Transportation Research Part A 152 (2021) 54–69

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Development of a search and rescue framework for maritime freight shipping in the Arctic

Lukas Benz, Christopher Münch, Evi Hartmann *

Chair of Supply Chain Management, Friedrich-Alexander University Nuremberg, Lange Gasse 20, Nuremberg, Germany

ARTICLE INFO

Keywords:
Arctic shipping
Northern Sea Route
Northwest Passage
Freight shipping
Search and rescue

ABSTRACT

In recent years, Arctic routes have been receiving increasing attention, as they offer a solution to capacity bottlenecks on the most frequented routes, such as the Suez Canal, Strait of Malacca, and Panama Canal. Due to climate change and melting polar ice, Arctic routes, especially the Northern Sea Route/Northeast Passage and Northwest Passage, are becoming increasingly competitive. The consequence of this development is an increase in maritime traffic in Arctic waters. Due to the harsh environment, maritime activities in the Arctic are associated with numerous risks, as reflected in the 512 incidents in the last decade. Therefore, sufficient search and rescue capabilities are necessary to ensure safety. Thus far, various studies have focused on different components of search and rescue, such as port infrastructure, icebreaker capabilities, and navigation. However, there is no study offering a framework for the required further development of search and rescue capabilities. Therefore, in this paper, a search and rescue framework is proposed. The development of the framework is based on a literature review of dimensions of search and rescue in the Arctic. Semi-structured interviews with 24 experts regarding the identified dimensions were conducted. The results of the qualitative content analysis show a total of 23 top-codes and 50 subcodes, which are presented and discussed. The discussion leads to the presentation of the search and rescue framework, including the dimensions *port infrastructure*, *search and rescue equipment*, *communication technology*, *navigation technology*, *standards and agreements,* and *cooperation* and the respective top-codes. Finally, limitations are addressed, and starting points for further research are proposed.

1. Introduction

Seaborne trade volumes have been rising continuously since 1995 and accordingly reached a new all-time high in 2018, with over 11 billion tonnes of goods loaded and shipped worldwide (UNCTAD, 2019). It is assumed that seaborne trade will continue growing in the coming decades, with an expected growth rate of 3.8% between 2018 and 2023 (Grzelakowski, 2019). The increase in volumes – especially between China and Europe – leads to congestion at bottlenecks on the most frequented sea routes, such as the Suez Canal, the Strait of Malacca, and the Panama Canal (Schneider, 2018). Therefore, alternative Arctic routes are receiving increasing attention (Lavissière et al., 2020), offering a solution to the capacity constraints (Buixadé Farré et al., 2014). Furthermore, it is expected that the melting of Arctic sea ice will continue, or even accelerate, in the next decades (Overland et al., 2019). These climatic changes towards a partially ice-free Arctic offer possibilities for the economic use of the Arctic Ocean (Dalaklis et al., 2018a; Xu and Yang, 2020) because

* Corresponding author.
E-mail addresses: lukas.benz@fau.de (L. Benz), christopher.muench@fau.de (C. Münch), evi.hartmann@fau.de (E. Hartmann).

https://doi.org/10.1016/j.tra.2021.07.006
Received 1 April 2020; Received in revised form 27 May 2021; Accepted 9 July 2021
Available online 17 August 2021
0965-8564/

Arctic routes are becoming more attractive due to easier navigation and the expansion of the navigable season. Additionally, existing oil and gas deposits attract the interest of countries and industries (Faury et al., 2020).

Currently, the Arctic is navigable for up to four months per year, which could be extended to six months by the use of stronger icebreakers (Button et al., 2017). In addition to sea ice, however, multiple other factors influence navigation safety (Shan and Zhang, 2019) and caused more than 293 accidents between 1995 and 2004 (Arctic Council, 2009) and 580 accidents between 2007 and 2018 in Arctic waters (Lloyds List, 2019). These accident figures make it necessary to have a search and rescue (SAR) strategy in place.

There are already numerous studies that account for Arctic-specific influencing factors for economic models (Faury and Cariou, 2016; Meng et al., 2017) or give overviews of possible risks when sailing through Arctic waters (Hill et al., 2015; Fu et al., 2018b; Milaković et al., 2018; Tseng and Cullinane, 2018; Zeng et al., 2020). Yet, few studies have focused on SAR in the Arctic. Research has been conducted into what SAR capabilities are needed to be best prepared for accidents to only a limited extent. Some researchers have dealt with the optimal allocation of ports and rescue bases (Pestov and Pilat, 2011; Liu et al., 2016; VanderBerg, 2018; Shan and Zhang, 2019). Marchenko et al. (2018) considered different emergency categories to determine the required response capacities. Dalaklis et al. (2018b) investigated icebreaker availability, as well as coordination centers, SAR assets, equipment and infrastructure, and concluded that more icebreakers and emergency management capabilities are necessary. Schmied et al. (2017) have given advice on the emergency command system and the competences which are required. Furthermore, in addition to international legal frameworks, there are already Arctic- and polar-specific agreements in place affecting SAR. However, there is currently no study providing a comprehensive overview summarizing mandatory SAR capabilities in the Arctic.

To close this research gap, this study addresses the following main research objectives:

- Identification of SAR dimensions in the Arctic region.
- Extension of the dimensions through qualitative expert interviews.
- Proposal of a SAR framework as a starting point for further development of SAR in the Arctic.

The article is structured as follows: after an overview of Arctic sea routes, maritime accidents in Arctic waters and the current state of SAR in the Arctic, a review of the relevant literature is conducted. Thereby, different dimensions are derived, which are then expanded in 24 semi-structured expert interviews. After the results of the interviews are presented and briefly described, a discussion is held at the level of the identified top-codes. A conclusion is presented in the final section, including limitations and suggestions for further research.

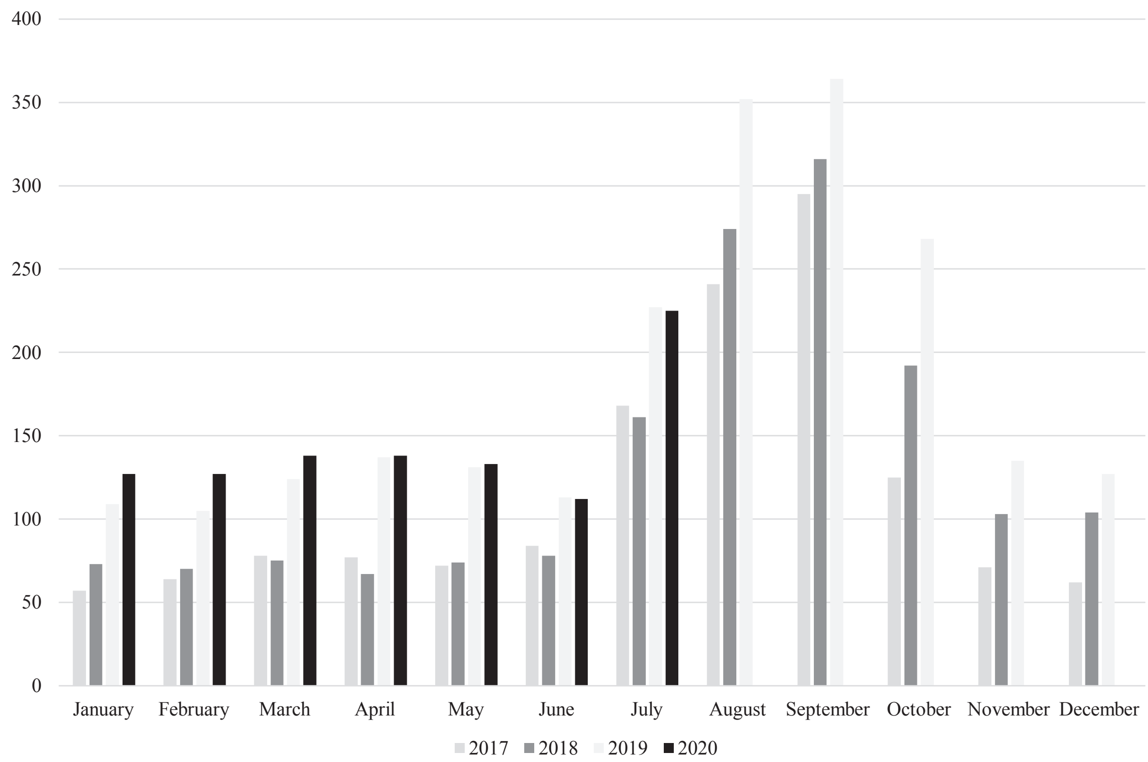

Fig. 1. NSR voyages (freight) from 2017 to 2020. Data source: based on data from Northern Sea Route Information Office/Centre of High North Logistics.

2. Theoretical background

2.1. Arctic sea routes

There are three shipping routes crossing the Arctic with the potential to transform freight shipping in the following decades: the Northwest Passage (NWP), the Northeast Passage (NEP) or Northern Sea Route (NSR), and the Transpolar Sea Route (TSR) (Hong, 2012; Humpert and Raspotnik, 2012). The NWP is a connection between the Atlantic and Pacific Oceans that runs along the coast of the United States, the Canadian Arctic and northern Alaska and through parts of Greenland's waters (Chircop, 2007). The NEP in particular is receiving increasing attention, as it connects China and Europe through the Russian and Norwegian Arctic, running along the coast of Siberia (Tseng and Pilcher, 2017), including the Barents Sea and the port of Murmansk (Østreng et al., 2013). Often used synonymously (Buixadé Farré et al., 2014), the NEP and NSR are in fact slightly different. According to Russian law, the NSR runs along the Novaya Zemlya archipelago to Cape Dezhnev by the Bering Strait (Solski, 2013) and, thus, represents a main part of the NEP. The TSR as the third *trans*-Arctic shipping route represents a connection between the Atlantic and the Pacific Oceans via the North Pole (Bennett et al., 2020).

In recent years, a considerable number of voyages have been carried out on the previously presented routes. An overview of the quantity of freight transports since 2017 is presented in Fig. 1. As can be seen from the figure, maritime freight operations on the NSR are consistently expanding. This is also reflected in the volume of freight transported, which grew by almost 84% from 2019 to 2020.

Furthermore, on the comparatively less frequented NWP, 59 transits have been completed since 2017 (Headland, 2020).

In the following section, the topic of maritime accidents in the Arctic is presented.

2.2. Maritime accidents in Arctic waters

The Arctic environment is characterized by extreme weather and ice conditions, remoteness from land and vulnerability of nature (Koshevyy and Shyshkin, 2017). In the last decade, 512 ship incidents have been reported in Arctic waters; machinery failure/damage was responsible for almost half of the incidents, due to the harsh environment (Allianz, 2020). There were two losses in 2019, one in the Canadian Arctic/Alaska and one in the Russian Arctic/Bering Sea (Allianz, 2020). Selected cases of Arctic maritime accidents are shown, among others, by Marchenko (2012), Bowo et al. (2019) and Fedi et al. (2020).

Given these accident statistics, numerous researches have been concerned with maritime accidents and the analysis of risk factors in the Arctic. For example, Fu et al. (2018b) identified potential risk factors for Arctic maritime transportation using an analytical hierarchy process method. Fu et al. (2018a) presented a risk assessment for major ship accidents in Arctic waters under uncertainty with a case of ships stuck in ice. Baksh et al. (2018) have developed a risk model using a Bayesian network to explore the possibility of maritime accidents (e.g., collisions, foundering, grounding) for the NSR. The authors of that study accounted for operational and environmental factors. Fedi et al. (2020) mapped and analyzed maritime accidents and the related casualties and incidents with a focus on the Russian Arctic and considered three accidents in connection with the Polar Code and the Polar Operational Limit Assessment Risk Indexing System (POLARIS) for preventative purposes.

Given the accident statistics, the research studies conducted and the expectation of increased maritime activities in Arctic waters, an adequate level of preparedness for emergency cases is needed (Marchenko et al., 2016a). In the following section, the current state of SAR operations in the Arctic is presented.

2.3. SAR operations in the Arctic

In the global context, the International Maritime Organization (IMO) defines SAR as an 'operation to render assistance to persons in distress at sea regardless of the nationality or status of such a person or the circumstances in which that person is found in accordance with the applicable Maritime Law and Conventions' (International Maritime Organization, 2006). There have been numerous agreements such as the International Convention for the Safety of Lives at Sea, the International Convention on Search and Rescue, and the Global Maritime Distress and Safety System, but due to the complex, remote and volatile environment in the Arctic area (Borch and Batalden, 2015), SAR missions are particularly challenging, because the harsh climate conditions could prevent expeditious intervention (Takei, 2013; SARC, 2017) .To create uniform regulations, clear responsibilities and a common understanding, different agreements affecting SAR in the Arctic region exist.

Firstly, the Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic was signed in 2011. The objective is to strengthen aeronautical and maritime SAR cooperation and coordination in the Arctic. *Inter alia*, SAR regions, competent authorities, SAR agencies and rescue coordination centers are defined (Arctic Council, 2011). In 2013, the Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic was passed with the objective to strengthen cooperation, coordination and assistance on oil pollution preparedness and response. This is also relevant for SAR, as a minimum level of equipment, program of exercises and trainings, and communication capabilities have to be available (Arctic Council, 2013).

With the adoption of the International Code for Ships Operating in Polar Waters (Polar Code) in 2014, steps were taken towards a new legal instrument to address safety and environmental risks related to polar shipping (Jensen, 2016). The Polar Code consists of various chapters that contain safety measures for risk mitigation, for example requirements for ship structure, fire safety/protection, safety of navigation, and communication requirements (IMO, 2016). Therefore, the Polar Code also affects the conditions for SAR in the Arctic.

The agreements are summarized in Table 1.

To summarize this section, the development of maritime shipping in the Arctic in recent years and the expected growth in the future, as well as the harsh environment causing numerous accidents, pose a challenge for SAR in Arctic waters. Therefore, further development of existing SAR activities in the Arctic is necessary.

3. Literature review

3.1. Port infrastructure

Arctic researchers agree that there is a lack of adequate infrastructure along the Arctic coastline (Stewart et al., 2013; Basharat and Oien, 2014; Osman, 2015; Grabowski et al., 2016; Palma et al., 2019). The number of modern ports, especially deep-water ports, is not sufficient to deal with the likely increase of maritime traffic in the Arctic (Hill et al., 2015; Abe and Otsuka, 2019). Ports support vessels crossing Arctic waters and serve as a starting point for SAR operations (Hill et al., 2015). Therefore, ports are an integral part of SAR centers (Shan and Zhang, 2019), which are further discussed in the following section According to VanderBerg (2018), strategically well-positioned ports are a critical factor in ensuring SAR operations, *inter alia*, due to their impact on emergency response times and the transmission of weather or ice data. Longrée and Hoog (2014) have indicated that not only ports but also icebreaker support in ports is required.

3.2. SAR equipment

A wide range of research regarding SAR equipment has been conducted regarding icebreaker capabilities (Dalaklis and Baxevani, 2017; Kiiski et al., 2018). According to Meng et al. (2017), icebreakers are important because they are needed to escort passing vessels and support SAR missions. In addition to icebreakers, stationary SAR capacities must also be considered. Longrée and Hoog (2014) have provided an overview of requirements for rescue centers, taking airport, harbour and settlement requirements into account. Furthermore, Dalaklis et al. (2018b) have indicated that these centers must play a coordinating role in emergency management. The centers form the basis for the provision of further equipment because various types of vehicle support are needed in SAR operations, for example, long-range helicopters (Jacobsen and Gudmestad, 2013). The importance of providing different vehicles is partly due to the decisive role of transport mode and transport time to hospital for the success of SAR missions (Haagensen et al., 2004). Additionally, the hospital infrastructure must be developed to provide telemedicine services (Woldaregay et al., 2017).

3.3. Communication technology

According to Kvamstad et al. (2009), a high-quality communication system is needed in the Arctic. The evaluated literature uniformly shows that Arctic communication infrastructure is currently lacking, and therefore, there is a need for improvement. Low Earth Orbit satellites are the main communication system used, and there is only one satellite, Iridium, to communicate over long distances in the Arctic area (Larsen et al., 2016; Marchenko et al., 2016b; Palma et al., 2019). Palma et al. (2019) have stated that there are Very High Frequency communication systems available that could be used for short distances but that would not be suitable for communication with coastal stations. Larsen et al. (2016) have indicated that information is transmitted by satellite-based augmentation systems or on-shore reference stations and that many maritime communication systems are based on Geostationary Earth Orbiter (GEO) satellites. Research has shown that problems with this type of communication arise at 708 N (Fjørtoft et al., 2009). These gaps pose a major problem, as ships are necessarily dependent on communication systems in emergency situations (Larsen et al., 2016).

3.4. Navigation technology

In the Arctic, with its harsh environment and geographic complexity, good navigation systems and ice predictions are necessary, providing information to support route decisions (Brubaker and Ragner, 2010; Buixadé Farré et al., 2014). Hill et al. (2015) have stated that navigational technology, including Global Positioning System (GPS) technology, is limited in the Arctic due to low satellite coverage, poorly functioning compasses and lacking hydrographic information. Furthermore, according to Meng et al. (2017), the results of ice and weather forecasting are subject to uncertainties and deviations. On the subject of decision-making in polar waters,

Table 1
Agreements effecting SAR.

Agreement/Code	Institution	Scope
Agreement on Cooperation on Aeronautical and Maritime Search and Rescue	Arctic Council	Respective areas of responsibility of each member and relevant required basic cooperation and coordination measures including joint review of SAR operations
Agreement on Cooperation on Marine Oil Pollution Preparedness and Response	Arctic Council	Mandatory obligation of mutual aid and support in case of an oil spill as well as adequate monitoring activities as preparedness tool for the timely discovery of oil spills in advance
International Code for Ships Operating in Polar Waters	International Maritime Organization	Provide regulations for safe ship operation and protection of the polar environment by risk mitigation

POLARIS is an important tool, which provides a risk assessment of operational capabilities for ships operating in ice-covered areas to evaluate navigational safety (Stoddard et al., 2016; Fedi et al., 2018a).

3.5. Standards and agreements

As shown in Section 2, agreements and binding rules for operations in Arctic waters, including for emergency cases, already exist. In general, geopolitical and political aspects play a major role, influencing both existing routes (Abe and Otsuka, 2019) and SAR activities in the Arctic. As one source of standards, the Polar Code is a political instrument to improve Arctic shipping (Fedi et al., 2018b). Prior to this, there were only regulations with an indicative character; these were incorporated in the Polar Code, which is binding for all actors (Buixadé Farré et al., 2014). The Polar Code specifies preventive measures, such as provisions for equipment, required technologies and necessary training, and it provides advice for operational standards to be integrated in the Polar Waters Operational Manual (IMO, 2016). Agreements made in the early years of the Polar Code act as supplements to its regulations. These additional aspects specifically cover SAR and marine oil pollution. The agreement on cooperation on aeronautical and maritime SAR in the Arctic, in addition to a geographical division of responsibilities for SAR activities, provides further rules aggregated at a high level (Arctic Council, 2011). In addition, the agreement on cooperation on marine oil pollution preparedness and response outlines the link between the involved nations, sets rules for the provision of necessary equipment and gives advice for operational guidelines (Arctic Council, 2013).

3.6. Cooperation

In addition to the standards and agreements already described, cooperation between the parties involved plays an important role, which is reflected in recommendations by the Arctic Council, e.g., for joint meetings, knowledge-sharing and training sessions (Arctic Council, 2011, 2013). Abe and Otsuka (2019) have indicated that international cooperation is the aspiration of some nations and is recommended for the further development of Arctic transport routes. Furthermore, with regard to sustainable development, working groups have been established by the Arctic Council to further increase cooperation in the private sector (Buixadé Farré et al., 2014). In addition, there are a number of cooperative activities between adjacent nations in place, including SAR training in the Arctic region (Ikonen, 2017).

As a result of the literature review, six dimensions necessary to design an SAR framework have been identified: *port infrastructure*, *search and rescue equipment*, *communication technology*, *navigation technology*, *standards and agreements,* and *cooperation.*

4. Methodology

The problem addressed in this study is a relatively unexplored subject, and therefore, an exploratory approach was chosen (Miles and Huberman, 1994). Semi-structured expert interviews were conducted based on dimensions derived from the literature until no significant new findings could be obtained (Yin, 2009). Interviews are an effective method of collecting comprehensive empirical data (Eisenhardt and Graebner, 2007). Thus, semi-structured expert interviews enabled structured data collection and, at the same time, offered the necessary degree of openness to new and unanticipated facts (Cannell and Kahn, 1968; Ananthram and Chan, 2013). In qualitative research, interviews are often utilized as a source for the explorative production of knowledge (Alvesson, 2003). As such, this approach was a valuable method for this research; such interviews are also applied in various research studies in the logistics and transportation area (Aygün and Oeser, 2017; Birkel et al., 2019; Buldeo Rai et al., 2019; Gruchmann et al., 2019; Lechler et al., 2019; Birkel and Hartmann, 2020; Boer et al., 2020; Lechler et al., 2020).

4.1. Data sampling and collection

The experts were identified through a stakeholder analysis conducted by the members of the research team. To limit bias in interview data, the following criteria were used to select the experts (Eisenhardt and Graebner, 2007). As the research interest was mainly focused on SAR in the Arctic region, the qualitative interviews were conducted with experts who have both professional experience and specialized knowledge in the fields of maritime freight transport and the Arctic region. In total, 24 qualitative, semi-structured expert interviews were conducted. Of these, four respondents were selected from the group of politics/non-governmental organization (NGO), while a further 12 interviews were conducted with practitioners, and eight were respondents from the group of scientists. Some have special qualifications based on their professional careers or experience. These qualifications included having a master mariner certification; being a former member of the coast guard; being an active ice navigator, ice advisor or Polar Code advisor; and acting as a specialist for environmental relations in the Arctic, politics and international relations in the Arctic, shipping companies (including shipping of dangerous goods), and ship and icebreaker building companies. The educational level of the experts is distributed as follows: six experts with a Ph.D., eight experts with a master's degree, two experts with a bachelor's degree and eight experts with an associate's degree. The expert sample covered 10 countries, five of which are observers and 19 of which are member states as defined by the Arctic Council. At least one expert from each Arctic Council member state was interviewed. The heterogeneity of the sample enabled us to generalize the results and counteract possible adverse effects of sample bias (Yin, 2009).

Table 2 provides an overview of all interview partners. For reasons of confidentiality, the names and institutions of the participants and their characteristics were made anonymous. The period of data collection extended from January to March 2020.

The collection of data in the expert interviews was founded on an interview guide that was compliant with the guidelines applicable

Table 2
Interview partners.

Expert	Country	Categroy	Area	Freight shipping		Arctic area		Educational background	Job level	Special qualification
				Work experience	Knowledge	Work experience	Knowledge			
1	Greenland	Science	Arctic research	13	3	13	4	Associate‘s degree	Director/CEO	–
2	Sweden	Business	Shipping company	31	5	31	5	Bachelor‘s degree	Director/CEO	Master mariner; Polar Code advisor
3	Norway	Politics/ NGO	–	1	4	10	4	Master‘s degree	Director/CEO	Specialist in ice advice
4	Finland	Politics/ NGO	–	3	2	3	5	Master‘s degree	Director/CEO	–
5	Germany	Business	Shipping company	40	3	0	2	Associate‘s degree	Director/CEO	Specialist for shipping of dangerous goods
6	Canada	Business	Shipping company	48	4,5	30	5	Bachelor‘s degree	Director/CEO	Master mariner; former Canadian Coast Guard; active Ice Navigator
7	Finland	Science	Arctic research	10	3	6	4	Ph.D.	Professor	–
8	Norway	Science	Arctic research	5	2	15	5	Ph.D.	Senior Researcher	Specialist for politics and international relations in the Arctic
9	Germany	Business	Insurance	12	3	12	3	Associate‘s degree	Manager	Very good knowledge of risk assessment
10	Finland	Business	Shipping company	15	4	20	4	Master‘s degree	Director/CEO	–
11	Canada	Business	Shipping company	28	5	11	4	Associate‘s degree	Director/CEO	–
12	Russia	Business	Shipping company	26	4	10	5	Master‘s degree	Director/CEO	Very good knowledge of risk assessment
13	Denmark	Business	Consultant	16	4	15	5	Associate‘s degree	Director/CEO	Master mariner
14	USA	Politics/ NGO	–	44	4	40	5	Master‘s degree	Politician	–
15	Canada	Business	Consultant	0	0	16	4,5	Ph.D.	Consultant	–
16	USA	Science	Arctic research	3	4	4	5	Master‘s degree	Senior Researcher	Specialist for politics and international relations in the Arctic
17	Finland	Science	Arctic research	0,5	2	15	4	Master‘s degree	Senior Researcher	–
18	Finland	Business	Shipping company	10	3	15	4	Associate‘s degree	Captain	Master mariner
19	Canada	Business	Shipping company	39	4	23	4	Associate‘s degree	Director/CEO	–
20	France	Science	Arctic research	12	3	12	5	Ph.D.	Professor	Specialist for politics and international relations in the Arctic
21	Greenland	Politics/ NGO	–	0	3	24	5	Master‘s degree	Director/CEO	Specialist for politics and international relations in the Arctic
22	Germany	Science	Arctic research	25	2	25	5	Ph.D.	Director/CEO	Specialist for environmental relations in the Arctic
23	Norway	Science	Arctic research	0	1	10	4	Ph.D.	Senior Researcher	–
24	Germany	Business	Shipping company	8	5	0	1	Associate‘s degree	Director/CEO	–

Table 3
Top-codes and subcodes within the SAR dimensions.

Dimension	Top-code	Subcode	Exemplary statement
Port infrastructure	Port characteristics (1)	Deep sea ports (14) Inland connection (4)	“[…] it is of course very important that the ports have enough water.” (E18) “[…] have logistics services in place […] and building better connection of railroad.” (E7)
	Port location (5)	Secure position (7) Reachability (4)	“You normally want to have a sheltered port locations […] so that vessels can get out of particularly bad weather.” (E15)
	Port equipment (4)	Ship yards (6) Fuel stations (5) Medical capacities (5) Ice breakers (5) Landing capacities (2) Technology (1) Trained staff (1)	“[…] projects don’t really take in consideration this necity to have reapair capacities, and especially maybe one or two dry docks.” (E20) “Infrastructure needs to be a identified facility to deal with some sort of casualities.” (E11) “They need supporting vessels in the ports, like port ice breakers and tugs.” (E10) “It’s necessary to have landing zones for aircrafts such as helicopters and planes, necessary to have refuelling and resupply capabilities […].” (E16) “[…] modern ports that have communication technology.” (E7)
SAR equipment	Involvement (1)	Local involvement (2) Military integration (2)	“It’s essential for being able to help people that we do have the navy up here […], trying to train local people for being part […] and to go in and help.” (E1)
	Ice breakers (13)	Escorting ice breakers (1) Mobile SAR points (7) Onboard equipment (4)	“Introduce a system that you have quasi sea-based SAR facilities, i.e. standby icebreakers, which can then intervene in the event of an incident.” (E5) “[…] strict and very clear requirements […] as regards the equipment of the ships […],and that there are sufficient spare parts on board.” (E9)
	SAR centers (5)	Rapid reaction forces (2) Helicopters (10) Airplanes (4) Positioning (1) Trained staff (9) Supply (3) Continuous availability (1)	Have oil spill response teams that will be deployed within a few days, […] to be able to start action against the pollution” (E13) “[…] it’s also about runways and helicopters, about fast means of transport.” (E24) “The staff of rescue stations, they should be individuals who are trained in arctic operations, so they know what to do if an emergency happens.” (E18) “They need to be trained in search and rescue procedures, […] the process of how search and rescue operations are undertaken […].” (E16)
Communication technology	Military technology (1)		“Military are having airplanes with specialized equipment […].” (E1)
	Coverage (14)	Satellite coverage (19) Internet bandwidth (3) Radio coverage (1)	“[…] need better satellite coverage, the radio infrastructure is not enough if we talk about central Arctic ocean.“ (E17) “It’s a lack of satellite coverage, and also internet bandwidth, that’s what we are hoping for in the future” (E3)
	Systems (1)	Backup systems (3) Interoperability (1) Stability (2)	“[…] could be really good to have […] a backup system, so they need to have a build out system to make it more stable.” (E2) “I would say the issue with communication technology […] is interoperability.” (E14)
	Ship equipment (2)		“I’d make sure these things are temperature proof, weatherproof […].” (E24)
Navigation technology	Weather forecasting (2)	Ice forecasting (4) Use of artificial intelligence (2)	“Weather forecasting is still a bit of a problem […], we don’t have good tracking […], because there isn’t enough real time data feeding the models.” (E6) “[…] Ice prediction by artificial intelligence based on atmospheric models […].” (E3)
	Data availability (2)	Geodata (1) Drones (3) Information Sharing (2) Military technology (2)	“Geodata availability […] and depth that are not that good surveyed.” (E18) “[…] unmanned drones to scout the ice ahead of the vessel […].” (E15) “The data is publicly available, it is only a matter of using and sharing this data.” (E7) “[…] we have the system for it, but you need to have that installed to the vessel.” (E2)
	Technological ship upgrading (2)	Vessel tracking (2) Ice thickness sensors (1)	“Navigation would be much easier with real-time vessel tracking of all ships passing through the Arctic.” (E13) “[…] another point is the modelling of ice conditions. You need not only a weather report, but also an ice thickness report for safe shipping.” (E14)
	Coverage (4)		“Satellites that we use for communication fly geostationary of course, that means they fly close to the equator, […] that does not cover the Arctic.” (E7)
Standards and agreements	Clarification of interests (2)		“[…] the Arctic Council being diluted […] by outsiders how think they the should have a place on the table, and I think thaťs wrong […].” (E6)
	Clarification of responsibilities (2)		“The point is always how are they implemented regionally and who is responsible […].” (E5)
	Standards (3)	SAR processes (1) SAR guidelines for ships (2) Training standards (2) Construction standards (2)	“[…] if there is a accident, the vessels should have enough gear to survive in arctic for five days, but it doesn’t have any guidlines of how they do it.” (E3) “We have one problem that we mentioned already, this is the question of training of crews, […] the other thing is the inspection, we doń t have standards for inspections.” (E17)

(continued on next page)

Table 3 (*continued*)

Dimension	Top-code	Subcode	Exemplary statement
		Route risk assessment (2)	"[…] to be prepared, and to do a proper risk analysis before undertaking any voyage, […] and the suitability of vessels that are trading in the Arctic." (E19)
	Polar Code (2)	Extension (2) Implementation review (4)	"There are agreements and conventions, to check that everyone sticks to them is a completely different problem […]. And I think the Polar Code is much too soft, especially with heavy oils." (E22)
	Country-specific solutions (1)		"It needs to be looked on country-by-country basis as well, […] the main idea is to have it more coherent what you have on the national level and what you bring on to the international agreement." (E7)
Cooperation	Knowledge sharing (3)	Accident reporting (2) Observation system (1)	"What is a big issue for science is to have an observation system for the Arctic, which is put together internationally to bring together the scientific data needed to understand the Arctic […]." (E22)
	Financing (1)		"[…] who has the interest, and who gives the money. This can be broken down very clearly to the commercial advantages and interests of the state. " (E5)
	Cross-border cooperation (4)	Dissolution of borders (6) Military cooperation (2)	"[…] formal, cross-country initiatives that can consider border crossing […]." (E16) "The navy […] do have exercises with other countries, it's not much, but iťs a beginning […]." (E1)
	Joint trainings (8)	Military drills (1) Anti-terrorism trainings (1)	"[…] need to make more training with the coastguards. I see more military drills, that going into the Arctic waters." (E1)
	Country-internal cooperation (1)		"[…] each country can improve this in there own way, and that information can be shared in much better way." (E21)

in the field of scientific research (Kvale, 1996; Ananthram and Chan, 2013). The list contained both closed and open questions, so the interviews were flexible enough to be explorative and, at the same time, directed enough to collect in-depth information from all respondents (Xing et al., 2011). As suggested by Kvale (2010), the interview questions were tested by five research experts to check their length, understandability, context and validity. After minor revisions, the interview guideline was split into two parts. The first part contained questions concerning the expert (e.g., current work level, work experience, knowledge of cargo shipping and the Arctic region, and level of education). In the second part, for each SAR dimension identified in the literature review (Section 3), we asked respondents what capabilities would be needed to develop a SAR framework in the Arctic region. To prevent any bias due to differences in interviewer responses, the same interviewer conducted all interviews.

4.2. *Coding and data analysis*

Each interview lasted between 30 and 80 min. All interviews were conducted in English. They were tape-recorded and then transcribed (Riege, 2003). Approval for the recording of tapes for transcription purposes was obtained before the interviews began. As much additional secondary data as possible was also collected to verify the results of the expert survey (e.g., internet sites of various institutions or reports of the various coast guards) (Maxwell, 1996; Yin, 2009). The transcripts were inductively analyzed using the qualitative content analysis approach (Mayring and Fenzl, 2014; Schreier, 2014) to find common words, phrases and expressions forming common themes in the 24 interviews. Thus, a first group of codes along the six SAR dimensions given in the literature review was developed, and several subcodes were identified along with these codes. Finally, the codes were integrated into our SAR framework. The identified categories were then compared with each other and complemented by the scientific literature (Yin, 2009; Krippendorff, 2013). Two researchers coded the same data independently of each other, then compared the findings and discussed parallels and discrepancies when using the codes to ensure the intercoder reliability was maximized (Frankfort-Nachmias and Nachmias, 1996). Following Holsti (1968), we calculated an intercoder reliability that resulted in a high value. This method, which uses several independent coders, is accepted, as it reduces the bias of the coder compared to using a stand-alone coder (Miles and Huberman, 1994; Weston et al., 2001). To ensure an iterative process, two rounds of comparison were carried out (Mayring and Fenzl, 2014). The identified codes were then compared and discussed among the research team members. In this way, an emerging coding scheme instead of a given coding scheme was developed (Dahlsrud, 2008). The categories can be found in Table 3 and are presented in the next section.

5. Discussion and development of a SAR framework

Ongoing climate change makes Arctic routes increasingly attractive for future shipping. They offer a unique opportunity to relieve traditional sea routes and enable shorter transport times. However, before Arctic routes develop into highly frequented sea routes like the Suez Canal or Panama Canal, a comprehensive SAR framework should be introduced. This would not only prevent potential shipping accidents but also protect humans and nature. In the following, we systematically reflect on our most significant findings concerning our SAR framework and discuss the results in light of the existing literature.

Table 3 illustrates the multiple dimensions of capabilities associated with SAR, including port infrastructure, SAR equipment, communication technology, navigation technology, standards and agreements, and cooperation. The further breakdown of the dimensions reflects the high diversity of individual capabilities. These include aspects such as the equipment and characteristics of the ports, the design and structure of SAR equipment, the availability of communication and navigation technologies, the need for specific standards and the intensive exchange and cooperation between Arctic states. In principle, there is a need for improvement in all six dimensions. The SAR framework is presented in Fig. 2.

5.1. Port infrastructure

Beginning with the dimension *port infrastructure*, we first consider port characteristics. The experts' opinions clearly show a particular need for more deep-sea ports in this area. This aligns with literature such as Abe and Otsuka (2019), Buixadé Farré et al. (2014) and Dalaklis et al. (2018b). There are several ports along the NSR, but they have been neglected since the Soviet era and are, therefore, in disrepair (Buixadé Farré et al., 2014). Compared to the NSR, the NWP's port infrastructure is highly underdeveloped, especially in the Canadian Arctic (Dalaklis et al., 2018b). In addition to their capacity as deep-sea ports, ports must also be optimized in terms of their distance from each other and the ship's route. The experts called for a manageable distance between ports so that a ship can dock at any time.

Furthermore, some experts demanded a port that is not hindered by harsh weather conditions. The experts also stressed that these ports must be accessible year-round. Further optimizations are, therefore, necessary to improve the port structure. Such an analysis was carried out by VanderBerg (2018), who identified only a few deep-sea ports in his mathematical model. In addition to the factors relevant for SAR, such as the distance to the shipping route and suitability as a deep-sea port, a large number of other factors were taken into account in the calculation. However, the result of his analysis shows an optimum by fulfilment of all criteria considered, which is why the proposed ports do not represent an adequate solution for SAR. Of the 32 ports analyzed, a deep-sea port only came 7th in his calculations, and in 6th place was a port located near an Arctic shipping route. As mentioned above, the experts considered not only the distance to the shipping route to be important, but also considered the distance between appropriate ports and their conditions (size, equipment, infrastructure, connection to the hinterland, etc.) to be particularly important. Ports should also be optimized with regard to SAR relevant factors to ensure that a sufficient number of suitable ports are within reach.

The experts also made recommendations for the equipment of the ports. A port must ensure that a ship can enter and anchor safely. This includes, for example, small icebreakers that keep the harbour area and the route free of ice at all times. Additionally, tugs are

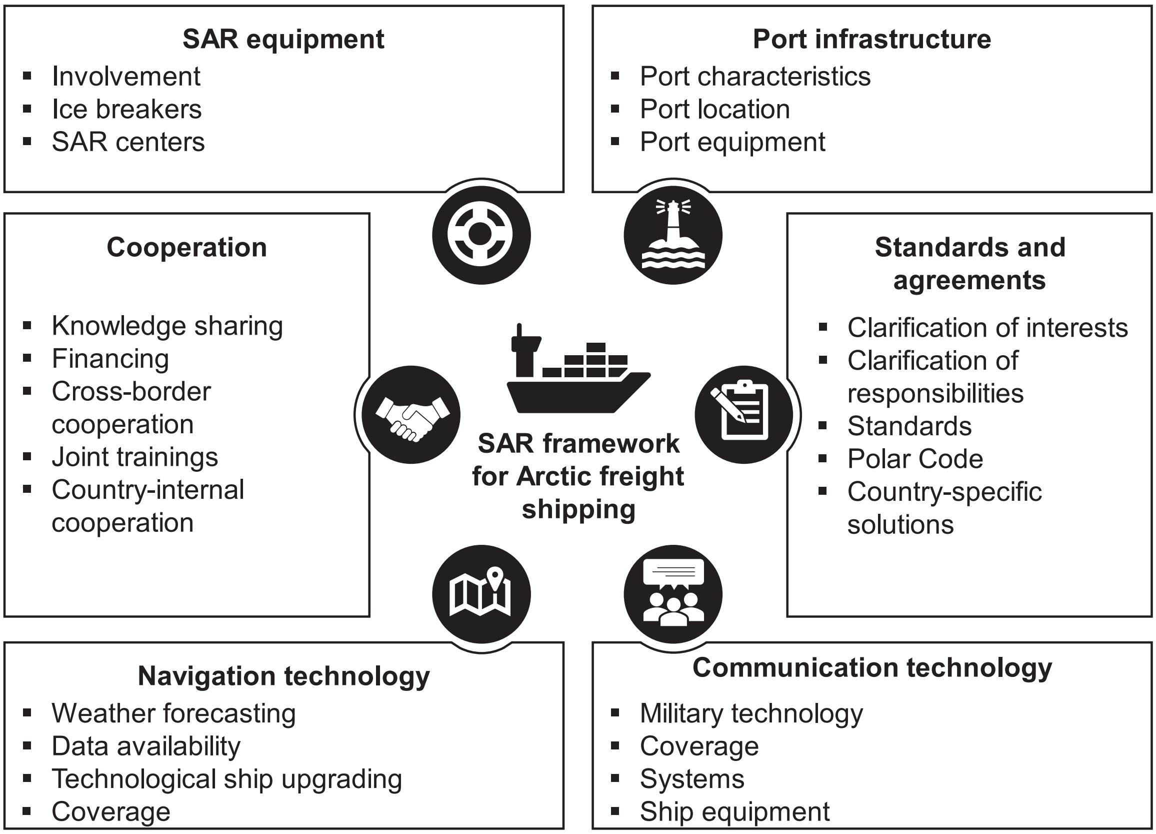

Fig. 2. SAR framework.

needed to manoeuvre large ships. Equipment for the salvage of vessels must also be kept available. A port should also have extensive and modern communication capabilities to communicate with ships and the hinterland, as well as helicopters and SAR personnel. A port should have both medical facilities and shipyards. Medical facilities can provide second aid and intensive care. Shipyards enable the repair and maintenance of ships in case of accidents or damage. Furthermore, a port should have sufficient capacity for replenishing fuel, food and drinking water. An unbroken hinterland connection must be ensured to supply the port and transport the injured and sick. This can be made possible by helicopter landing areas, runways for aircraft, roads or railways. This recommendation aligns with Longrée and Hoog (2014), who, in their study, distinguished a three-stage division into port, airport and settlement zones and proposed a three-step development concept. The good infrastructure is linked to the availability of well-qualified port personnel who can work in the areas mentioned. Medical staff, technicians and navigators are of particular relevance.

5.2. SAR equipment

Next, we examine the second category of our SAR classification. The *SAR equipment* is characterized on the first level by the top-codes involvement, icebreakers and SAR centers.

Concerning the dimension of SAR equipment, it is primarily the agreement of the experts on the additional need for further icebreakers that should be mentioned. However, there are apparent differences between the routes. While the NWP has hardly any icebreaker capacity (Parsons et al., 2011), several icebreakers are already in operation in Russian waters (Liu et al., 2016; Meng et al., 2017). To enable commercial navigation through the Arctic, icebreaker escorts are indispensable due to the ice conditions, and the Arctic icebreaker fleet must be expanded, which aligns with the literature (Buixadé Farré et al., 2014; Dalaklis et al., 2018b; Abe and Otsuka, 2019). Some efforts to expand icebreaker capacity are already being made by some Arctic countries. For example, Russia designed the icebreaker class 'Project 22220′, the first icebreaker of which has already been in operation (Arktika) since September 2020, and four more icebreakers are under construction (Sibir, Ural, Yakutiya and Chukotka) with planned completion between 2021 and 2027 (Skripnuk et al., 2020; Teplukhina et al., 2020). Moreover, even more powerful icebreakers are planned within the icebreaker class 'Project 10510′. These should be commissioned by 2027 (Sevastyanov and Kravchuk, 2020). Nevertheless, more icebreakers and year-around operation are still needed (Skripnuk et al., 2020).

In addition to the expansion of the icebreaker fleet, technological development and ship upgrades with more powerful engines are essential points that the experts underlined. Meng et al. (2017) have also mentioned the increasing age of the Arctic icebreaker fleet. Dalaklis et al. (2018b) reached similar conclusions, describing the Russian icebreaker fleet in detail in their paper and recommending further increasing the number of atomic icebreakers.

In addition to the pure accompanying function of icebreakers, the experts considered so-called standby icebreakers to be necessary to patrol Arctic routes, so they can be deployed at any time. This should both guarantee availability and shorten response times. However, the equipment on board the icebreakers must also be expanded. In addition to the introduction of standards for equipment, the equipment must be expanded to include equipment for medical emergencies. Furthermore, the icebreakers should have a reserve tank for fuel as well as reserves of food and drinking water on board.

Another interesting point that has not yet received much attention in the literature is the use of mobile SAR stations. Some experts have suggested implementing mobile SAR stations. Often patrolling as icebreakers and quickly available, these mobile SAR stations would be equipped for emergencies. Helicopters should also be stationed on the mobile SAR stations to ensure rapid deployment. The mobile SAR points should have sufficient medical equipment and personnel on board to provide medical care.

The involvement of civil and military resources as additional SAR resources is another relevant point that was mentioned by the experts and that has so far received no attention in the literature. According to the experts, it makes sense to integrate the resources of local people into SAR activities in order to increase SAR capacities and to ensure quick and efficient response in case of emergencies. Locals have resources (e.g., ships, snowmobiles, buoys, tows) that can be deployed quickly, as well as the necessary knowledge about local conditions (e.g., draft, weather conditions, ice conditions) (Ford et al., 2010; Pearce et al., 2015; Clark et al., 2016; Clark et al., 2018). Comprehensive training is necessary to involve local people in SAR activities and to use human resources effectively. In particular, because many communities are only minimally prepared for the current SAR requirements, it is necessary to train residents in various areas: first aid, emergency management, multi-agency responses (Ford and Clark, 2019). Systematic involvement of the locals leads to the creation of a local workforce (e.g., Canadian Coast Guard Auxiliary) (The Standing Committee on Fisheries and Oceans, 2018). Such a local workforce could significantly relieve and support SAR staff, especially in relation to minor incidents or in remote communities (Byers and Covey, 2019). According to the experts, the resources of the military, and the police should also be integrated into SAR activities. These two public institutions have a wide range of well-equipped resources (such as aircrafts, helicopters, boats, icebreakers, satellites and qualified personnel) (Smith, 2017; Byers and Covey, 2019). Response times can be reduced by using this modern equipment (Ford et al., 2010; Smith, 2017).

There is also an indicated need for additional SAR centers, which aligns with the existing literature (Larsen et al., 2016; Milaković et al., 2018). The SAR network should consist of full-time SAR centers and smaller SAR centers. The larger SAR centers then serve as control centers for emergencies. However, they are also be responsible for coordination between small SAR centers and mobile SAR points. Dalaklis et al. (2018b) have described a similar concept (headquarters, marine rescue coordination centers and marine rescue subcenters) along the Russian coast, but this approach is not yet practicable due to long distances, long reaction times and seasonal availability (Longrée and Hoog, 2014). However, it is precisely this constant availability of all SAR centers and their rapid operational readiness – whether small or large, centralized or remote, onshore or offshore – that experts consider as a decisive criterion for securing the shipping routes in the Arctic.

Furthermore, the distribution of SAR centers has so far only been based on country-specific regulations. A new distribution of the individual SAR centers should be designed to optimize both country-specific and cross-border response capabilities. The results of Shan and Zhang (2019), whose analysis of optimal rescue bases covered the entire Arctic region, could be valuable for the establishment of new SAR bases. There is an agreement between the interviewed experts and the literature that parts of the old military infrastructure (military bases) should be reused (Longrée and Hoog, 2014). The planning should also take into account the analysis of Pestov and Pilat (2011), which shows the impact that minor changes could have on the whole network. In the opinion of some experts, however, the expansion and new construction of SAR centers is associated with additional requirements for the SAR centers. These should enable a two-level SAR concept, first aid and second aid. First aid operations should be ensured by helicopters. These provide a fast means of transport over short and medium distances (Palma et al., 2019). Small and fast boats also guarantee a quick response. An analysis of different rescue scenarios using helicopters and rescue boats can be found in the study of Jacobsen and Gudmestad (2013). The equipment for second aid mainly includes airplanes. An additional point that has not been considered in the literature so far is the use of drones for first aid. Aside from first aid for people, the fast response of oil pollution teams is also necessary. Furthermore, well-trained SAR personnel are also an essential aspect of a successful SAR framework. SAR staff should be trained not only on the procedures of SAR operations (e.g., how to conduct SAR operations, how to respond to a rescue request or how to assist in emergency calls) but also in the medical field (medical personnel). Furthermore, SAR staff should be trained on dealing with poor weather and a lack of communication, as well as on diplomatic skills and languages.

5.3. *Communication technology*

In the field of *communication technology*, the experts agreed that there is a lack of suitable tools for communication, which has also been confirmed in some studies (Kvamstad et al., 2009; Milaković et al., 2018). The experts indicated that the area-wide satellite coverage is particularly important for ship-to-shore communication. Coverage of shadow zones is currently not yet present, and further development is needed. This need for satellite coverage was also identified by Kvamstad et al. (2014) in the MARENOR project (Maritime Radio System Performance in the High North). As described in their study, common maritime communication systems based on GEO satellites (e.g., Inmarsat) cannot be used in Arctic waters because their coverage limit is 81.3°N, and instability and signal loss occur from 70°N (Kvamstad et al., 2014). The only satellite system that covers the polar sea completely is Iridium, which is suitable for non-critical voice communications and the transmission of short messages with low time requirements (Larsen et al., 2016). However, even here, instabilities and system failures occur repeatedly (Kvamstad et al., 2014). The experts underlined that, in addition to comprehensive satellite coverage, appropriate bandwidth is also required to enable SAR missions. This need has also been identified by Buixadé Farré et al. (2014) and Palma et al. (2019). According to the experts, to achieve a suitable communication network, the use of military technology should be made possible for civil shipping. In addition to the availability of these technologies, all passing ships must be equipped with these technologies and interoperability between different providers or systems must be guaranteed. The experts also suggested what the communication technologies on the ships should look like. It is essential that the installed technology be weather- and ice-proof and able to withstand the rough conditions of the Arctic. Maintaining redundant systems is also suggested to continue operations in the event of a system failure. In addition to regular communication, the experts advocated for the development of an emergency communication system that would still be operational even if all other onboard systems failed.

5.4. *Navigation technology*

In contrast to communication technology, the experts claimed that area-wide coverage plays only a subordinate role in *navigation*. This finding is reflected in the relevant literature (Kvamstad et al., 2014; Larsen et al., 2016). Kvamstad et al. (2014) clearly showed that satellite coverage combining satellite systems at high latitudes is sufficient for navigation purposes. However, they pointed out that inaccuracies may occur. These inaccuracies can only be resolved in the Arctic by reference stations, but their coverage is still lacking and must be improved (Larsen et al., 2016). In addition, the experts also saw potential for improvement in the transmission speed of weather and ice data. This point can be combined with the findings from the dimension communication technology. The existing communication infrastructure is not suitable for the rapid exchange of extensive data.

Another important point the experts mentioned is the forecasting of weather and ice conditions. Some studies have reported that comprehensive ice charts and calculations are already available (Meng et al., 2017; Milaković et al., 2018). Furthermore, Kvamstad et al. (2009) have described the possibility of ice forecasts by using synthetic-aperture radar and near-ship ice monitoring. Nevertheless, the experts saw room for improvement, especially in the forecasting of drifting ice masses (such as drift ice, icebergs and ice floes). One possible approach is the use of machine learning or artificial intelligence based on atmospheric models. In addition to improving weather and ice forecasts, the experts emphasized the need for availability of real-time data. Drones, which can be used for ice forecasts and monitors, were mentioned. In addition to weather and ice data, the availability of hydrographic data was also mentioned. This point is highlighted in the literature as well. Pruyn (2016) named missing data as the main cause of grounding. As with communications technology, the experts noted that the technology must also be available on ships and that military solutions must be made available for civilian shipping.

5.5. *Standards and agreements*

In addition to the proposed measures mentioned above, future Arctic SAR capability development should be consistent with established international *standards and agreements*. The International Convention on Maritime Search and Rescue, as well as the agreements on SAR and oil pollution, did not propose precise infrastructural requirements for adequate SAR operations in the Arctic.

Their purpose was mainly to establish responsibilities among the Arctic states and state the importance and necessity of cooperation between the countries, in particular the exchange of information and joint training. This is confirmed in the literature; Rottem (2014) analyzed various agreements from Norway's perspective and found that they are mainly used for political and symbolic reasons to raise awareness of necessary SAR infrastructure in the Arctic without actually improving the infrastructure. Some experts called for a more specific and extended version of the standards, taking the Polar Code as an example. This aligns with the research of Buixadé Farré et al. (2014) and Dalaklis et al. (2018b), who have indicated that the previous agreements do not assign responsibility for the concrete physical implementation of responses. The experts also demanded that these standards and agreements be implemented in all Arctic countries. To this end, a monitoring system should be introduced to regularly check available SAR resources. As Buixadé Farré et al. (2014) have described, the Arctic has also gained increasing political interest. Since the establishment of the Arctic Council in 1996 by the five states with large Arctic Ocean coasts and the three other states within the Arctic Circle, an increasing number of countries have been integrated into this intergovernmental forum. Some experts did not consider these participants to be beneficial and therefore suggested the clarification of interests.

Furthermore, the experts demanded the revision and rewriting of standards related to SAR to raise awareness of SAR and be prepared for emergencies. One possibility is the cross-border standardization of SAR equipment for all Arctic states. Chircop and Czarski (2020) examined the harmonization of national legislation in the five Arctic states and established that, despite a high level of convergence with the Polar Code, differences still exist. For example, the experts emphasized in particular the standardization of communication between ports and national SAR centers, clarification of responsibilities, and arrangements for border crossing or dismantling in the case of emergency. The experts also recommended the standardization of SAR processes. Among others, the following aspects must be defined: priorities, procedures, and responsibilities in case of emergencies. These regulations should extend to all routes. In addition, the experts highlighted the importance of the Polar Code and claimed that the requirements should be strengthened. They criticize in particular that a variety of safety requirements, such as the operating manual, ship structure, safety of navigation, life-saving equipment and arrangements, communication, voyage planning, crew, training, etc. are only to be fulfilled on a voluntary basis. In addition, the interviewed experts point out that pollution from ships and the regulation of heavy fuel oil are not taken into account in current regulations and need to be discussed more intensively, which is in line with the literature (Sun, 2019, 2020). Furthermore, they recommended a mandatory risk assessment to enable shipping companies to determine whether they are ready for a voyage through the Arctic. POLARIS is an exemplary option that has already received growing attention in the literature (Stoddard et al., 2016; Fedi et al., 2018a; Fedi et al., 2020).

5.6. Cooperation

The experts saw an urgent need for improvement in *cooperation*. One crucial point is the sharing of information. As sensitive military or semi-military data (coast guard) is at stake, the experts called for mutual trust. Less problematic but recommended by the experts is the sharing of scientific data obtained through scientific observation systems. The experts saw great potential in joint SAR trainings and exercises. These must first be expanded both bilaterally and multilaterally and involve several countries. Joint training will help overcome the language problems and cultural barriers identified by Schmied et al. (2017). Regardless, training must be intensified and include various emergency scenarios. This recommendation aligns with the findings of Schmied et al. (2017), who concluded that past training has been limited in both scope and complexity. The experts also indicated that pure training alone is not sufficient but that trainings must be subsequently jointly evaluated and assessed to identify potential for improvement. In addition to cooperation between countries, internal cooperation between military, police, rescue services and civil rescue facilities is essential. Another point of interest is the financing of all expenses related to SAR. It must be clarified who is to pay for investments in the SAR's infrastructure and who will pay for its maintenance. It must also be determined who will finance the training of personnel. Likewise, it must be clarified who will bear the costs of border and cross-border operations.

6. Conclusion

Arctic maritime freight shipping has become an increasingly important topic in research in recent years, which can be attributed to capacity bottlenecks on usual routes and global warming. Arctic ice is melting, which increases the competitiveness of Arctic routes. When considering the risks of navigation in Arctic waters, the insufficient SAR capabilities play an important role for many researchers.

This paper aims to conduct systematic research on SAR in the Arctic. The main objective of this work is to propose a SAR framework serving as a starting point for further development of SAR in the Arctic region. For this purpose, a literature review for the identification of SAR dimensions is conducted. Afterwards, qualitative expert interviews for the extension of the dimensions are conducted and the transcripts are analyzed using a qualitative content analysis approach.

The study identifies the dimensions *port infrastructure*, *SAR equipment*, *navigation technology*, *communication technology*, *standards and agreements*, and *cooperation* as part of the SAR framework.

In the dimension *port infrastructure*, the paper confirms that there is a need for more deep-sea ports. Additionally, the distance between the ports, between ports and the shipping routes as well as the inland connection of the ports must be considered. Furthermore, recommendations for equipment of ports are given, e.g., small ice breakers and tugs, ship yards, landing capacities, and trained personnel.

For *SAR equipment*, the study includes the expansion of icebreaker capacity, also for escort missions, and suggests mobile SAR points equipped with the necessary onboard equipment. In addition, permanently available, easily accessible SAR centers equipped with rapid reaction forces, helicopters, aircraft and trained personnel are proposed to strengthen the SAR in the Arctic region.

The equipment of ships with technologies as well as the coverage is considered for both *communication and navigation technology*. For communication technology, the research highlights the satellite and radio coverage and internet bandwidth. Backup systems, and interoperability/stability of the systems, and the use of military technology are proposed as development areas. For navigation technology, weather forecasting - especially ice forecasting using artificial intelligence – and the availability of data offer room for improvement.

The further development of *standards and agreements* for SAR processes, guidelines for ships, trainings, ship construction, and route risk assessment is also identified, going in line with the extension and an implementation review of the Polar Code. The elaboration of country-specific solutions, and the clarification of interests and responsibilities are also identified for future improvement.

Additionally, the study suggests an extension of cross-border and country-internal *cooperation* as well as joint trainings, knowledge sharing and financing.

In sum, the results offer a wide range of improvement areas for SAR in the Arctic region.

From a theoretical perspective, this paper offers a framework for future research to systematically develop SAR in the Arctic. The study contributes to the existing scientific discourse by aggregating existing necessary dimensions and extending them with expert support. From a practical perspective, the results can serve as a starting point for the further development of SAR in the Arctic. Furthermore, the framework offers the possibility for those involved in further development to contextualize their own activities.

The results of this study have some limitations that need to be considered. A general constraint of the research is that transpolar routes, which, in addition to the NSR and NWP, represent a further option for maritime freight traffic, are not explicitly considered. Additionally, the study could not consider dependencies between the identified dimensions. Furthermore, economic aspects of SAR, for example, through cost-benefit analysis, are not included and could be taken into account in following studies. Further research could be conducted on the extent to which the dimensions influence each other. Quantitative research could also determine the sensitivity of the individual components over the short, medium and long terms. Furthermore, the focus on freight transportation does not address the issue of cruise shipping. Here, there is a further need for research on how the existing framework should be adapted or extended. Additionally, this study does not take into account future developments in traffic flows. Future studies may develop models in which forecasts for the use intensity of the different routes are derived in order to draw conclusions for the further development of SAR. This could include new business models, strategic decision-making approaches and methods of futurology. Although a solid starting point for further SAR development has been established with the base of 24 experts in this study, future studies are needed to develop a guideline with concrete actions for further improvement of SAR in the Arctic region. In this context, it is advisable to examine the plausibility and feasibility of the starting points elaborated in this study.

CRediT authorship contribution statement

Lukas Alexander Benz: Conceptualization, Methodology, Investigation, Writing – original draft, Writing - review & editing, Visualization, Project administration. **Christopher Münch:** Conceptualization, Methodology, Validation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Evi Hartmann:** Conceptualization, Methodology, Writing – original draft, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abe, M., Otsuka, N., 2019. Northern Sea Route (NSR) as a Major Transport Route: Opportunities and Challenges: Volume 5 Issue 4. Asian Transport Studies 617–637.

Allianz, 2020. Safety and Shipping Review 2020: An annual review of trends and developments in shipping losses and safety. https://www.agcs.allianz.com/content/dam/onemarketing/agcs/agcs/reports/AGCS-Safety-Shipping-Review-2020.pdf.

Alvesson, M., 2003. Beyond NE positivists, romantics, and localists: a reflexive approach to interviews in organizational research. Acad. Manag. Rev. 258, 13–33.

Ananthram, S., Chan, C., 2013. Challenges and strategies for global human resource executives: Perspectives from Canada and the United States. European Manage. J. 31, 223–233.

Arctic Council, 2009. Arctic Marine Shipping Assessment 2009 Report.

Arctic Council, 2011. Agreement on aeronautical and maritime search and rescue in the Arctic.

A. Council Agreement on cooperation on marine oil pollution preparedness and response in the Arctic 2013.

Aygün, T., Oeser, G., 2017. Challenges and opportunities of Turkish food retail in Germany from a value chain perspective. Int. J. Retail Distribut. Manage. 45, 308–327.

Baksh, A.-A., Abbassi, R., Garaniya, V., Khan, F., 2018. Marine transportation risk assessment using Bayesian Network: Application to Arctic waters. Ocean Eng. 159, 422–436.

Basharat, S., Oien, K., 2014. Accidents and Emergency Response in the Arctic Sea, in: OTC Arctic Technology Conference. OTC Arctic Technology Conference, Houston, Texas. 2014-02-10. Offshore Technology Conference.

Bennett, M.M., Stephenson, S.R., Yang, K., Bravo, M.T., de Jonghe, B., 2020. The opening of the Transpolar Sea Route: Logistical, geopolitical, environmental, and socioeconomic impacts. Marine Policy 104178.

Birkel, H., Veile, J., Müller, J., Hartmann, E., Voigt, K.-I., 2019. Development of a Risk Framework for Industry 4.0 in the Context of Sustainability for Established Manufacturers. Sustainability 11, 384.

Birkel, H.S., Hartmann, E., 2020. Internet of Things – the future of managing supply chain risks. Supply Chain Management Int. J. 25, 535–548.

Boer, J.d., Lambrechts, W., Krikke, H., 2020. Additive manufacturing in military and humanitarian missions: Advantages and challenges in the spare parts supply chain. Journal of Cleaner Production 257, 120301.

Borch, O.J., Batalden, B.-M., 2015. Business-process management in high-turbulence environments: the case of the offshore service vessel industry. Maritime Policy Manage. 42, 481–498.
Bowo, L.P., Prilana, R.E., Furusho, M., 2019. A Hybrid Methodology for Maritime Accident Analysis: The Case of Ship Collision, in: Volume 3: Structures, Safety, and Reliability. ASME 2019 38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, Scotland, UK. 09.06.2019 - 14.06.2019. American Society of Mechanical Engineers.
Brubaker, R.D., Ragner, C.L., 2010. A review of the International Northern Sea Route Program (INSROP) – 10 years on. Polar Geogr. 33, 15–38.
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., Wighting, J., 2014. Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure. Polar Geography 37, 298–324.
Buldeo Rai, H., Verlinde, S., Macharis, C., Schoutteet, P., Vanhaverbeke, L., 2019. Logistics outsourcing in omnichannel retail. Int. J. Phys. Distribut. Logist. Manage. 49, 267–286.
Button, K., Kramberger, T., Vizinger, T., Intihar, M., 2017. Economic implications for Adriatic seaport regions of further opening of the Northern Sea Route. Maritime Economics Logist. 19, 52–67.
Byers, M., Covey, N., 2019. Arctic SAR and the "security dilemma". Int. J. 74, 499–517.
Cannell, C.F., Kahn, R.L., 1968. Interviewing. In: Lindzey, G., Aronson, E. (Eds.), The handbook of social psychology, second ed. Addison-Wesley, Reading, MA, USA, pp. 525–595.
Chircop, A., 2007. Climate change and the prospects of increased navigation in the Canadian Arctic. WMU J. Maritime Affairs 6, 193–205.
Chircop, A., Czarski, M., 2020. Polar Code implementation in the Arctic Five: has harmonisation of national legislation recommended by AMSA been achieved? Polar J. 29, 1–19.
Clark, D.G., Ford, J.D., Pearce, T., Berrang-Ford, L., 2016. Vulnerability to unintentional injuries associated with land-use activities and search and rescue in Nunavut, Canada. Social Sci. Med. 1982 (169), 18–26.
Clark, D.G., Ford, J.D., Tabish, T., 2018. What role can unmanned aerial vehicles play in emergency response in the Arctic: A case study from Canada. PLoS ONE 13, e0205299.
Dahlsrud, A., 2008. How corporate social responsibility is defined: an analysis of 37 definitions. Corp. Soc. Responsib. Environ. Manag. 15, 1–13.
Dalaklis, D., Baxevani, E., 2017. Maritime Routes in the Arctic: Examining the Level of Traffic and Port Capabilities along the Northern Sea Route. Ocean Yearbook 31.
Dalaklis, D., Baxevani, E., Siousiouras, P., 2018a. The Future of Arctic Shipping Business and the Positive Influence of the International Code for Ships Operating in Polar Waters. J. Ocean Technol. 13, 76–94.
Dalaklis, D., Drewniak, M.L., Schröder-Hinrichs, J.-U., 2018b. Shipping operations support in the "High North": examining availability of icebreakers along the Northern Sea Route. WMU J. Maritime Affairs 17, 129–147.
Eisenhardt, K.M., Graebner, M.E., 2007. Theory Building From Cases: Opportunities and Challenges. Acad. Manag. J. 50, 25–32.
Faury, O., Cariou, P., 2016. The Northern Sea Route competitiveness for oil tankers. Transport. Res. Part A Policy Pract. 94, 461–469.
Faury, O., Cheaitou, A., Givry, P., 2020. Best maritime transportation option for the Arctic crude oil: A profit decision model. Transport. Res. Part E Logist. Transport. Rev. 136, 101865.
Fedi, L., Etienne, L., Faury, O., Rigot-Müller, P., Stephenson, S., Cheaitou, A., 2018a. Arctic Navigation: Stakes, Benefits and Limits of the POLARIS System. J. Ocean Technol. 13, 54–67.
Fedi, L., Faury, O., Etienne, L., 2020. Mapping and analysis of maritime accidents in the Russian Arctic through the lens of the Polar Code and POLARIS system. Marine Policy 118, 103984.
Fedi, L., Faury, O., Gritsenko, D., 2018b. The impact of the Polar Code on risk mitigation in Arctic waters: a "toolbox" for underwriters? Maritime Policy Manage. 45, 478–494.
Fjørtoft, K., Bekkadal, F., Kvamstad, B., 2009. Maritime communication to support safe navigation. In: Weintrit, A. (Ed.), Marine Navigation and Safety of Sea Transportation. CRC Press.
Ford, J., Clark, D., 2019. Preparing for the impacts of climate change along Canada's Arctic coast: The importance of search and rescue. Marine Policy 108, 103662.
Ford, J.D., Pearce, T., Duerden, F., Furgal, C., Smit, B., 2010. Climate change policy responses for Canada's Inuit population: The importance of and opportunities for adaptation. Global Environ. Change 20, 177–191.
Frankfort-Nachmias, C., Nachmias, D., 1996. Research methods in the social sciences, fifth ed. Arnold, London, p. 17.
Fu, S., Zhang, Di, Montewka, J., Zio, E., Yan, X., 2018a. A quantitative approach for risk assessment of a ship stuck in ice in Arctic waters. Saf. Sci. 107, 145–154.
Fu, S., Yan, X., Zhang, Di, Zhang, M., 2018b. Risk influencing factors analysis of Arctic maritime transportation systems: a Chinese perspective. Maritime Policy Manage. 45, 439–455.
Grabowski, M., Rizzo, C., Graig, T., 2016. Data challenges in dynamic, large-scale resource allocation in remote regions. Saf. Sci. 87, 76–86.
Gruchmann, T., Schmidt, I., Lubjuhn, S., Seuring, S., Bouman, M., 2019. Informing logistics social responsibility from a consumer-choice-centered perspective. Int. J. Logist. Manage. 30, 96–116.
Grzelakowski, A., 2019. Global Container Shipping Market Development and Its Impact on Mega Logistics System TransNav. Int. J. Marine Navigat. Safety Sea Transport. 13, 529–535.
Haagensen, R., Sjøborg, K.-A., Rossing, A., Ingilae, H., Markengbakken, L., Steen, P.-A., 2004. Long-range rescue helicopter missions in the Arctic. Prehospital Disaster Med. 19, 158–163.
Headland, R.K., 2020. Transits of the Northwest Passage to end of the 2019 navigation season.
Hill, E., LaNore, M., Véronneau, S., 2015. Northern sea route: an overview of transportation risks, safety, and security. J. Transport. Security 8, 69–78.
Holsti, O.R., 1968. Content Analysis. In: Lindzey, G., Aronson, E. (Eds.), The handbook of social psychology, second ed. Addison-Wesley, Reading, MA, USA.
Hong, N., 2012. The melting Arctic and its impact on China's maritime transport. Res. Transport. Economics 35, 50–57.
Humpert, M., Raspotnik, A., 2012. The future of Arctic shipping along the Transpolar sear route. Arctic Yearbook 2012, 281–307.
Ikonen, E., 2017. Arctic Search and Rescue capabilities survey: Enhancing international cooperation 2017.
IMO, 2016. Polar code 2016. Intl Maritime Org.
International Maritime Organization, 2006. SAR Convention, 1979: International Convention on Maritime Search and Rescue, 1979, as amended by resolution MSC. 70(69) and MSC. 155(78), 3rd ed. International Maritime Organization, London, 26 pp.
Jacobsen, S.R., Gudmestad, O.T., 2013. Long-Range Rescue Capability for Operations in the Barents Sea, in: Volume 6: Polar and Arctic Sciences and Technology; Offshore Geotechnics; Petroleum Technology Symposium. ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering, Nantes, France. 09.06.2013 - 14.06.2013. American Society of Mechanical Engineers.
Jensen, Ø., 2016. The International Code for Ships Operating in Polar Waters: Finalization, Adoption and Law of the Sea Implications. Arctic Review on Law and Politics 7.
Kiiski, T., Solakivi, T., Töyli, J., Ojala, L., 2018. Long-term dynamics of shipping and icebreaker capacity along the Northern Sea Route. Maritime Economics Logist. 20, 375–399.
Koshevyy, V.M., Shyshkin, O., 2017. VHF/DSC – ECDIS/AIS Communication on the Base of Lightweight Ethernet. In: Weintrit, A. (Ed.), Marine Navigation. CRC Press, pp. 385–390.
Krippendorff, K., 2013. Content analysis: An introduction to its methodology. Sage, Los Angeles, London, New Delhi, Singapore, 441 pp.
Kvale, S., 1996. InterViews: An introduction to qualitative research interviewing, 14th ed. Sage, Thousand Oaks, CA, 326 sider.
Kvale, S., 2010. Doing interviews, 1st ed. Sage, Los Angeles, 157 pp.
Kvamstad, B., Bekkadal, F., Grythe, K., Jensen, I., Haakegaard, J.E., Behlke, R., 2014. The MARENOR Project – Maritime Radio System Performances in the High North, in: OTC Arctic Technology Conference. OTC Arctic Technology Conference, Houston, Texas. 2014-02-10. Offshore Technology Conference.

Kvamstad, B., Fjørtoft, E., Bekkadal, F., 2009. A case study from the emergency operation in the Arctic seas. TransNav Int. J. Marine Navigat. Safety Sea Transport. 153–159.
Larsen, L.-H., Kvamstad-Lervold, B., Sagerup, K., Gribkovskaia, V., Bambulyak, A., Rautio, R., Berg, T.E., 2016. Technological and environmental challenges of Arctic shipping—a case study of a fictional voyage in the Arctic. Polar Res. 35, 27977.
Lavissière, A., Sohier, R., Lavissière, M.C., 2020. Transportation systems in the Arctic: A systematic literature review using textometry. Transport. Res. Part A Policy Pract. 141, 130–146.
Lechler, S., Canzaniello, A., Hartmann, E., 2019. Assessment sharing intra-industry strategic alliances: Effects on sustainable supplier management within multi-tier supply chains. Int. J. Prod. Econ. 217, 64–77.
Lechler, S., Canzaniello, A., Wetzstein, A., Hartmann, E., 2020. Influence of different stakeholders on first-tier suppliers' sustainable supplier selection: insights from a multiple case study in the automotive first-tier industry. Business Res. 13, 425–454.
Liu, Y., Fan, H., Zhao, Q., 2016. Complex Network Theory Model of Arctic Marine Rescue and Emergency Response. International Journal of Simulation: Systems, Science and Technology.
Lloyds List, 2019. Lloyd's List Intelligence Casualty Statistics.
Longrée, M., Hoog, S., 2014. Backbone for Escape, Evacuation and Rescue From Arctic Facilities: A Systematic Approach, in: Volume 10: Polar and Arctic Science and Technology. ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, California, USA. 08.06.2014 - 13.06.2014. American Society of Mechanical Engineers.
Marchenko, N., 2012. Russian Arctic Seas. Springer Berlin Heidelberg, Berlin, Heidelberg.
Marchenko, N., Andreassen, N., Borch, O.J., Kuznetsova, S., Ingimundarson, V., Jakobsen, U., 2018. Arctic Shipping and Risks: Emergency Categories and Response Capacities. TransNav Int. J. Marine Navigat. Safety Sea Transport. 12, 107–114.
Marchenko, N., Borch, O.J., Markov, S.V., Andreassen, N., 2016a. Maritime safety in the high north - Risk and preparedness: Rhodes, Greece, June 26-July 1, 2016 : Volumes 1-4, 2016, 1233–1240.
Marchenko, N., Borch, O.J., Markov, S.V., Andreassen, N., 2016b. Maritime Safety in The High North – Risk and Preparedness: Rhodes, Greece, June 26-July 1, 2016 : Volumes 1-4, 2016.
Maxwell, J.A., 1996. Qualitative research design: An interactive approach. Sage Publ, Thousand Oaks, Calif., p. 153
Mayring, P., Fenzl, T., 2014. Qualitative Inhaltsanalyse. In: Baur, N., Blasius, J. (Eds.), Handbuch Methoden der empirischen Sozialforschung. Springer VS, Wiesbaden, pp. 543–556.
Meng, Q., Zhang, Y., Xu, M., 2017. Viability of transarctic shipping routes: a literature review from the navigational and commercial perspectives. Maritime Policy Manage. 44, 16–41.
Milaković, A.-S., Gunnarsson, B., Balmasov, S., Hong, S., Kim, K., Schütz, P., Ehlers, S., 2018. Current status and future operational models for transit shipping along the Northern Sea Route. Marine Policy 94, 53–60.
Miles, M.B., Huberman, A.M., 1994. Qualitative data analysis, second ed. Sage, Thousand Oaks, Calif., p. 338
Osman, A., 2015. Emergency Response in the Arctic, in: SPE E&P Health, Safety, Security and Environmental Conference-Americas. SPE E&P Health, Safety, Security and Environmental Conference-Americas, Denver, Colorado, USA. 2015-03-16. Society of Petroleum Engineers.
Østreng, W., Eger, K.M., Fløistad, B., Jørgensen-Dahl, A., Lothe, L., Mejlænder-Larsen, M., Wergeland, T., 2013. Shipping in Arctic Waters. Springer, Berlin Heidelberg, Berlin, Heidelberg.
Overland, J., Dunlea, E., Box, J.E., Corell, R., Forsius, M., Kattsov, V., Olsen, M.S., Pawlak, J., Reiersen, L.-O., Wang, M., 2019. The urgency of Arctic change. Polar Sci. 21, 6–13.
Palma, D., Varnajot, A., Dalen, K., Basaran, I.K., Brunette, C., Bystrowska, M., Korablina, A.D., Nowicki, R.C., Ronge, T.A., 2019. Cruising the marginal ice zone: climate change and Arctic tourism. Polar Geogr. 42, 215–235.
Parsons, J., Dinwoodie, J., Roe, M., 2011. Northern opportunities: A strategic review of Canada's Arctic icebreaking services. Marine Policy 35, 549–556.
Pearce, T., Ford, J., Willox, A.C., Smit, B., 2015. Inuit Traditional Ecological Knowledge (TEK) Subsistence Hunting and Adaptation to Climate Change in the Canadian Arctic. Arctic 68, 233.
Pestov, I., Pilat, M., 2011. Modelling Search and Rescue systems with dynamical networks, in: 2011 IEEE Symposium on Computational Intelligence for Security and Defense Applications (CISDA). 2011 Ieee Symposium On Computational Intelligence For Security And Defence Applications - Part Of 17273 - 2011 Ssci, Paris, France. 2011. IEEE, pp. 31–38.
Pruyn, J.F., 2016. Will the Northern Sea Route ever be a viable alternative? Maritime Policy Manage. 43, 661–675.
Riege, A.M., 2003. Validity and reliability tests in case study research: a literature review with "hands-on" applications for each research phase. Qualitative Market Res. Int. J. 6, 75–86.
Rottem, S.V., 2014. The Arctic Council and the Search and Rescue Agreement: the case of Norway. Polar Rec. 50, 284–292.
SARC, 2017. Arctic search and rescue capabilities survey: Enhancing international cooperation.
Schmied, J., Borch, O.J., Roud, E.K.P., Berg, T.E., Fjørtoft, K., Selvik, Ø., Parsons, J.R., 2017. Maritime Operations and Emergency Preparedness in the Arctic-Competence Standards for Search and Rescue Operations Contingencies in Polar Waters. In: Latola, K., Savela, H. (Eds.), The Interconnected Arctic — UArctic Congress 2016. Springer International Publishing, Cham, pp. 245–255.
Schneider, A., 2018. Northern Sea Route. Problems of Economic Transition 60, 195–202.
Schreier, M., 2014. Qualitative Content Analysis. In: Flick, U. (Ed.), The Sage Handbook of Qualitative Data Analysis. Sage, London, pp. 170–183.
Sevastyanov, S., Kravchuk, A., 2020. Russia's policy to develop trans-arctic shipping along the Northern sea route. Polar J. 13, 1–23.
Shan, Y., Zhang, R., 2019. Study on the Allocation of a Rescue Base in the Arctic. Symmetry 11, 1073.
Skripnuk, D.F., Iliyushchenko, I.O., Kulik, S.V., Stepanov, M.M., 2020. Analysis of the current state of the Northern Sea Route and the potential development of the icebreaker fleet, in: IOP Conference Series: Earth and Environmental Science. 5th International Conference "Arctic: History and Modernity", Saint-Petersburg. 18-19 March 2020.
Smith, T., 2017. Search and Rescue in the Arctic: Is the U.S. Prepared? RAND Corporation.
Solski, J.J., 2013. New Developments in Russian Regulation of Navigation on the Northern Sea Route: Arctic Review on Law and Politics, vol. 4, 1/2013 pp. 90–119.
Stewart, E.J., Dawson, J., Howell, S., Johnston, M.E., Pearce, T., Lemelin, H., 2013. Local-level responses to sea ice change and cruise tourism in Arctic Canada's Northwest Passage. Polar Geogr. 36, 142–162.
Stoddard, M.A., Etienne, L., Fournier, M., Pelot, R., Beveridge, L., 2016. Making sense of Arctic maritime traffic using the Polar Operational Limits Assessment Risk Indexing System (POLARIS). In: IOP Conference Series: Earth and Environmental Science, p. 12034.
Sun, Z., 2019. International Regulation of Heavy Fuel Oil Use by Vessels in Arctic Waters. Int. J. Mar. Coast. Law 34, 513–536.
Sun, Z., 2020. Closing Gaps of Fuel Use Regulation of Arctic Shipping. Int. J. Mar. Coast. Law 35, 570–595.
Takei, Y., 2013. Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic: an assessment. Aegean Rev Law Sea 2, 81–109.
Teplukhina, I.V., Bogdanov, V.I., Tsvetkov, A.S., 2020. Experience of Preparing Large Workpieces for Reactor Vessels of a New Generation of Universal Atomic Icebreakers. Metallurgist 63, 951–959.
The Standing Committee on Fisheries and Oceans, 2018. When every minute counts: maritime search and rescue, Ottawa, Canada.
Tseng, P.-H., Cullinane, K., 2018. Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model. Maritime Policy Manage. 45, 422–438.
Tseng, P.-H., Pilcher, N., 2017. Assessing the shipping in the Northern Sea Route: a qualitative approach. Maritime Business Rev. 2, 389–409.
UNCTAD, 2019. UNCTAD Handbook of Statistics 2019. United Nations Publicatio, New York.
VanderBerg, J.D., 2018. Optimal Arctic Port locations: a quantitative composite multiplier analysis of potential sites. Polar Geogr. 41, 55–74.
Weston, C., Gandell, T., Beauchamp, J., McAlpine, L., Wiseman, C., Beauchamp, C., 2001. Analyzing Interview Data: The Development and Evolution of a Coding System. Qualitative Sociol. 24, 381–400.

Woldaregay, A.Z., Walderhaug, S., Hartvigsen, G., 2017. Telemedicine Services for the Arctic: A Systematic Review. JMIR Med. Informat. 5, e16.
Xing, Y., Grant, D.B., McKinnon, A.C., Fernie, J., 2011. The interface between retailers and logistics service providers in the online market. Eur. J. Mark. 45, 334–357.
Xu, H., Yang, D., 2020. LNG-fuelled container ship sailing on the Arctic Sea: Economic and emission assessment. Transport. Res. Part D Transport Environ. 87, 102556.
Yin, R.K., 2009. Case study research: Design and methods, fourth ed. Sage, Thousand Oaks, p. 219.
Zeng, Q., Lu, T., Lin, K.-C., Yuen, K.F., Li, K.X., 2020. The competitiveness of Arctic shipping over Suez Canal and China-Europe railway. Transp. Policy 86, 34–43.