' (e.g., research, icebreakers), and general cargo vessels (PAME, 2020). Amid the social, environmental, and economic challenges (Afenyo, Jiang, and Ng 2019), the Arctic's economic growth and emerging maritime supply chain networks have created competitions among stakeholders (e.g., ship operators), Arctic and non-Arctic countries alike (Government of Canada 2019). The increase in non-Arctic observer members of the Arctic Council since its establishment in 1996 indicates the strategic importance of these new waterways.

Having say so, most navigators face unique risks peculiar to the specific conditions of the Arctic. As depicted by the *International Code for Ship Operations in Polar Waters* (hereinafter called the 'Polar Code'), under the 'hazard sources' section such risks are caused by sea ice, low temperatures, extended periods of darkness, high latitude, extreme weather conditions, remoteness, lack of data, lack of crew experience, and the lack of search and rescue services (International Maritime Organization (IMO) 2020). Illustrative examples can be found in Figures 2a and 2b, while some current radars cannot detect icebergs while navigating in these waters. These imply that it requires very experienced captains and crew to successfully pass through any hidden icebergs unscathed. In this regard, physical risks (e.g., extreme weather events, icebergs), the lack of infrastructure

(a) (b)

Figure 2. A and 2b. Sample Arctic shipping risk factors that include 1) poor visibility and 2) ice coverage.

constituting such risks (e.g., poor communication equipment, incomplete charts, remoteness from search and rescue), and enhanced human errors in the Arctic (e.g., operational malfunction due to cold weather, lack of tailor-made training) are considered as the key factors during an insurance underwriting (P and Club 2014).

Hence, it requires shipping stakeholders' support in planning and preparation for, absorbing, recovering from, and adapting to the Arctic environment (Linkov et al. 2014). It is critical to identify and understand the contributions of Arctic Shipping Resilience Builders (ASRBs) to effectively enhance the system's performance in the new environment. These are the measures that build absorptive, restorative, and transformative capacities of the system (Linkov et al. 2014); and directly and indirectly affect the safety of transportation. Considering the wide variety of stakeholders engaged in the shipping industry, we safely assume that stakeholders differ in terms of backgrounds, knowledge, beliefs, and concerns about the industry, especially in Arctic shipping. Such differences, affected by dissimilar power and interests, could be due to psychological distance (PD): a cognitive separation between self and other instances such as persons, events, or times (Trope and Liberman 2003), and exacerbated by the scarcity of accident data in the Arctic, not helped by data inaccuracy due to frequent underreporting (Marchenko et al. 2016; Goerlandt and Montewka 2015; Goerlandt et al. 2017). Furthermore, using different classifications and definitions to analyze such events has made it complex to explore root causes, and thereby plan and prepare for the challenges the new environment presents (Luo and Shin 2019). Such difference due to PD is reflected in stakeholders' contributions in supporting sustainable development.

Although the economic concerns in Arctic shipping have been widely discussed (e.g., Theocharis et al. 2018), there is little research on specific risk factors (e.g., Østreng et al. 2013), such as accidents analysis (e.g., Afenyo et al. 2017), factors addressing safe navigation (e.g., Fu et al. 2018), and related development obstacles (e.g., Tseng and Cullinane 2018). More recent research provided better insight, but still, it is difficult to fully understand whether the current Arctic shipping practices are adequate in addressing the expected levels of safety and resilience. Furthermore, the gap unfavorably affects the implementation of risk transfer measures (e.g., P&I insurance) in support of the development and defining the tolerable operation uncertainty.[3] Finally, investigating such is critical from the business ethics perspective. Extensive literatures identify externalities as major sources for business ethics and suggest that any practice, which has negative externalities and requires another party to take a significant loss without consent or compensation, are regarded as unethical (Cosans 2009). Exploring such could shed light on reduced interests in major shipping lines overtime in the Arctic area, despite the initial drive. Table 1 shows a summary of the major works with regards to resilience in general and specifically regarding Arctic shipping management.

Despite such, there is a scarcity of research investigating comprehensive systems for identifying, measuring, and prioritizing actions for ASRBs. To our best knowledge, there is no research that develops an effective framework to effectively measure ASRBs based on the definition of resilience. Thus, it is of utmost importance to develop a tool to fill this gap: with the development of the Arctic Shipping Resilience Index (ASRI) as the appropriate way to do so. ASRI must be comprehensive enough to incorporate a holistic view of Arctic seafarers on shipping resilience. This is pivotal considering the enforcement of the Polar Code which draws a baseline for important actions expected to be followed and completed by all the Arctic shipping stakeholders. Hence, we develop an ASRI based on the weighted combination of the top-20 ASRBs using Fuzzy Analytical Hierarchy Process (FAHP) and measure the index from seafarers' perspective based on their satisfaction. It is a pioneer attempt to comprehensively determine the level of resilience in Arctic shipping by creating an index dedicated to safety and resilience enhancement. The index can be easily updated and so can offer invaluable references to different Arctic stakeholders (e.g., insurance underwriters in their practice) on the safety and resilience levels in both the short- and long-terms.

The rest of the paper is structured as follows. Sections 2 and 3 explain the Arctic regulatory framework and the methodology, respectively. Section 4 consists of the key findings and discussions, while the conclusion can be found in Section 5.

Table 1. A summary of the major works with regards to resilience in general and specifically Arctic shipping management.

Publication	Description
El Baz and Ruel (2021)	Discusses the robustness of supply chains in the context of the COVID-19 pandemic. The concluded that risk assessment is key to understanding the supply chain resilience. A total of 470 firms participated in the study
Abeysekara, Wang, and Kuruppuarachchi (2019)	Assessed how the apparel industry in Sri Lanka built resilience in their supply chain systems
May (2019)	Outlines how community can adapt to extreme weather events through effective governance in Louisiana coastal areas
Wu, Zhang, and Wan (2019)	Developed a model for assessing the ability of maritime shipping systems to recover from a natural disaster. The study helps to identify the most vulnerable points in the maritime transportation system
Liu et al. (2018a)	The authors examined how supply chain resilience influences the performance of the firms involved in the operation and use of the system.
Lam and Bai (2016) (20162016	A model was developed which integrates both the risks of supply chain and customer perspective to improve upon maritime supply chains.
Xu et al. (2019)	Developed a framework for addressing resilience of chain systems.
Liu et al. (2018b)	Developed a framework for identifying the vulnerabilities in supply chains. This framework was applied to a Maersk Shipping routes for East Asia route.
Thekdi and Santos (2016)	The authors integrated a method of assessing the resilience of the Port of Virginia in Hampton Roads, VA, USA to sudden natural disasters.
Asadabadi and Miller-Hooks (2018)	The authors adopted a game theory approach to assessing the resilience of the global supply chain.
Black and Glaser-Segura (2020)	Addressed the need for an updated form of current supply chains, in order to improve their resilience for such occurrence as the COVID-19 pandemic
Berle, Asbjørnslett, and Rice (2011)	The investigators developed a methodology to transform the formal safety assessment framework to one that addresses specifically maritime supply chain vulnerability

2. The Arctic Regulatory Framework

Seven Polar Class (PC) ships are defined by the International Association of Classification Societies (IACS) through the *Unified Requirements for Polar Class Ships* that underline the minimum requirements for operations in polar waters. First published in 2007, it was designed to unify definitions implemented by different classification societies. It incorporates concepts from the earlier versions, while it has its own definitions for design scenarios, ice mechanics concepts, strength formulations, and operational requirements. For example, guidelines initiated by the Finnish Transport and Communications Agency and the Swedish Maritime Administration—known as the *Finish-Swedish* or *Baltic Ice Class*—categorized ships into six classes (TRAFICOM, 2017) used by several classification societies for years before the enactment of the IACS rules. Based on the IACS rules, PC1 (the highest class) refers to ships capable of year-round operation and PC7 (the lowest rank) denotes those capable of summer/autumn operation in thin first-year ice that might include old ice (International Association of Classification Societies (IACS) 2019). Unlike the Baltic ice class which is intended for operating only in first-year ice, the possibility of encountering multi-year ice is also taken into consideration. Furthermore, even in the design of the lowest class (PC7), these are considered. Later, such inputs were used in the development of the Polar Code.

The Polar Code was entered into force by the IMO in January 2017 to respond to increasing traffic and accidents in the Polar regions. This supplemented the *International Convention for the Safety of Life at Sea* (SOLAS) and the *International Convention for the Prevention of Pollution from Ships* (MARPOL). In July 2018, amendments to the International Convention for Seafarers (STCW) were developed to support the requirement for training using the Polar Code. In addition, the IMO's Maritime Safety Committee (MSC) regulated how such measures should be applied to non-SOLAS vessels operating in the polar (including the Arctic) waters. There are other navigation-related conventions, such as the *International Regulations for Preventing Collisions at Sea* (COLREGs) which have yet been updated to reflect the special environment in the Arctic. The Polar Code provides guidelines for safe operation and protection of the polar environment by addressing risks present in polar waters which are not adequately mitigated by other treaties. It is designed to address the lack of data in the Arctic (Fedi, Faury, and Gritsenko 2018). It is applied to ships differently depending on where, when, and how they operate in polar waters. Ship operators and/or owners must meet the Polar Code requirements and fully understand risks through a comprehensive list of hazards as outlined in the Code: 1) equipment (e.g., windows on bridge, lifeboats, clothing, ice removal), 2) design and construction (e.g., ship categories, material, and structure), and 3) operational and manning practice (e.g., training and certificate, and polar water operation manual). It should be complemented by rules and regulations locally enforced by governments. That said, the Polar Code should be a base upon which other complementary measures be built. It is the responsibility of shipowners, builders, and operators, and the Arctic countries to comply with all applicable acts and regulations.

3. Methodology

We developed an ASRI based on the weighted combination of the top-20 ASRBs using FAHP. After then, we measure the index from seafarers' perspective including the relative importance of ASRBs and their level of satisfaction.

3.1. Arctic Shipping Resilience Builders (ASRBs)

As stated earlier, ASRBs include those measures incorporated into the level of preparation of a particular system based on its built-in capacities. In turn, these attributes are expected to reduce the frequency and/or severity of time, quality, and cost-related risks. That said, ASRBs are defined with three *f* constraints: 1) being or expected to be different in Arctic shipping environment, 2) act as a risk prevention and/or reduction measure in response to time disruption, damage to quality, and additional financial loss during operation (Vilko, Ritala, and Hallikas 2016; Panahi et al. 2020), and 3) have minimum overlap between them. Considering such, we extracted ASRBs from relevant literatures which encompass research articles, professional reports, and industrial guidelines and standards (e.g., the Polar Code). This has led to the identification of 18 preliminary attributes. In addition, four Master Mariners (MMs) with at least 25 years of shipping experience in icy conditions (at least five years specifically in the Arctic area) were consulted through in-depth, semi-structured interviews. This resulted in identifying new attributes. Leveraging our knowledge on the shipping industry, we compiled all the obtained information by re-wording suggestions and combining proposed ones, resulting in 23 attributes. After then, we invited them to rank the top-20 measures. After two rounds of circulating the outcomes, we reached a consensus among all the participants on the list of measures for the rest of the research process. During each round, we modified the wordings to reflect the inputs of the interviewees. We tried to minimize the overlap between the proposed attributes but sometimes it was not possible. Where this happened, their inclusion was based on their differences. Here we relied on the literature reviews to identify the list as exercised in many such research. To complement and make our review even stronger we interviewed those who are in the field to strengthen our understanding and create a more practical list. After finalizing the list of top-20 ASRBs (Table 2), we categorized them into four groups, namely 1) crew, 2) navigation service, 3) shipping, and 4) ship technology (Table 3).

3.2. Research process

To determine the relative importance weight of ASRBs, we used the FAHP method based on Buckley (1985); an extension of the classical AHP method (Saaty 19801980). FAHP is like AHP in addressing the problem built on pairwise comparison, as well as including fuzzy rather than crisp (non-fuzzy) values (Lotfizadeh 1965) in deciding the relative importance of ASRBs. This enabled it to effectively incorporate human perception (e.g., PD, see section 1)—critical to understand the ASRBs. In any case, the literature has given strong support as to why this approach is appropriate,

Table 2. The Arctic Shipping Resilience Builders (ASRBs).

ASRB	Description	Source
Anti-icing system	Sensor used to detect icing which helps to timely react against ship icing from the atmosphere as well as sea spray.	Rashed et al (2016)[4] and Personal communication with experts
Communication system	Includes a real-time (voice and data) message transmission and the use of Global Maritime Distress and Safety System.	Polar Code[5]
Crew change plan	Governed by the Maritime Labor Convention (MLC), it is generally based on crew's rank and the vessel type. This varies for different shipping lines.	Maritime Labor Convention (2006., as amended and in 2018)[6]
Crew experience	Years of experience sailing in the Arctic and non-Arctic region	Polar Code
Ice-breaker service	Ice-breakers are used to escort/guide ships through the route.	Personal communication
Ice detection system	Used mainly *ice under pressure*, which is challenging to detect, or predict and for which captains are heedless until ship besetment.	Rashed et al (2014), Polar Code
Implemented Polar-class ship	Ship classes defined by the International Association of Classification Societies (IACS) based on their navigability in ice condition.	Panahi et al. (2020)[7]; Polar Code
Navigation hardware	That mechanical hardware contributing to the steering and movement of the ship, such as rudder, and propeller.	Panahi et al. (2020); Polar Code
Oil spill response	Readiness and response of countries to oil spills in order to protect marine and coastal environments.	Rashed et al (2014); Afenyo et al. (2021); International Convention for the Prevention of Pollution from Ships (MARPOL)
Operational manual	Enacted by the Polar Code, it covers a broad range of issues from engineering systems details to monitoring procedures, and emergency provision. Specifically, it supports educated operational decision making.	Panahi et al. (2020); Polar Code
Position identification system	E.g., paper navigation chart, Electronic Chart Display Information Systems (ECDIS), Global Positioning System (GPS), and Global Navigation Satellite System (GNSS).	Panahi et al. (2020); Polar Code
Port, harbor or other stevedoring facilities	Infrastructure and facilities used for loading and unloading operation, cargo delivery, etc.	Polar Code; Rashed et al (2014); Afenyo et al. (2021)[8]
Refueling and bunkering service	Such services are necessary to continue operation considering the possibility of ships getting stuck in remote regions.	Panahi et al. (2020); Polar Code
Restricted visibility navigation system	Those systems contribution to the navigation of the ship specially under the restricted visibility such as Automatic Identification System (AIS), echo sounder, fog signaling apparatus, navigation lights, radar, Automatic Radar Plotting Aid (ARPA), and Very High Frequency (VHF) radio.	Panahi et al. (2020); Polar Code
Search and rescue service	Required equipment and support in case of emergency.	Panahi et al. (2020); Polar Code
Ship ergonomics	Considers the interactions among human and other elements of a system	Panahi et al. (2020); Polar Code
Ship repair service	Facilities to address emergency repair needs of ships.	Panahi et al. (2020); Polar Code
Training and certification	Training and certifications enacted by STCW and required facilities.	Panahi et al. (2020); Polar Code
Voyage planning process	Efforts made to develop the voyage plan, including full attention to details.	Polar Code; Afenyo et al. (2021); Panahi et al. (2020)
Weather chart and forecast	Site specific marine weather charts and forecasts.	

especially for 'vague' problems (Kabir and Hasin 2011). The major steps for data analysis were divided into seven steps (Figure 3) which had been widely used in solving maritime-related problems (e.g., Tseng and Cullinane 2018; Garg and Kashav 2019; Tseng and Pilcher 2019; Mou et al. 20202014).

Table 3. Categorization of the Arctic Shipping Resilience Builders (ASRBs).

Category	ASRB	Category	ASRB
Crew	• Crew change plan • Crew experience • Operational manual • Training and certification	Vessel	• Anti-icing system • Ice detection system • Navigation hardware • Implemented Polar-class ship • Ship ergonomics
Navigation Service	• Communication system • Ice-breaker service • Position identification system • Restricted visibility navigation system • Weather chart and forecast	Shipping	• Oil spill response • Port, harbor, or other stevedoring facilities • Refueling and bunkering service • Ship repair service • Search and rescue service • Voyage planning process

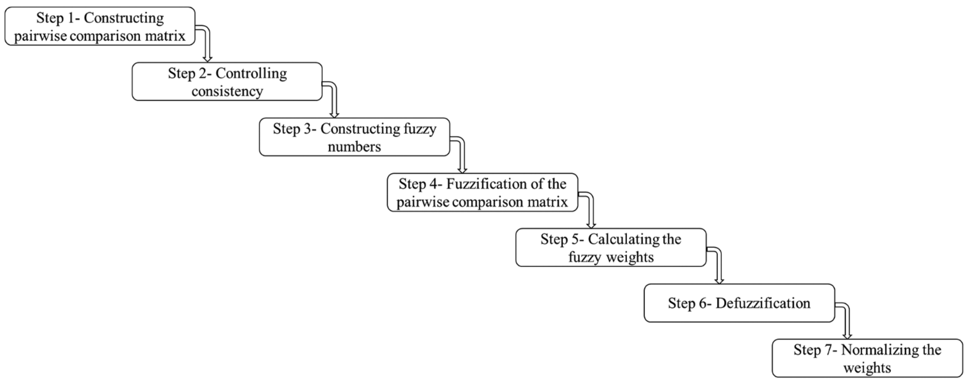

Figure 3. The seven steps of data analysis in this study.

In the following, the steps are briefly described:

- *Step 1*: It started with a pairwise comparison of the defined categories and ASRBs. A nine-point scale of relative importance was used (e.g., 1: 'equal importance', 3: 'moderate importance', 5: 'strong importance', 7: 'very strong importance', 9: 'extreme importance'). AHP is a tool that uses not only mathematical, but also psychological principles in its core ideas (Miller 1956). Thus, we split the levels in the hierarchy to keep the assignments of the pairwise comparisons within the human assessment capacity. We categorized the ASRBs into four categories (Table 3), understanding that there might be overlap between them. To address this, we built five pairwise comparison matrixes: one to determine global weights and four others to determine the local ones.
- *Step 2*: We examined and verified the consistency of the inputs by calculating the Consistency Ratio (CR), recommended to be less than 0.1 (Saaty 1980) for five pairwise comparison matrixes.
- *Step 3*: Mean values were assigned to each cell and the pairwise matrix was transferred to the third step. Here we defined the fuzzy numbers, for which we used the triangular membership function (Buckley 1985).
- *Step 4*: The pairwise comparison matrixes were re-built based on the created fuzzy numbers.
- *Step 5*: The fuzzy weights were calculated using the geometric mean method (Buckley 1985).
- *Step 6*: The weights were transformed into crisp numbers.
- *Step 7*: The numbers were normalized to keep their sum equal to one.

By determining the weight of ASRBs, we got the ASRI that was quantified based on the other set of inputs provided by relevant stakeholders.

3.3. Data collection

We conducted a survey to determine the weight of the ASRBs using FAHP and the level of satisfaction of each ASRB. Although it was desirable to have a large sample size, the definition was still subjective. That said, there were no concrete measures to determine the acceptable sample size, a minimum of 20–30 participants was generally accepted (see: e.g., Ng et al. 2018; Tseng and Cullinane 2018; Panahi et al. 2020). Furthermore, as random sampling was difficult to achieve considering remoteness of participants, we used a non-probability sampling approach (Goodman, 1961). This technique, known as cold-calling or chain sampling, does not give all the individuals in the population equal chances of being selected; and might include community bias; but it is useful when one tries to reach a population that is inaccessible or hard to find (Vogt and Burke, 2011). This technique has been used in similar research (e.g., Ng et al. 2018). To satisfy the minimum sample size requirements while considering the limitations, we conducted the survey within a six-month timeframe. This included all subjects available—making the sample a better representative of the entire population, but there was the possibility of community bias. This was addressed by restricting the chain of connection (Panahi et al. 2020).

Data collection started in August 2019 by asking the crew onboard the Canadian research icebreaker *Amundsen* to fill in a survey questionnaire during a voyage crossing the NWP (where we also joined the voyage). We approached potential respondents who satisfied the following criteria: 1) being master, or first or second officer; 2) had experience working on cargo carriers in the Arctic for at least five years; and 3) had experience in the shipping industry for at least one decade. After the voyage was completed in September 2019, a snowball sampling technique was applied to gather more data over the next six months (until February 2020). The same criteria used on the *Amundsen* was maintained. While we were on the *Amundsen*, some respondents recommended other relevant professionals to us. We followed up on these contacts and those also linked us to others. Together we administered 101 surveys, among those 68 were answered fully, four partially, and 29 not satisfactorily. For completed responses, we controlled their consistency by calculating the CR for the corresponding pairwise matrix and consequently discarded those not satisfying the measure of being less than 0.1, either at global or at the local level (Saaty 1980). This resulted in putting aside several questionnaires. Finally, 61 valid responses were included for further processing and analysis (referred as 'respondents' for the rest of the paper).

4. Key Findings and Discussions

The relative global importance in this study signifies how critical a particular factor is in building resilience. This means that a high-ranked ASRB on the scale is critical to the extent that, if not properly addressed, it would have more negative contributions to the overall resilience of the system. On the other hand, satisfaction describes the level of acceptance attached to what has been done with that factor in the resilience building process. The two are required to give a clear understanding of the system's resilience. In this regard, the four stated ASRB categories (Table 3) showed the following ranks in terms of global weights: 1) ship, 2) shipping, 3) navigation, and 4) crew. After then, we calculated the local weight of ASRBs in respective categories to determine their global weights. In doing so, we multiplied such local weights and the corresponding global weight of their categories.

The relative importance of ASRBs based on FAHP analysis can be found in Table 4 where the weights of the identified ASRBs were in the same range.[9] This was what could be expected to some extent before the data collection, as our focus was on the top-20 ASRBs. *Crew experience* was identified as the most important attribute. So, it was important to consider individual ASRBs than

Table 4. The relative importance of Arctic Shipping Reslince Builders (ASRBs).

Rank	ASRB	Relative global importance score (*100)
1	Crew experience	6.51
2	Navigation hardware	6.49
3	Operational manual	6.42
4	Implemented Polar-class ship	6.10
5	Ice detection system	6.08
6	Restricted visibility navigation system	5.85
7	Position identification system	5.59
8	Oil spill response	5.50
9	Training and certification	5.32
10	Ice-breaker service	5.14
11	Weather chart and forecast	4.85
12	Port, harbor, or other stevedoring facilities	4.63
13	Voyage planning process	4.60
14	Ship repair service	4.50
15	Ship ergonomics	4.42
16	Communication system	4.14
17	Search and rescue service	3.96
18	Refueling and bunkering service	3.79
19	Anti-icing system	3.59
20	Crew change plan	2.50

the general categories for which ranking could be misleading. Although the *crew* category was ranked fourth in the suggested categories, *crew experience* was the most important ASRB in the list. This combination of ASRBs formed a measurable ASRI which could be used by different stakeholders (e.g., insurance companies, governments, related international organizations/councils, etc.).

Measuring the level of satisfaction, together with the level of importance, of the ASRBs helped us to identify those requiring urgent actions. To maximize visibility and analytical power, we illustrated ASRI through an importance-satisfaction matrix diagram (Figure 4) (cf. Slack 19941994; Azzopardi and Nash 2013). In doing so, we measured the level of satisfaction of seafarers with ASRBs through the seven-point Likert scale (1: 'extremely dissatisfied', 2: 'moderately dissatisfied', 3: 'slightly dissatisfied', 4: 'neutral', 5: 'slightly satisfied', 6: 'moderately satisfied', and 7: 'extremely satisfied').

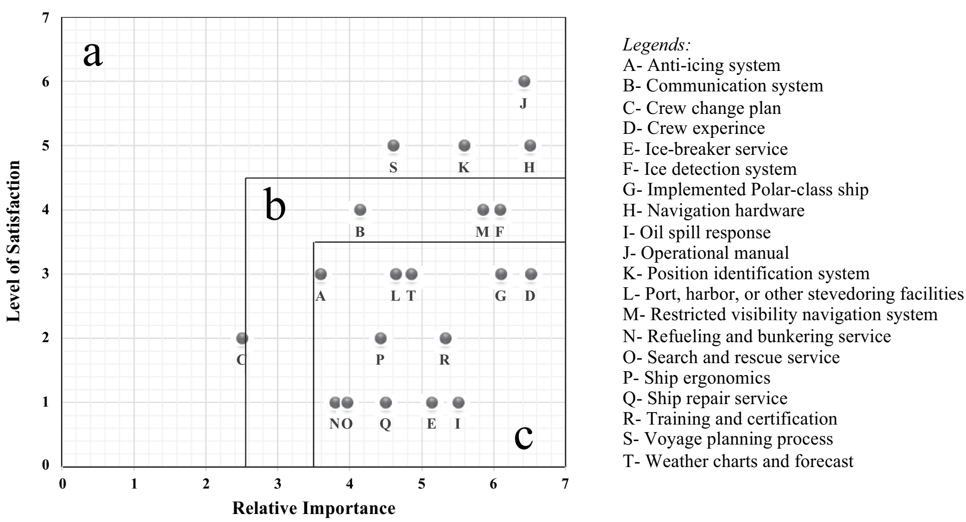

Figure 4. The importance-satisfaction matrix diagram.

The matrix diagram did not only add clarity to the key findings, but also offered priorities that required strong attention and urgent actions, especially in the context of the three major regions (A, B, and C), as follows:

- *Region A*: ASRBs that do not require much attention and actions (low importance-low satisfaction; low importance-high satisfaction; high importance-high satisfaction)
- *Region B*: ASRBs that require some attention and, if resources allow, actions (middle importance-low satisfaction; middle importance-middle satisfaction; high importance-middle satisfaction)
- *Region C*: ASRBs that require strong attention and urgent actions (high importance-low satisfaction)

In Figure 4, five, three, and 12 ASRBs lie at Regions, A, B, and C, respectively, suggesting that there is still much room for improvements. With crew experience having the highest importance between all identified ASRBs, it means that seafarers are slightly dissatisfied. This could be explained by the fact that the environment was new to most seafarers coming to the Arctic in their early years of works. Considering the growth of Arctic shipping, this seemed reasonable. Also, the findings suggested a huge difference on what seafarers encountered between non-polar icy sea surface (e.g., Baltic Sea) and during their first trip to Arctic areas, including those who possessed rich ice (non-polar) navigation experience. Of course, the situation might improve with further training and certification. Following the scores for *training and certification* (Figure 4) we could deduce that seafarers were moderately dissatisfied with current practices.

Hitherto, the Polar Code does not require MMs to have ice experience: just proven experience in polar waters is adequate for certification. Thus, it is realistically possible that a certified MM might have never 'seen ice' until the ship approached the perilous moment. Similarly, there are other Arctic-specific situations, such as 'getting stuck' on ice surface while drifting towards unwelcome barriers (e.g., iceberg), and running out of time. Very few, if any, such scenarios were experienced through training and certification which called for more scenario-oriented training involving such situation during preparation. To address this, some ship operators employed an ice navigator who joined the bridge team and supported navigation in challenging situations. Besides, recommended trainings were not effectively implemented due to the lack and weakness of simulators. As reiterated by many respondents, some ice navigators 'just turned the water's color from blue to white' which was not enough to simulate the conditions in the Arctic area. Moreover, there was another issue on the quality of training and certification. Many respondents complained that training providers often only cared about passing the learners' examinations, irrespective of their language of understanding or cognitive capacity. A transparent and open database on passing rates could improve this situation: indeed, the lack/substantial low rate of failures might hurt the credibility and reputation of the training and certification sector. Another issue was the deficiency in experience and knowledge transfer between generations onboard. Several respondents noted that knowledge dissemination on ships was not happening like before and suggested a few reasons in explaining why this was the case, notably losing power, position, or ego in general.

PC ships classified by related rules and regulation are intended to guide shipowners, designers, and operators in choosing an appropriate class to match the intended service of the ship. Therefore, any selected PC ships would be based on a balance between ice conditions, the operational requirements, and costs. Despite its high importance in Arctic shipping, seafarers were slightly dissatisfied with the implemented ships. This might be due to the weather variability in the Arctic area, which sometimes made it challenging to take the predetermined routes. This might pose a challenge which might call for re-defining the classification, as using lower PC ships might result in unbearable consequences. For example, navigation in ice without the required support considering the lack of ice-breaker service, for which seafarers were extremely dissatisfied might result in propeller damage. This is rather a difficult situation to be in the Arctic considering the minimal ship repair service available. Besides, ship schedule was adversely affected by time-consuming loading/unloading activities in support of the local communities (e.g., Fox Basin, NU, Canada) considering the lack of port, harbor, or other stevedoring facilities. This disrupted the voyage plan by tightening shipping schedules, which might cause domino effects and increased the possibility of accidents. At some locations, ship crews must deliver the packages, case by case, due to the lack of such facilities. At these locations, the whole (un-) loading operation was conducted by a sealift. After that, the team needed to ensure that it has received the signature of all the customers before leaving, thus complicating the schedules. This could be exacerbated by the tide in shallow waters, as losing time might result in getting stuck with restricted depth for a certain (sometimes extended) period. In addition, ships might encounter local current which could be accompanied by Arctic gusty winds while undertaking operations in such regions.

Considering Arctic shipping hazards which might be similar for the confined zones between the Arctic and non-Arctic environments but are completely different in exposed areas: it is mandatory to implement the user-centric approach and optimized the design for the crew and their dedicated work demands in the Arctic areas. This would minimize the negative implications of such issues which might jeopardize safety and efficiency and gave rise to another unwelcome consequences (Mallam, Lundh, and MacKinnon 2015; Endrina et al. 2019 2019) on time, quality, and costs. Crew members often descended wet or icy steps hurriedly forgetting to hold on the handrails, especially when facing hazardous situations. That said, seafarers were moderately dissatisfied by ship ergonomics, i.e., the science of fitting a workplace to user needs. Therefore, a better utilization of seafaring experience in the design of PC ships could increase the value of design as an accessible alternative for revisions of the classifications' rules and regulations. This study largely complemented previous research (Table 1) in that, with an improved Arctic shipping management system, the safety and resilience of Arctic shipping could be enhanced tremendously, thus improving the costs and efficiency of Arctic shipping and the accompanied logistics and supply chains. While Arctic shipping becomes more popular, it takes time before it could be more frequently used. Indeed, as mentioned, there is an urgent need to develop a mechanism for effective decision-making, with the ASRBs being the most important resilient building measures.

5. Conclusion

The rapid rate of ice melt has increased shipping activities in the Arctic area, with Arctic countries ramping up the narratives to favor the movement of goods *via* conventional means (e.g., the Suez Canal). To do so, developing a tool to identify, measure, and address Arctic shipping's safety and resilience become extremely important. This study used information from seafarer's perception to develop an Arctic Shipping Resilience Index (ASRI) based on the Fuzzy Analytical Hierarchy Process (FAHP). Data was collected starting from a research voyage through the Northwest Passage in Canada that resulted in 61 valid responses, upon which the levels of importance and satisfaction of different Arctic Shipping Resilience Builders (ASRBs) were investigated. The ARSI was illustrated through an importance-satisfaction matrix diagram which helped researchers, policymakers, practitioners, and other relevant stakeholders to identify measures that required strong attention and urgent actions in establishing safe and resilient Arctic shipping system.

The findings highlight the ASRBs that require urgent action (i.e., those with high importance and low satisfaction level) with crew experience and implemented PC ships on top. That said, over half of the ASRBs did not follow the general trends of the balance between importance and satisfaction. If not resolved, it could result in unfavorable consequences. In fact, some ASRBs that were ranked high at the importance level were, in many cases, not high at the satisfaction front, posing relevant questions on the credibility of the current approaches in promoting safe and resilient Arctic shipping. That said, the ARSI could be frequently updated to monitor the situation in the Arctic, affecting researchers and stakeholders' future actions for improvements, notably insurance underwriting guidelines, research priorities, regulation requirements, investment and construction, and workforce training and certification.

While the seafarer's perspective plays a critical role, that alone is not enough. Further research is needed to explore how other actors, especially those with high-power and interests, look at the situation. By doing so, we can examine each resilience builder and explore the reason behind probable differences among the key stakeholders. This would lead to broader applications. For example, ship operators could work on those fueled by seafarers' PD, knowledge gap, or the lack of clarification, and resolve them in a short period before such factors adversely affect the performance and efficiency of operations. Indeed, this study complements previous research on shipping safety and resilience and the need for a mechanism to identify the most critical resilience building measures. There are challenges to both building resilience in the Arctic specifically and shipping in general. Although ASRBs are Arctic-specific, there are others that are common to all other regions. Thus, further research is required to develop a framework to address the yet-to-be-addressed uncertainties, as human perception to the Arctic shipping players might be biased. This study offers a strong base upon which future research could be developed and further improve the safety and resilience of Arctic shipping.

Notes

1. It was created through satellite-based the Automatic Identification System (AIS) data which provides the spatial location of vessels at a given time The original data is provided by the Norwegian Coastal Administration (www.havbase.no) and further processed by DNV and WWF. The map is generated by the authors using WWF Arctic Geographical Information System (arkgis.org/).
2. The report covers a wider area than defined by the Polar Code, enacted by the *International Maritime Organization* (IMO) in 2017 (i.e., above 60 degrees north) to include Greenland.
3. Managers are eager to stay between risk tolerance (for which they are prepared for) and risk appetite (for which they are eager to undertake). This enables them to get more opportunities while addressing the downside of risk. This is known as staying within 'tolerable uncertainty' (ISO, 2018).
4. Rashid, T., Khawaja, H. A., & Edvardsen, K. (2016). Review of marine icing and anti-/de-icing systems. *Proceedings of the Institute of Marine Engineering, Science, and Technology. Part A, Journal of Marine Engineering and Technology*. https://doi.org/10.1080/20464177.2016.1216734.
5. Persson, J. (2016). *Polar Code: a practical guide to basic and advanced Polar Code certificate*. 90 North Ice Consulting.
6. h ttps://www.ilo.o rg/wcmsp5/groups/p ublic/—ed_norm/—normes/documents/normativeinstrument/wcms_763684.pdf.
7. Panahi et al. (2020): Reflecting on forty years contextual evolution of Arctic port research: The past and now. *Transportation Research Part A: Policy and Practice* 144:189–203.
8. Afenyo, M. Ng, A.K.Y., Jiang, C. (2021): 'A multi-period model for assessing the socio-economic impact of oil spills in the Arctic'. *Risk Analysis: An international Journal* (in press, doi: 10.1111/risa.13773).
9. The relative global importance of ASRBs is multiplied by 100 as such weights were originally calculated, using FAHP with the total sum of one.

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