UNDERSTANDING OPERATIONAL RISKS OF LOW/NON-ICE-CLASS SHIPS NAVIGATING IN CANADIAN ICY WATERS

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Abstract

The unpredictability of ice and weather conditions may cause unexpected ship-ice encounters, which can be hazardous, especially for ships not sufficiently equipped for operation in the presence of sea ice. This study uses a combination of classic accident analysis and a more proactive approach, including historical data analysis and knowledge elicitation from experts to understand the historical statistics and functionality of low/non-ice-class ships sailed in icy waters in Canada. Ice-related marine accidents analysis showed that most drifting/besetting incidents and hull damages due to ice contact occurred in sub-arctic waters and in shoulder seasons. A Functional Resonance Analysis Method (FRAM) model based on experts' knowledge showed the significance of the human factor, the ship management company, regulatory requirements, and governmentally provided information and supports (like advisory and icebreaking) in collaborative decision-making in strategic navigation. A statistical analysis of the Polar Operational Limit Assessment Risk Indexing System (POLARIS) risk indices based on historical ship positions (AIS data) and ice charts showed that it is likely that ships safely navigated in sea-ice that was heavier than POLARIS recommendations. Outcomes can be used to investigate the efficacy of regulatory arrangements, government provided supports and shipping company operating processes for safe ship navigation in ice.

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List of Abbreviations

AIRSS	Arctic Ice Regime Shipping System
AIS	Automated Identification System
ASTD	Arctic Ship Traffic Data
CCG	Canadian Coast Guard
CHS	Canadian Hydrographic Service
ETTO	Efficiency-Thoroughness Trade-Off
FRAM	Functional Resonance Analysis Method
GIS	Geographic Information System
IACS	International Association of Classification Societies
IMO	International Maritime Organization
ICEHR	Interdisciplinary Committee on Ethics in Human Research
MANICE	Manual of Ice
MCTS	Marine Communications and Traffic Services Centres
MODIS	Moderate Resolution Imaging Spectroradiometer
NORDREG Zone	Northern Canada Vessel Traffic Service Zone
PAME	Protection of the Arctic Marine Environment
Polar Code	International Code for Ships Operating in Polar Waters
POLARIS	Polar Operational Limit Assessment Risk Indexing System
PWOM	Polar Water Operational Manual
Res.	Resolution
RIO	Risk Index Outcomes
RIV	Risk Index Value
SAR	search and rescue
SMS	Safety Management System
SOLAS	International Convention of the Safety of Life at Sea
TCPS 2	Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans 2022
TSB	Transportation Safety Board
WGS	World Geodetic System
WMO	World Meteorological Organization

1. Introduction

1.1. Background

Ship navigation is a challenging operation due to the complexity of the tasks and the unpredictability of the environment. It can be even more challenging in Canadian waters, especially in Arctic regions, as it is associated with many hazards that have not been completely identified due to a lack of experience in the area. Canadian Arctic and sub-Arctic regions share some characteristics, like the presence of sea ice, which significantly affects shipping operations.

Shipping activities have increased in Canadian waters [1]. Protection of the Arctic Marine Environment (PAME) reported a 44% increase in the number of unique ships that sailed in the Northwest Passage in 2019 in comparison to 2013. The report also showed a 107% increase in distance sailed [2]. Researchers showed that although sea ice reduction can encourage marine transportation in the region, the increase in Arctic shipping is not correlated with the effects of global warming, which causes overall sea ice reduction. This increase can be explained by the increasing industrial and tourism interests in the region [1]. This increasing trend is expected to continue, considering the presence of rich natural resources and economic motivations in the area [3]. It was shown that despite global warming, sea ice presence in the Canadian Arctic will be significant for at least the next 50 years [4]. Increasing shipping activities in the Canadian Arctic due to growing economic incentives will become more challenging because of the relatively unknown and unpredictable hazards associated with the region.

The number of significant incidents in the region is not high due in part to maritime safety policies and techniques and relatively few shipping activities in the Canadian Arctic. Low occurrences do not necessarily provide reliable conclusions for practical safety management based on the traditional accident prevention approaches. The identified root cause of accidents is shown to be identical in many cases [5] and consequently does not provide much data for safety management. It should be noted that shipping accidents in general, and especially in the Arctic, can have severe consequences and can impact future activities significantly, so relying on reactive approaches may not be the best. Proactive approaches for taking steps to maintain and improve safety need a good understanding of actual operations [6]. In the case of shipping within Canadian waters, understanding different aspects of shipping activities is necessary to keep operations within desired limits and to control its impact on the natural environment.

Ship navigators need to consider a variety of factors to keep sailing safe and efficient. Ship specifications and capabilities have a prominent role in the decision-making process of ship navigators [7]. These factors are (to some extent) addressed as criteria for decision-making in shipping regulations, especially in Polar Regions [8] [9] [10]. The International Maritime Organization (IMO), in the Guidelines for Voyage Planning, Resolution A.893(21), recommends considering "the condition and state of the vessel, its stability, and its equipment; any operational limitations; its permissible draught at sea in fairways and in ports; its maneuvering data, including any restrictions;" for ship route plan appraisal. It is also recommended that the safe speed, maneuvering characteristics of the vessel, and its draught concerning the available water depth during the planning phase and "the reliability and condition of the vessel's navigational equipment" during navigation execution are taken into account [9]. IMO also requires considering the ship and its equipment's operational limitations for Polar navigations [8].

Canadian regulations discuss a set of environmental factors like wind, sea current, sea ice, temperature, and geospatial parameters like waterways depth and width, marine traffic, designated protected areas, and densities of marine mammals that should be taken into account for ship operations, especially in the Polar Regions [10]. In addition, ship navigators should consider a lot of environmental and geospatial variables as well as ship-related parameters in their decision-making [7].

Understanding how ship navigators consider ship capabilities against operating conditions in navigation planning and execution is important for safety enhancement because ship capabilities and characteristics are difficult, and most of them impossible, to change or adapt during navigation. On the other hand, despite significant improvements in the available data and accuracy of forecasting environmental conditions, there are relatively high levels of inaccuracies in data and uncertainties in the predictions considering the fact that environmental parameters can be inherently dynamic. Thus, navigators should adapt their plan and operation to ship and environmental parameters.

This study uses a technique called the Functional Resonance Analysis Method (FRAM) to identify and analyze different activities and their relations required to plan, appraise, execute, and monitor ship navigation in Canadian waters. This study will focus on ship capabilities and condition considerations prior to and during ship navigation, which are directly related to decision-making and decision-making criteria in different phases of a voyage in Canadian waters. The main source of information was interviews with experienced ship navigators in Canadian icy waters; however, historical data of ice-related marine incidents/accidents, ship navigations (AIS data), and ice charts are used to understand possible ship-ice encountering instances.

1.2. Objectives and Research Questions

The main purpose of this research is to understand the role of ship capabilities in ship planning and execution and discuss related factors in Arctic navigation and other Canadian icy waters.

This study tries to answer the following questions:

1- How do ship navigators become informed of ship capabilities and assumed operating conditions?
2- How do ship navigators consider ship capabilities and assumed operating conditions in their decision-making process in Canadian icy waters?
3- Are ships likely to experience more severe operating conditions than expected from operational and regulatory recommendations in planning navigation in Canadian icy waters?

All ship-related parameters that are defined in the design and classification process and should be taken into account for route planning and navigation will be considered as ship capabilities in this research. Operating conditions in this research refer to environmental and geospatial factors.

This study may also offer answers to the following secondary questions:

1- How do Canadian regulatory and government provided supports affect non-ice-class ship navigation in Canadian icy waters?
2- How do ship management companies influence ship navigation planning in icy waters?

This study aims to gain insights into the topic through analysis of historical data and FRAM modeling based on interviews with experts.

2. Literature Review

2.1. Safety-I and Safety-II

Many standardized methods for measuring safety are based on knowledge from past accidents or the probability of identified hazards and their identified consequences [11]. Based on this view, safety -as a desirable condition- is tightly correlated with avoiding known or identified undesired situations. This approach, which is called Safety-I, is effective as long as the concerned system or technology and its environment are well-understood, controllable, and, to some extent, predictable. The effectiveness of the Safety-I approach decreases when the available data for probability calculations and identifying hazards is not sufficient due to changes in the system or a lack of understanding of the system, especially when the system is intractable or has intractable components or parts like humans and their collective entities (teams and organizations) [12]. Also, when the analysis focuses on accidents, biases may affect the assessment [7]. On the other hand, successful operations, which prevail in ongoing systems, can provide more information for enhancing safety in comparison to only using scattered and unique unsuccessful instantiations [12]. Safety-II tries to ensure that everything is within desired limits instead of focusing only on scenarios that may go wrong. In other words, while Safety-II is built on and appreciates the benefits of Safety-I, it puts more emphasis on success rather than failure. Safety-II assumes a system works well because people within the system can adjust to different situations. This approach insists on proactive safety management by understanding how a system works and how it responds to different variability within the system and its environment [6].

In this research, acknowledging the benefits of Safety-I and II approaches, accident/incident analysis, as a Safety-I approach, is carried out to understand past ice-related occurrences in Canadian waters and to address them as possible undesired situations in designing the Safety-II portion of the study. The Safety-II part of the study includes a systematic analysis of actual operations and a historical analysis of probable values of a currently accepted risk assessment tool considering prevailing ice conditions and ships' ice classifications. It is discussed in the research plan in sections 3.3 and Figure 5.

2.2. Functional Resonance Analysis Method (FRAM)

Among the techniques that have been introduced based on the Safety-II approach, the functional resonance analysis method (FRAM) provides a practical methodology for analyzing a task or system. Researchers have been using FRAM increasingly in different domains, especially in healthcare and aviation [13]. It has mostly been used for safety management, accident/incident investigation, hazard identification/risk management, and complexity management [14]. In the maritime domain, researchers used FRAM for different purposes, including but not limited to understanding complex operations like mooring [15], accident investigation [16] [17], and safety management [18].

The FRAM, introduced by Erik Hollnagel, uses everyday activities to analyze past occurrences and future possibilities. This method provides a visual presentation of different scenarios in a socio-technical system based on four principles:

- same sources for failure and success
- adaptability of socio-technical systems
- emergent outcomes
- resonance in the variability of functions

FRAM uses hexagonal shapes to show identified functions in a system, while each function can be characterized by six aspects: input, output, preconditions, resources, time, and control (Figure 1). Relations between functions in a system are illustrated by connecting different aspects.

Although FRAM provides a graphical representation of the system, its analysis is verbal or descriptive [19].

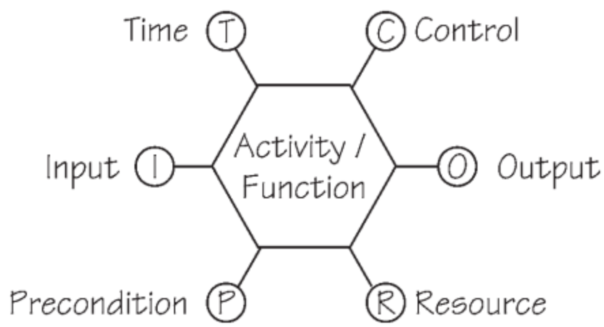


Figure 1 A hexagon representing a function [20]

Hollnagel in FRAM: Functional Resonance Analysis Method book [20] describes different aspects of a function in FRAM. Below is an outline:

- Input is anything that may initiate the function. It may be hard material, data, or energy that the function uses or transforms to produce an outcome. A function may have different inputs, all or some required to start the function, yet a function may be started even without identified input.
- Output is basically the result of a function. Like input, it can be material, data, a sort of energy, or a state of change. The output of a function will be consumed, utilized, or make a change of state in other aspects of a downstream function.
- A precondition is a prerequisite or requirement of the function; however, it does not start the function. Yet, precondition may be required before the function starts.
- A resource is something that a function uses or requires to complete the function. Resources can be information, energy, specific skills, or tools. Resource is usually required while the function is being carried out.

- The time aspect represents temporal conditions that may influence or regulate the sequencing conditions of a function.
- Control, as its name suggests, is a monitoring or regulating aspect of a function. Control may be a plan, regulatory, or oversight system that measures or supervises how a function is executed.

In FRAM terminology, functions that have only input(s) or output(s) are called background functions and functions with more that two aspects are called foreground functions [20]. The background functions form the boundary of the analysis.

A FRAM is carried out in four steps:

1- Identifying and describing everyday activities that make the system functional with desired outcomes
2- Identifying actual and potential variability for both normal acceptable and out-of-range operations
3- Learning aggregation of variability in every instantiation of the system
4- Proving recommendations and solutions for managing and controlling variability and avoiding undesired outcomes [20]

In the first step, all functions and their relations should be described in proper detail. When the first step is taken, a visual representation of the system can be produced based on the descriptions and inter-relations between functions and their aspects. An example is shown in Figure 2.

The output of a function is not always exactly as expected. This offset of perfection, which may be acceptable or unacceptable, is called variability. In the FRAM terminology, variability propagates in the system through the outputs of functions. This variability may be dampened or increased by other functions. A function may have internal or external sources of variability [20].

"Variability can be examined in two ways: (1) as a variable signal of an output of single and combined functions, and (2) as the variable functional paths that produce an outcome of the system" [18]. The second way variability is examined, is correlated to the term "functional signature". A FRAM model of a system tries to cover as many modes and scenarios or events in the system as possible. The variability of functions in the system shows its effects as a functional signature for that particular event [18]. Collective information about the range of variability in functions, their outputs, and overall outcomes of the system for different scenarios/events can provide information for understanding how the system adapts to various conditions, which can be used in system and safety management.

FRAM is a powerful method for understanding complex systems, discussing variability in them, and managing safety; however, its inability to provide quantifiable results may be a disadvantage for some purposes [21]. Some researchers tried to compensate for this drawback by introducing new techniques like reinforced learning to the existing method [22] or applying numerical analysis on information collected from FRAM [23]. Still, these techniques' accuracy and effectiveness in general or other applications have not been investigated.

Figure 2 shows an example of a FRAM model built for understanding Arctic ship navigation. D. Smith et al. [7] created this model based on interviews with captains with experience in Arctic navigation and reviewed the Exxon Valdez grounding accident as an example of utilizing this model for information gathering and processing [7]. The current study will try to expand this model in more detail, considering research questions 1 and 2 and secondary research questions. Also, see the research methodology in sections 3.3.

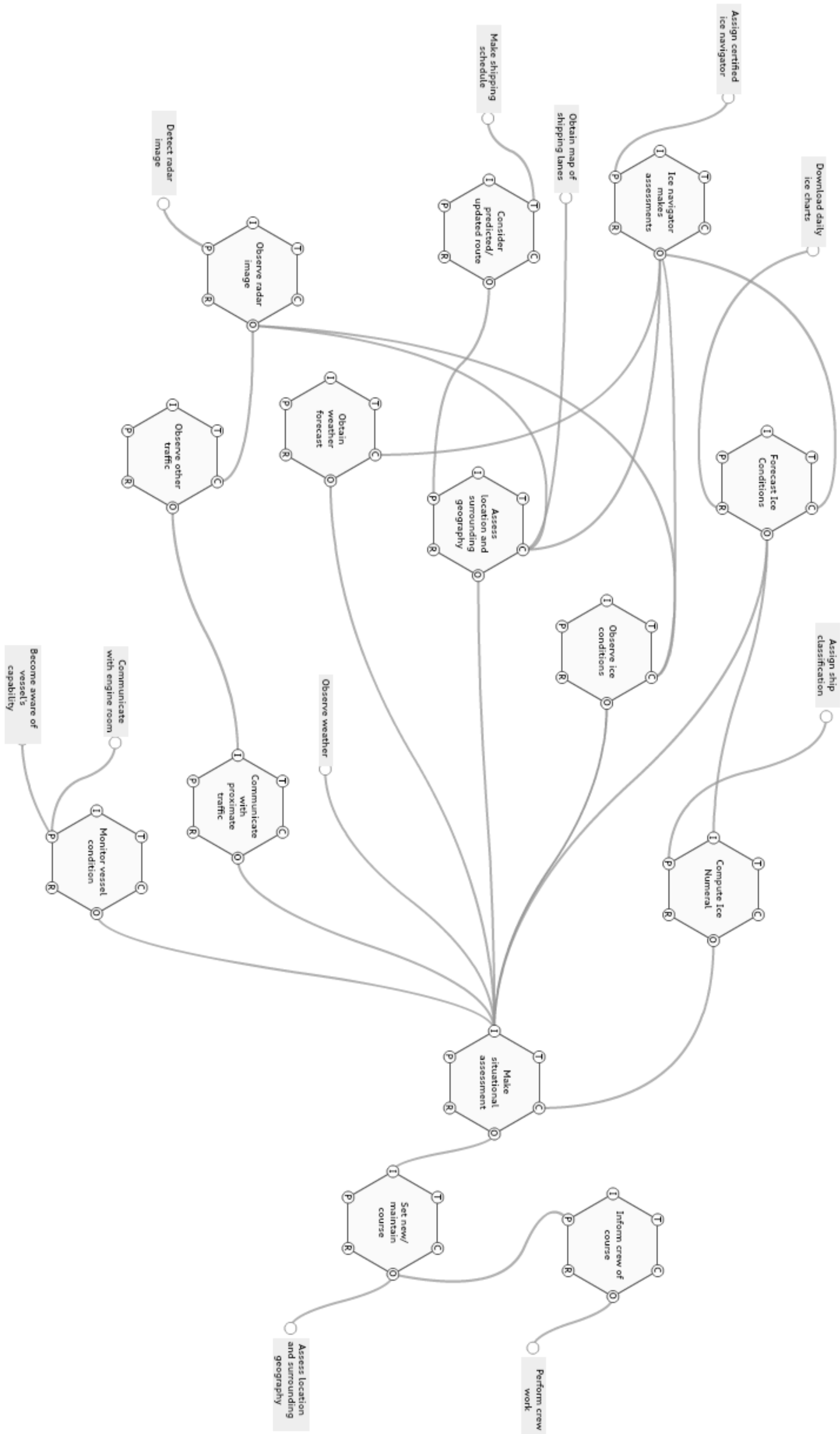


Figure 2 FRAM model for ship navigation with input from ship navigators [7]

This study uses FRAM to understand how ship navigators consider ship specifications and capabilities in the decision-making process during navigation in Canadian waters. This research will primarily focus on low/non-ice-class ship navigation in the presence of sea ice (as a significant hazard in both Arctic and sub-Arctic waters) in Canadian waters; however, organizational, and regulatory factors that may be identified during investigations will be considered.

2.3. Semi-Structured Interview

Among different data collection approaches in FRAM studies, semi-structured interviews are used commonly to create FRAM models [13] [14].

Interviews are flexible techniques to collect vast amounts of information about a particular subject and are widely used in the realm of human factor studies. Interviews can be executed in three generic types: structured, semi-structured, and unstructured [24].

A semi-structured interview "is defined as an interview with the purpose of obtaining descriptions of the life world of the interviewee in order to interpret the meaning of the described phenomena" [25]. In a semi-structured interview, some of the questions are pre-determined; however, an interviewer can manage the interview with further questions that were not exactly planned in advance to gather new information [24]. Because of the relative flexibility in a semi-structured, the interviewer can elicit more knowledge from different angles and keep the dialogue focused on the targeted subject [26], which makes it an effective tool for probing and open-ended data collection and/or research questions [27]. Despite all the relative advantages of semi-structured interviews, their quality heavily depends on the interviewer and interviewee's performance during the interview. Also, collecting large samples (interviewing many people) is practically limited in many studies, and analyzing the huge amount of data and notes is timely and requires substantial effort [24] [27].

There are some general steps and guidelines to complete a semi-structured interview. Adams [27] outlines general steps to prepare and conduct semi-structured interviews: “selecting and recruiting the respondents, drafting the questions and interview guide, techniques for this type of interviewing, analyzing the information gathered” [27]. The current study used semi-structured interviews to elicit ice navigation knowledge from experienced ship navigators to create a FRAM model addressing research questions 1 and 2 as well as secondary research questions.

2.4. Ice Charts

The Canadian Ice Services provides information on ice and icebergs in Canada’s waters which helps to improve shipping safety and efficiency [28]. They use aerial, shipboard and shore station sources to collect data for preparing various ice products, which may be used for many purposes like scientific studies and strategic and tactical operations. These products use a coding system called egg codes to communicate sea-ice-related information [29]. Egg codes are a symbology adopted in the Manual of Ice (MANICE) based on the World Meteorological Organization (WMO) nomenclature [30] to report and document ice observations in Canada. An egg code reports the ice conditions in a defined region on an ice chart, typically referred to as an ice regime. An ice regime is an area containing relatively uniform ice conditions. Egg codes consist of information on ice concentration, stage of development, and ice form in its attributed area, which are represented in an oval form. Figure 3 shows the general form of an egg code [29].

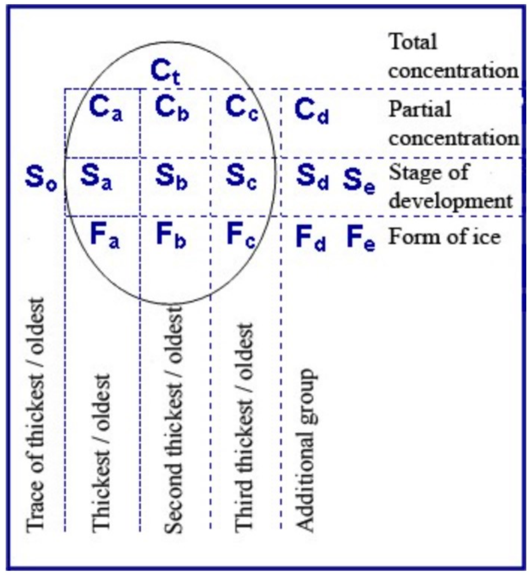
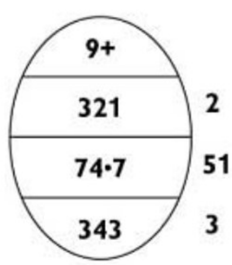


Figure 3 Summary diagram of the Egg Code [29]

Ice concentration (C) shows total (C_t) or partial (C_a, C_b, C_c, and C_d) concentration of ice in the reported area in tenths. Stage of development (S) reflects the thickness of the ice, with older ice corresponding to thicker ice and younger ice corresponding to thinner ice [29]. Form of ice (F) reflects the size of ice floes and uses a coding system from 0 to 9 and X. 0 represents "pancake ice" increasing to 7 which represents "giant floes" with more than 10 kilometer width, 8 represents fast ice, 9 represents icebergs, growlers or floebergs, and X represents undetermined, unknown or no form ice [29]. Figure 4 shows an example of ice code in MANICE [29].



Description: 9+/10 total ice concentration. 3/10 old ice in small floes, 2/10 think first-year ice in medium floes, 1/10 thin first-year ice in small floes, 2/10 grey-white ice in small floes, and the remaining 2/10 is new ice with no floe form.

Figure 4 An example of ice code in MANICE [29]

The Canadian Ice Service provides digitalized historical ice charts based on the ice condition three days before and three days after the nominal day [29]. An overview of the digitalized ice charts format can be found in this link: https://library.wmo.int/doc_num.php?explnum_id=9270

Digitalized weekly ice charts include shapefiles which include spatial information of the different areas on the reported region. Each area in the chart is associated with some attributes that provide information about the area and ice conditions in the form of an egg code [31]. In this study, digitalized weekly ice charts along with historical ship locations in the Hudson Bay area are used to understand possible ice conditions that ships experienced.

2.5. POLARIS

The International Code for Ships Operating in Polar Waters (Polar Code) requires that ship capabilities and limitations in Polar waters be determined and included in their Polar Water Operational Manual (PWOM) [8]. The POLAR Code (MSC.1/Circular.1519) provides guidance for assessing operational capabilities and limitations in ice called the Polar Operational Limit Assessment Risk Indexing System (POLARIS) guideline [32]. POLARIS provides a risk evaluation methodology considering the ship's ice class, which represents some of the ship's technical specifications, and the ice conditions, including ice types and associated concentrations. Ice types are classified by the stage of development o the ice, which have associated ice thickness ranges. POLARIS Risk Index Values (RIVs) are assigned for each ice type and open water in the ice regime, considering the ship's ice class. POLARIS also considers decayed ice conditions and operating under icebreaker escort [32]. Calculated Risk Index Outcomes (RIO), which are used to define criteria for operational limitations, are determined using the below formula:

"$RIO = (C_1 x RIV_1)+(C_2 x RIV_2)+(C_3 x RIV_3)+\ldots(C_n x RIV_n)$

Where $C_1 \ldots C_n$ are the concentrations (in tenths) of ice types within the ice regime; and

$RIV_1 \ldots RIV_n$ are the corresponding Risk Index Values for each ice type." [32]

Table 1 shows the RIO operational criteria. When a situation is identified as elevated operational risk, the navigator should follow a series of recommendations, including a speed limit, shown in Table 2. Tables 3 and 4 show the RIV values for general use and decayed ice, respectively.

Table 1 Risk Index Outcome Criteria [32]

RIO_{SHIP}	*Ice classes PC1-PC7*	*Ice classes below PC 7 and ships not assigned an ice class*
RIO ≥ 0	Normal operation	Normal operation
-10 ≤ RIO < 0	Elevated operational risk*	Operation subject to special consideration**
RIO < -10	Operation subject to special consideration**	Operation subject to special consideration**

Table 2 Recommended speed limits for elevated risk operations [32]

Ice Class	Recommended Speed Limit
PC1	11 knots
PC2	8 knots
PC3-PC5	5 knots
Below PC5	3 knots

Table 3 Risk Index Values [32]

Ice Class	Ice-Free	New Ice	Grey Ice	Grey White Ice	Thin First Year ice 1st Stage	Thin First Year Ice 2nd Stage	Medium First Year Ice less than 1 m thick	Medium First Year Ice	Thick First Year Ice	Second Year Ice	Light Multi Year Ice, less than 2.5 m thick	Heavy Multi Year Ice
PC1	3	3	3	3	2	2	2	2	2	2	1	1
PC2	3	3	3	3	2	2	2	2	2	1	1	0
PC3	3	3	3	3	2	2	2	2	2	1	0	-1
PC4	3	3	3	3	2	2	2	2	1	0	-1	-2
PC5	3	3	3	3	2	2	1	1	0	-1	-2	-2
PC6	3	2	2	2	2	1	1	0	-1	-2	-3	-3
PC7	3	2	2	2	1	1	0	-1	-2	-3	-3	-3
IA Super	3	2	2	2	2	1	0	-1	-3	-3	-4	-4
IA	3	2	2	2	1	0	-1	-2	-3	-4	-5	-5
IB	3	2	2	1	0	-1	-2	-3	-4	-5	-6	-6
IC	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8
Not Ice Strengthened	3	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-8

Table 4 Risk Index Values-Decayed ice conditions [32]

Ice Class	Ice-Free	New Ice	Grey Ice	Grey White Ice	Thin First Year ice 1st Stage	Thin First Year Ice 2nd Stage	Medium First Year Ice less than 1 m thick	Medium First Year Ice	Thick First Year Ice	Second Year Ice	Light Multi Year Ice, less than 2.5 m thick	Heavy Multi Year Ice
PC1	3	3	3	3	2	2	2	2	2	2	1	1
PC2	3	3	3	3	2	2	2	2	2	1	1	0
PC3	3	3	3	3	2	2	2	2	2	1	0	-1
PC4	3	3	3	3	2	2	2	2	1	0	-1	-2
PC5	3	3	3	3	2	2	2	2	1	-1	-2	-2
PC6	3	2	2	2	2	1	2	1	0	-2	-3	-3
PC7	3	2	2	2	1	1	1	0	-1	-3	-3	-3
IA Super	3	2	2	2	2	1	1	0	-1	-3	-4	-4
IA	3	2	2	2	1	0	0	-1	-2	-4	-5	-5
IB	3	2	2	1	0	-1	-1	-2	-3	-5	-6	-6
IC	3	2	1	0	-1	-2	-2	-3	-4	-6	-7	-8
Not Ice Strengthened	3	1	0	-1	-2	-3	-3	-4	-5	-7	-8	-8

Operations subject to special consideration should follow procedural requirements defined in the guide and should be carried out with "extreme caution". This implies the possibility of survival in undesired ice conditions when navigation is executed cautiously. However, the guidance emphasizes avoiding such conditions in voyage planning.

For planning purposes, when a vessel is intended to be escorted by a capable icebreaker, a value of ten can be credited to the RIO. The guidance also provides other recommendations to avoid damage due to sea and glacial ice, mainly focused on procedural considerations in PWOM and operational considerations, which heavily rely on navigation team performance [32].

Different studies investigated possible applications of POLARIS for planning and decision-making in combination of other techniques or considerations [33] [34] [35]. It is shown that POLARIS is not a self-sufficient risk assessment tool because it only considers ice conditions and ship capabilities and does not include weather and sea conditions, operational requirements and human factors [36] [37]; however, it is the only risk assessment tool for icy waters navigation introduced by IMO.

In this study, the use of POLARIS, as a currently accepted risk assessment tool, along with other considerations captains have for icy water navigations, is investigated using FRAM and addresses research question 2, which focuses on icy water navigation decision-making considering ship capabilities. Also, the historical statistics of POLARIS RIO in the Hudson Bay region are investigated, which addresses the research question 3.

2.6. Automatic Identification System Data

According to the international convention of the Safety of Life at Sea (SOLAS), all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards, and all passenger ships should be equipped with an Automated Identification System

(AIS) to exchange data ship-to-ship and with shore-based facilities [38]. AIS helps identifying ships for different purposes, including navigation and search and rescue [39].

AIS provides ships' identity as well as some navigational information such as position, heading, rate of turn, speed, and more [39]. It should be noted that AIS provides vessels Speed Through the Ground. This speed is different from Speed in Water, which is required when the concern is operating in icy water. The AIS data transmission temporal resolution requires 2 seconds to 6 minutes in different situations [39]

Researchers used historical AIS data along with historical ice charts to investigate navigation patterns [40] and assess the risks of icy water navigation [41].

AIS data are available to the public through commercial and non-commercial firms. Protection of Marine Environment (PAME), which is one of six IMO Arctic Council working groups, provides historical information of ship tracks by ship type in the Arctic for scientific and policy-making use. This data also includes ship ice classes based on Finnish-Swedish Ice Class Rules. It is called Arctic Ship Traffic Data (ASTD) [42]. This study uses ASTD AIS data to analyze historical POLARIS RIO for different ship types for shoulder seasons in the Hudson Bay area.

2.7. Geographic Information System (GIS)

Geographic Information Systems (GISs) are (usually computer-aided) systems to store, analyze and present data related to locations on the surface of the earth [43]. Experts defined GIS in different ways; however, in all of them, GIS deals with geographical (or spatial) information as a reference for attributes (or statistical or non-locational data) [44]. In other words, "GIS handles data based on their locations in a coordinate reference system" [45]. Although GIS is not necessarily a computer-based system, most current functionalities require a higher computing capacity that a software can provide [45].

"Geoinformatics and spatial analysis are becoming increasingly interdisciplinary, and their applications are expanding into new fields such as healthcare, retail, entertainment" [46]. In the maritime domain, GIS is widely used for marine resource management and policy-making as well as scientific studies, especially on the marine environment [47]. GIS is also used to study planning [48] and the safety of navigation in icy waters [35] [41].

In this study, GIS is used to overlay ships' historical locations (historical AIS data) on their attributed historical ice charts and calculate POLARIS RIO for each instance to answer the third research question in section 1.2.

2.8. Efficiency-Thoroughness Trade-off (ETTO)

Many complex tasks require a significant amount of consideration of issues or phenomena that are not completely understandable, predictable, and/or tractable. As a result, things may go wrong due to unpredicted, ununderstood, and consequently, uncontrolled situations. In an ideal world, people should understand all possible situations and manage them to avoid any undesired outcome, but it is not feasible for many systems, especially those that involve natural environments and humans and collective entities of humans (like organizations and societies). In most cases, available resources, including material and time, are limited to understanding, predicting, and/or controlling all aspects of the task and influencing factors perfectly. Erik Hollnagel introduced the Efficiency-Thoroughness Trade-off (ETTO), which suggests that people often have to trade off between the resources they spend to prepare for and complete a task [49].

In ETTO, **“Efficiency** means that the level of investment or amount of resources used or needed to achieve a stated goal or objective are kept as low as possible … **Thoroughness** means that an activity is carried out only if the individual or organisation is confident that the necessary and sufficient conditions for it exist so that the activity will achieve its objective and not create any unwanted side-effects” [49]. Thoroughness, which focuses on preconditions for ensuring the outcome, always requires consuming resources, which in many cases are unlimited due to the current status of human knowledge and capabilities. As a result, it is impossible to maximize efficiency and thoroughness simultaneously [49]. Researchers used ETTO principles to characterize performance variability [50]. In marine navigation examples, it was shown that navigators have to make multiple trade-offs between different goals related to the safety and efficiency of the operation to respond to changes in the situations. [51].

According to Hollnagel, ETTO can happen due to limited availability of resources, a need to conserve resources for contingencies, social or organizational pressure, individual attitudes and traits, and the nature of humans [49]. These causes resulting in ETTO have been discussed on the role of human performance in marine accidents [52]. ETTO principles can explain how navigators handle constantly changing situations with limited resources and a variety of technical, regulatory, and operational considerations, which is discussed to some extent in 6.3.

3. Methodology

3.1. Research Plan

This research used a combination of Safety-I and Safety-II approaches to investigate the research questions. Figure 5 shows the study’s general plan.

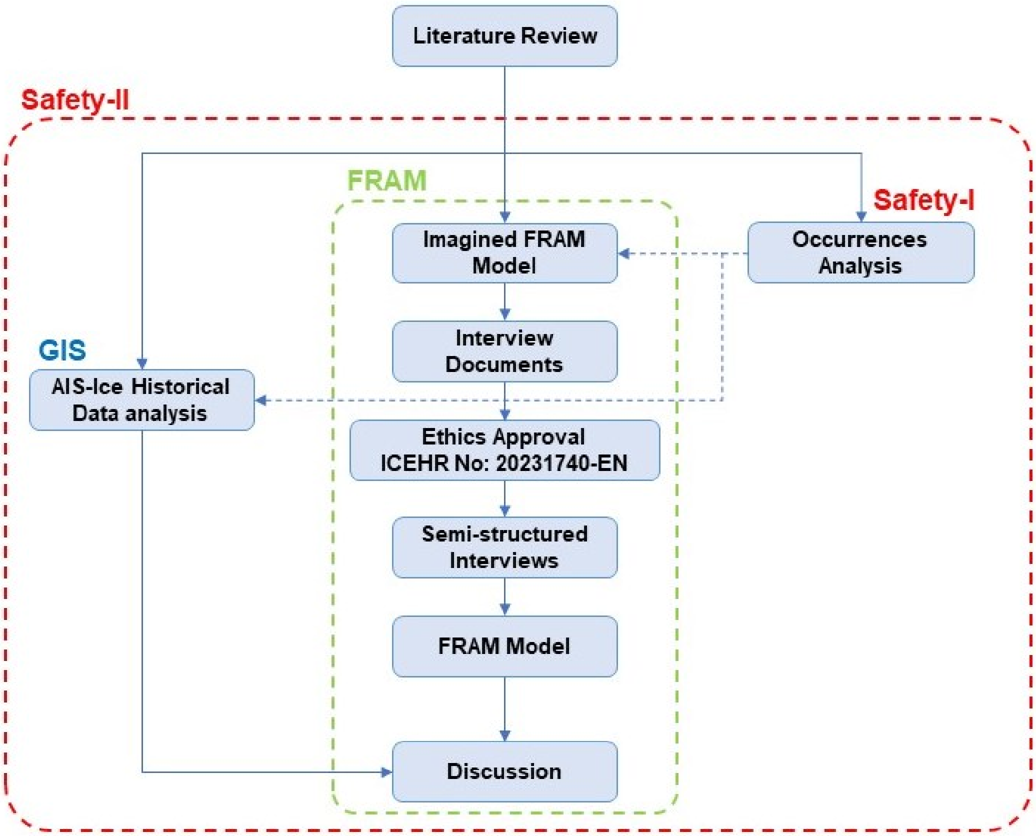


Figure 5 Research plan

After the literature review, considering traditional approaches to safety assessments, an occurrence analysis was carried out to understand ice-related accidents/incidents in Canadian waters. Results were used to pursue a Safety-II approach toward understanding the safety of navigation in ice in Canadian waters. The Safety-II portion of the study included two parts: FRAM and Geographic Information System (GIS) analysis. The results of the occurrence analysis gave an insight into possible risks that could be considered in the FRAM study to create the imagined model and the interview instrument. The Safety-I part of the study also provided an idea of the interest period for GIS analysis. Results will be discussed to develop a broader understanding of ship navigation in Canadian icy waters.

3.2. Occurrence Analysis

The Transportation Safety Board (TSB) defines marine occurrences as:

- “any accident or incident associated with the operation of a ship
- any situation or condition that the Board has reasonable grounds to believe could, if left unattended, induce an accident or incident described above.” [53]

The TSB of Canada provides a summary of maritime incidents and accidents in Canadian waters since 1975. This data is publicly accessible in the below link: https://www.tsb.gc.ca/eng/stats/marine/index.html

The .csv file provides information about the date, weather, sea state, location, occurrence type, ship(s) involved, injuries, pollution, etc. It also provides a brief summary of the occurrence.

On 18 August 2009, Transport Canada published a Safety Bulletin No. 04/2009 on the application of IACS URI in the Canadian Waters, which explains “Transport Canada’s policy towards the application of new rules respecting structural and machinery requirements for polar ships, promulgated by the International Association of Classification Societies (IACS), as referenced from an International Maritime Organization (IMO) document.” [54] This bulletin supported the full implementation of new approaches in IMO and IACS to the safety in the Polar regions. So, it was decided to focus this part of this study on occurrences on or after 2009.

Summary of occurrences reported by TSB from 2009 to 2022 was filtered to find occurrence:

- with reports of the presence of sea ice and/or icebergs
- that ice was mentioned in their summary

Then

- Occurrences irrelevant to the ship and its machinery (like Man Over Boards) were removed.

- Repeated occurrences from different sources were merged to avoid double entries.

Results were analyzed to learn different sources of ice-related occurrences in Canadian waters, which were used in the Safety-II part of the study.

3.3. FRAM

The functional resonance analysis method (FRAM) was the primary technique in this study. Data required to build a FRAM model was collected through knowledge elicitation from interviews with ship captains, officers, ice navigators, and route planners who have experience or have been involved in at least one ship navigation in the presence of ice in Canadian waters.

Creating the FRAM model required the following steps:

1- Providing an imagined ship navigation model based on, occurrence analysis, literature, current regulations and guidelines review.
2- Preparing interview documents.
3- Applying and receiving ethics clearance (ICEHR Number: 20231740-EN)
4- Interviewing experts and providing an As-done navigation model.
5- Discussing identified functions and their possible variabilities.

In step one, different parameters regarding ship capabilities and operating conditions required to plan, execute, and monitor typical ship navigation in Canadian waters were identified based on available information in literature, regulations, procedures, and guidelines. The term “ship capabilities” in this study includes factors that determine the abilities of the ship and its equipment like hull strength, ship stability, propulsion power, maneuver characteristics, etc. “Operating conditions” in this study refer to environmental factors like wind, sea current, sea ice, temperature, and geospatial factors like waterways depth and width and marine traffic. The following documents were reviewed and considered to create the imagined FRAM model shown in Figure 6. The table of references for functions in this model is provided in Appendix II. This study does not argue that this imagined FRAM model is comprehensive and perfect. This FRAM model was created to understand the general relations between regulatory expectations and actual icy waters navigation presented in the D. Smith et al. [7] work. The following regulations and procedures were reviewed:

- IMO POLAR Code [8]
- IMO Res. A.893(21) Guideline for Voyage Planning [9]
- Ice Navigation in Canadian Waters [10]
- Canada Navigation Safety Regulations [55]
- Canada Arctic Shipping Safety and Pollution Prevention Regulations [56]
- Vessel Traffic Services Zones Regulations [57]

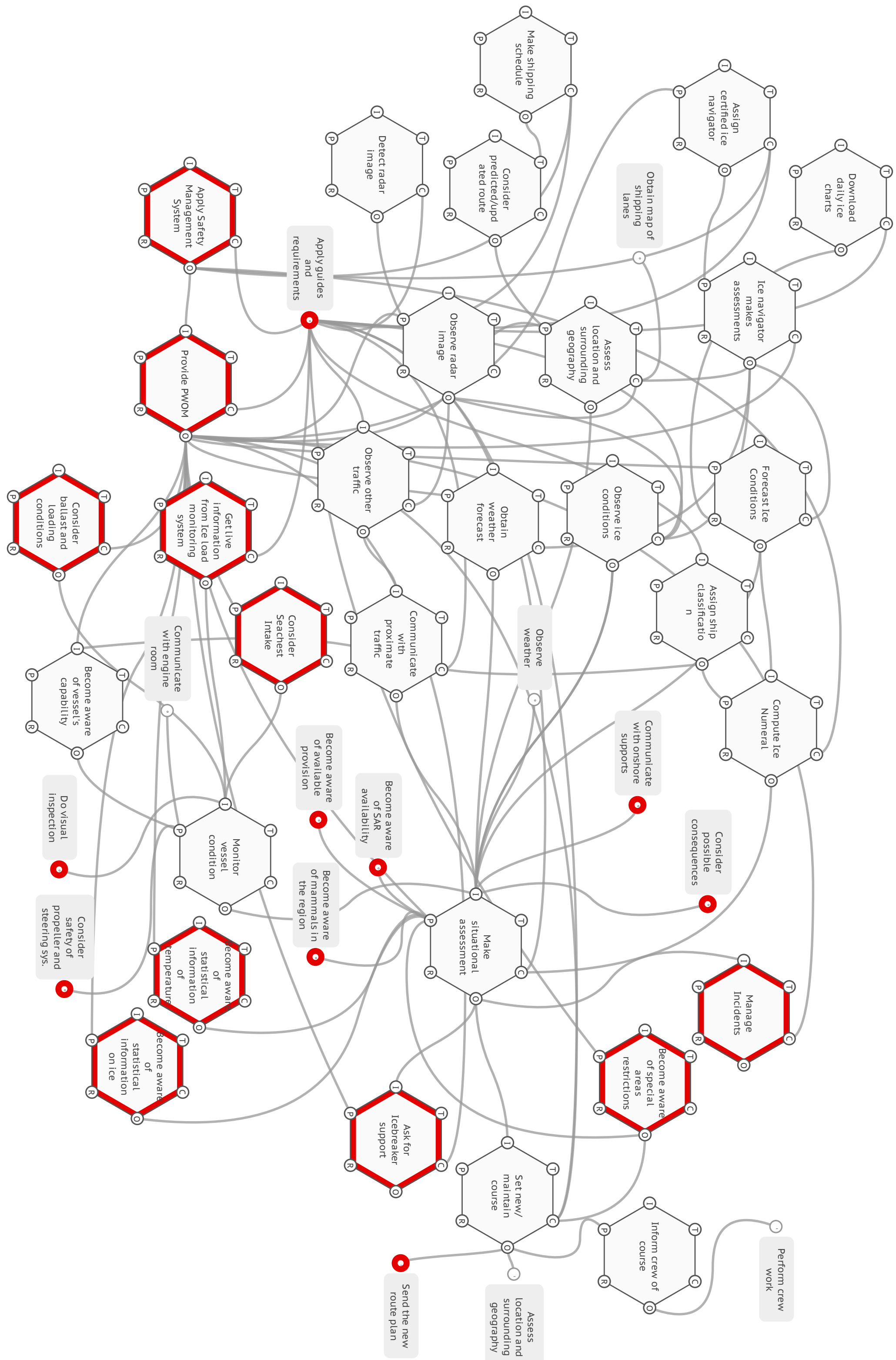


Figure 6 Icy waters navigation Imagined FRAM model - red functions are created based on reviewed regulations and white functions are based on the D. Smith et al. [7] work

The imagined model gave an idea of possible parameters that may be discussed during interviews. This model is called the imagined model as it is based on beliefs and expectations of the modeler. This model can be checked and adjusted from the information collected in interviews.

Step two includes preparing the required documents for knowledge elicitation through semi-structured interviews. The following documents were provided to plan and execute interviews:

- Semi-structured interview guide
- Recruitment Email and announcement
- Informed Consent Form
- Experience Form

Above documents can be found in the Appendix III.

The semi-structured interview guide was built based on the literature review, imagined-FRAM model, and outcomes of the occurrence analysis. Information collected through these three activities gave an idea of important factors to start the discussion in the interviews. The interview guide was purposefully designed to target possible background functions of the below functions in the D. Smith et al. work [7]:

- Become aware of vessel's capabilities,
- Consider predicted/updated route,
- Make shipping schedule,
- Compute Ice Numeral.

The ethical considerations of this study were applied according to the requirements of Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans – TCPS 2 (2022) [58]. Conforming to the Memorial University of Newfoundland policies titled Ethics of Research

Involving Human Participants [59], the ethics proposal was submitted to the Ethics Board for approval. The proposal covered all requirements addressed in TCPS 2 (2022). (See Appendix III-E - ICEHR Number: 20231740-EN)

The interviewees were planned to be individuals among current or retired ship masters and officers, route planners, and ice navigators who have been involved in the planning or navigation of at least one ship voyage in the presence of ice in Canadian waters. The participants recruitment advertisement was sent to some of the potential participants in the research supervisory committee's professional networks and recruitment was expanded using the snowball technique where participants were asked to distribute advertisements to other potential participants they know.

At the third step of the FRAM study, the research team arranged a time for a videoconference with volunteers. A copy of the Informed Consent Form and Experience Form was sent to them before the meeting for their review and completion. The Experience Form was designed to gain participants' backgrounds and relative experiences in the scope of the study. This gave the research team a general idea of participants' expertise and experiences. The meetings were carried out with one participant and one interviewer online.

The interview was split into three sections: (1) Briefing, (2) Navigation decision-making, and (3) Closing. Interviews started with briefings and were followed by an introduction to the purpose and scope of the study (first section). Researchers ensured every detail of the informed consent form was clear for the participant. Afterward, with the participant's consent, video and audio recording was started. In the second section, participants were asked to describe sequences of activities they normally do to complete their ship route planning and navigation job. Participants were generally asked to describe the following:

- What do they consider from ship capabilities in each step in ship navigation?
- What do they require to get this information, and how do they obtain it?
- What are the typical outcomes of their decisions based on this information, and how may ship navigation be affected by it?

These questions were addressed in more detail in the interview guide (Appendix III). The interview guide is purposefully designed to navigate the interview to elicit experts' knowledge and experience of research questions in section 1.2. The interviews' body was structured in the following sections:

- Before getting onboard: which addresses the communications between the shipping company and ship navigators, and ship navigators' activities regarding understanding the mission and initial planning (Research Questions 1 and 2)
- After getting onboard and before starting the voyage, which addresses the familiarization process with the ship and its capabilities and route planning (Research Questions 1 and 2)
- During navigation, which addresses the activities and considerations for monitoring the ship condition and adjusting planning and operation accordingly (Research Questions 1 and 2)
- Special circumstances" which captures occasional changes due to unplanned or unexpected situations (Research Questions 1 and 2)
- POLARIS questions: which focuses on the application of POLARIS in the planning and navigation (Research Questions 1, 2, and 3)
- Company, consultant, and authorities: which navigates the discussion to capture the organizational aspects of the operation (Secondary Research Questions 1 and 2)

- General questions and participant's preferences of getting information and support: which captures participants' opinions of current procedures and regulations (All research Questions)

Because of the nature of semi-structured interviews, questions were not limited to the interview guide and sometimes covered other issues to capture different functions of the shipping operations. At the end of the meeting (closing), the interviewer asked participants for their feedback and comments and highlighted their concerns regarding ship navigation in Canadian icy waters. Finally, the recordings were stopped, and the meetings were completed.

Meetings were held, recorded, and transcribed via Webex. The recorded audio was transcribed, and the transcription was sent to participants to review, change, or add to them. Participants had one week to respond. If they did not respond within this time, the transcript was considered approved. The approved transcripts were analyzed and aggregated to identify functions and their relationships to create a FRAM model for the targeted activities.

The fourth step was focused on discussing some of the identified functions based on the information gathered from interviews. Collecting numerical data or analyzing marine occurrences based on the FRAM model was not in the scope of this study; however, it can be considered in future works.

3.4. GIS Analysis

POLARIS was suggested by IMO as an interim guideline for safe operations in ice [32] and the Arctic Ice Regime Shipping System (AIRSS), a requirement of Canadian maritime regulations in the Arctic [56], are adopted as major decision-making tools for navigation in icy conditions in Canadian waters. Ice Numerals are an element of the AIRSS guideline and are considered analogous to POLARIS values. From the early stages of the literature review, it was found that computing POLARIS RIOs and AIRSS Ice Numerals according to according to their respective methodologies, are an important factor in planning and navigation in icy waters. D. Smith et al. [7] also showed how ice numerals are considered in icy waters navigation.

In the current study, historical ships' positions were overlaid on ice charts to understand the historical statistics of POLARIS RIO values in Canadian icy waters. ASTD AIS data between 2012 and 2022 and digitalized weekly ice charts from the Canadian Ice Services were obtained to do this analysis.

Digitalized weekly ice charts include shapefiles that can be read and processed in a Geographic Information System (GIS) software. Each area in the chart is associated with some attributes that provide information about the area and ice conditions in the form of an egg code [31]. Weekly regional ice charts were downloaded from the below link:

https://iceweb1.cis.ec.gc.ca/Archive/page1.xhtml

"The underlying reference frame for the data [for coastlines in these charts] is the World Geodetic System of 1984 (WGS84) using the updated WGS Earth ellipsoid (2004)" [60]. So, this coordination system was utilized in the analysis.

Figure 7 Shows the geographical coverage of historical ice charts in the Canadian ice archive.

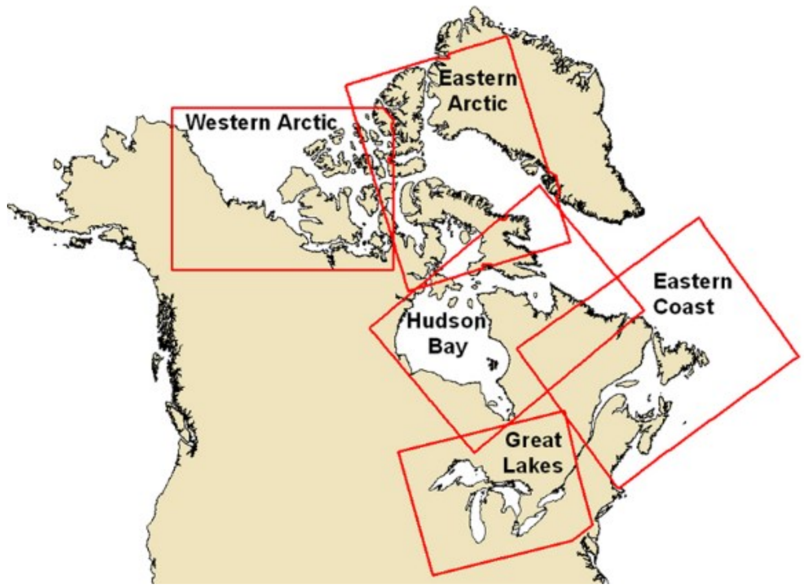


Figure 7 Historical weekly ice charts [61]

Hudson Bay was selected as the region of interest for this analysis because more AIS data from low/non-ice-class ships were available for the region. It was theorized that the possibility of encountering relatively heavy ice in shoulder seasons is higher. This theory (to some extent) can be backed up by ice-related hull damages and groundings from occurrence analysis (section 4.1). It can be due to increasing shipping activity in the icy waters, fast changes in ice conditions and movement in shoulder seasons, or a combination of these. In that analysis, it was found that most such incidents happened in April, which was the shoulder season in many cases. For the Hudson Bay area, the shoulder season can be considered from the start of June to the end of July, while a significant decrease in ice concentration is generally expected to happen in July [62]. So, this study was carried out for the Hudson Bay area for July month 2013 to 2022.

Digitalized ice charts are provided based on the ice condition three days before and three days after the nominal day [29]. Figure 8 shows how weekly ice charts cover the calendar day for the interest period.

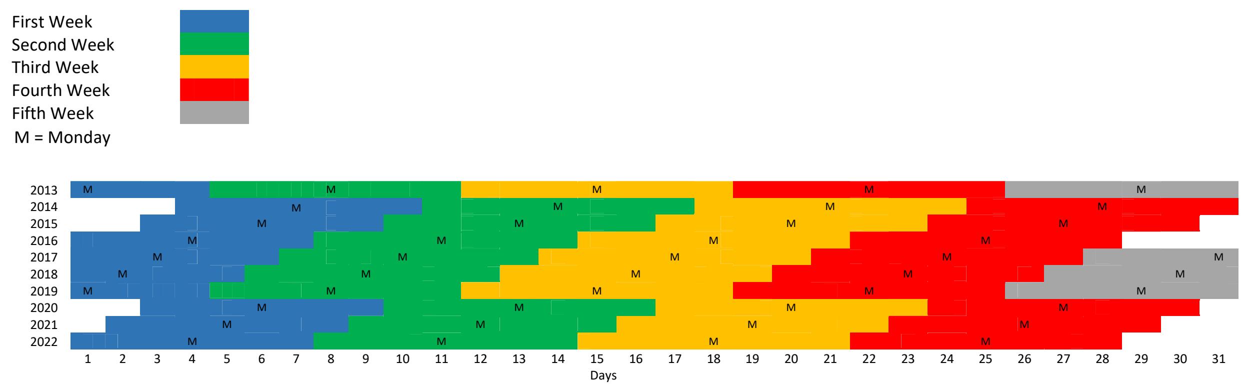


Figure 8 Historical weekly ice chart coverage in July 2013 to 2022

To execute this analysis, a geospatial analytical tool was required to overlay AIS data on historical ice charts to calculate the POLARIS Risk Index Outcome (RIO) for each reported position. For this study, QGIS was used for this data analysis. QGIS is a free and open-source geographic information system. QGIS website: https://www.qgis.org/en/site/

First, AIS data were separated based on correlated weekly ice charts and saved as a separate file. Then, each AIS file was sorted based on the ship's ice class, and different ice class data were saved as a separate .csv file. So, an ice chart and a .csv file for each ship's ice class were created for a week. POLARIS RIO values for each ship type were calculated for each region in the ice chart. There is discrepancy between WMO ice types (used in egg codes) and the ice type defined in POLARIS. Egg codes and POLARIS ice types are equated as per Table 5. This assumption is based on the ice multiplier table in [10]. Finally, each ship type and position was joined to its correlated RIO on the ice chart. Then, the results were saved in the form of .csv files for statistical analysis. Figure 9 demonstrates the process of GIS analysis in QGIS software.

Table 5 Egg Codes - Ice Types Equivalents

Ice Charts Egg Code	Ice Thickness	Ice Types in POLARIS Tables
		Ice Free
1or 2	< 10 cm	New Ice
4	10-15 cm	Grey Ice
3 or 5	15-30 cm	Grey White Ice
8	30-50 cm	Thin First Year Ice 1st Stage
7 or 9	50-70 cm	Thin First Year Ice 2nd Stage
1•	70-120 cm	Medium First Year Ice
6 or 4•	>120 cm	Thick First Year Ice
8•		Second Year Ice
7• or 9•		Heavy Multi Year Ice

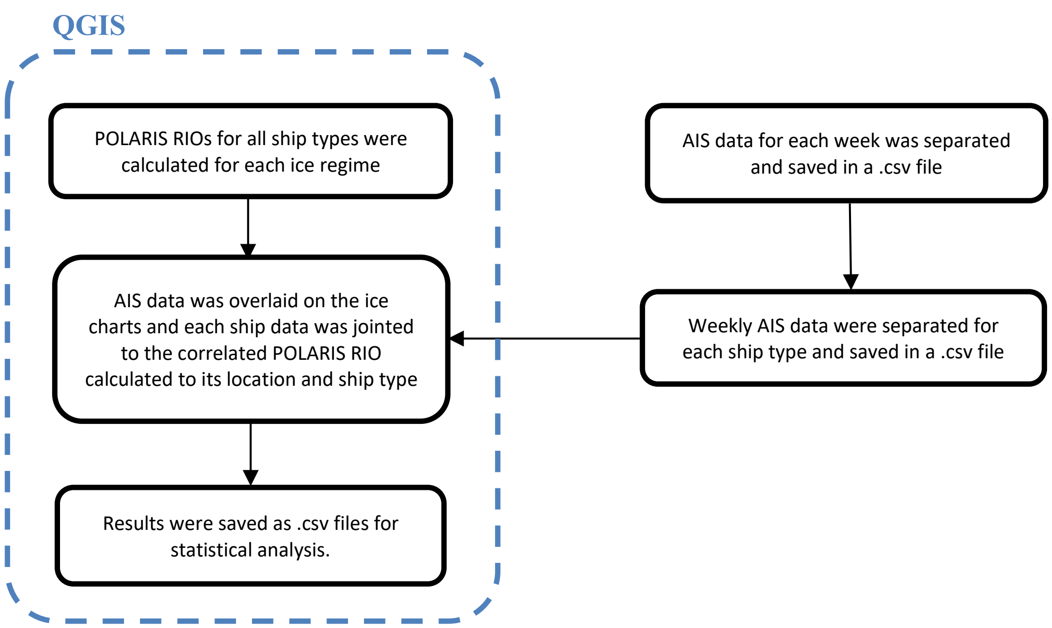


Figure 9 GIS analysis

This analysis shows the historical data of possible ship-ice encountering instances and their RIOs which provides equivalence to determine whether ships are likely to experience more severe ice conditions than expected from operational and regulatory planning requirements (Research Questions 3). As this analysis uses historical ice charts, results will provide an indication of the reliability of historical ice information for planning purposes using POLARIS, which are identified functions in the imagined-FRAM model (section 3.3), D. Smith et al. work [7], and as-done FRAM model (section 4.2). Furthermore, comparing the lowest RIOs (higher ice damage risks) with historical ice-related incidents/accidents data (section 4.1) in the same region in the period of the study shows if navigation in lower RIO can be correlated to reportable (considerable) incidents.

4. Results

4.1. Occurrence analysis

Maritime occurrences between 2009 and 2022 reported by the Transport Safety Board (TSB) of Canada were reviewed for ice-related incidents/accidents. After cleaning up and sorting data, 244 occurrences were identified as directly or potentially sea ice related. Summaries of all 244 occurrences were reviewed, and the following categories were identified:

- Ice damage to the hull,
- Besetting and drifting (directly resulting from sea ice),
- Underwater appendages failure/damage (skeg, propeller, and steering),
- Sea water Suction malfunction (due to ice/icing),
- Main engine and transmission failure/malfunction,
- Collision to icebreaker or another vessel in a convoy,
- Aground/allision/collision/close quarter situations in icy waters without mentioning ice in the summary,
- Others (consists of 19 different occurrences that do not fit with the above categories).

In the above occurrences, those with a direct role of ice (mentioned in their summary) in hull damage (40 Occ.) and besetting/drifting (33 Occ.) were short-listed which can be found in Appendix I. The statistics of these two categories are presented in the form of graphs. Figure 10 to Figure 12 show the number of occurrence reports of sea ice damages to ship hulls for different ship types (Figure 10), time of the year (Figure 11), in different shipping areas (Figure 12). Figure 14 to Figure 16 show the number of occurrence reports of drifting and/or besetting occurrences due to sea ice pressure for different ship types (Figure 14), time of the year (Figure 15), in different shipping areas (Figure 16).

OpenWebGIS (http://opengis2.ddns.net/gis/opengis_eng.html) was used to show locations of occurrences on map. Figure 13 demonstrated the locations of ice damages to ship hull occurrences and Figure 17 shows sea ice-related occurrences of drifting and/or besetting occurrences.

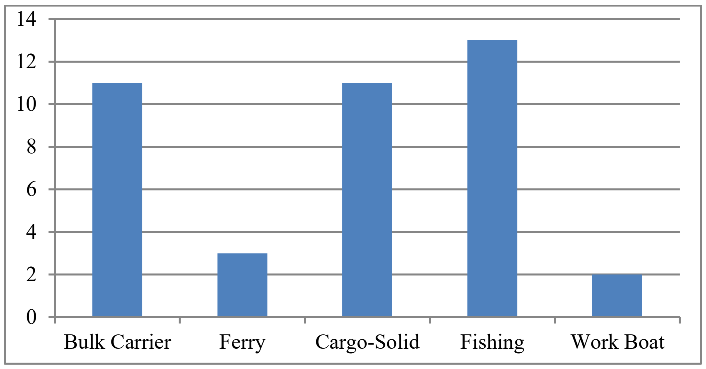


Figure 10 Number of reported ice damages to hull occurrences for different ship types - TSB reports in Canadian waters, 2009 to 2022

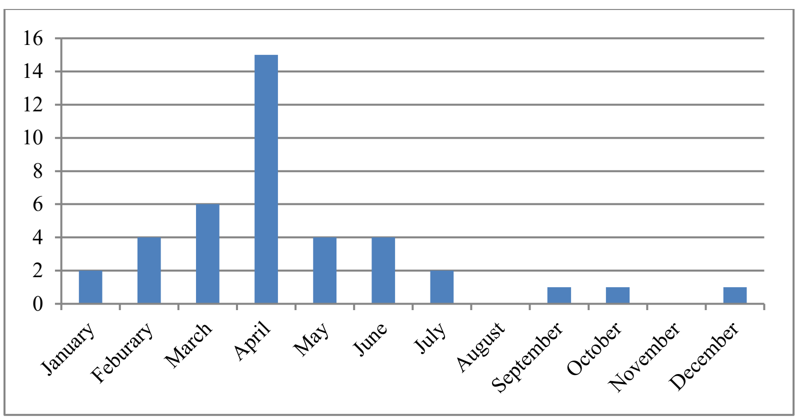


Figure 11 Number of reported ice damage to hull occurrences in different months - TSB reports in Canadian waters, 2009 to 2022

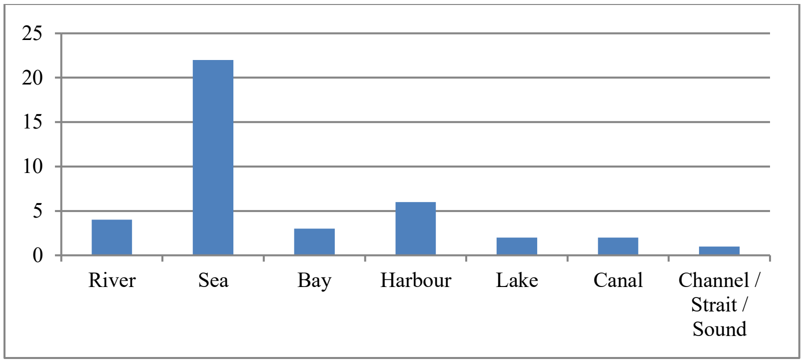


Figure 12 Number of reported ice damage to hull occurrences in different shipping areas - TSB reports in Canadian waters, 2009 to 2022

Figure 13 Locations of reported ice damage to hull occurrences - TSB reports in Canadian waters, 2009 to 2022

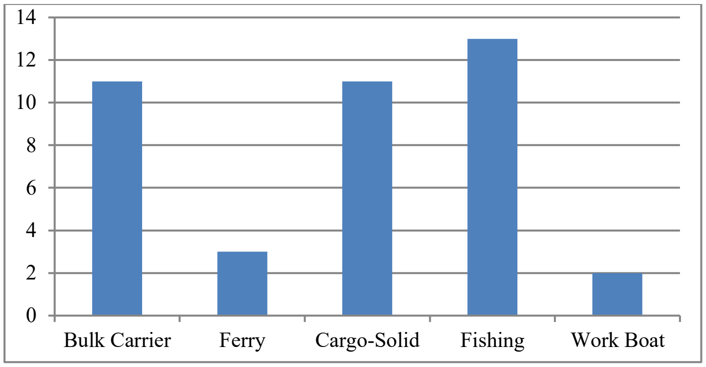


Figure 14 Number of sea reported ice-related besetting/drifting occurrences for different ship types - TSB reports in Canadian waters, 2009 to 2022

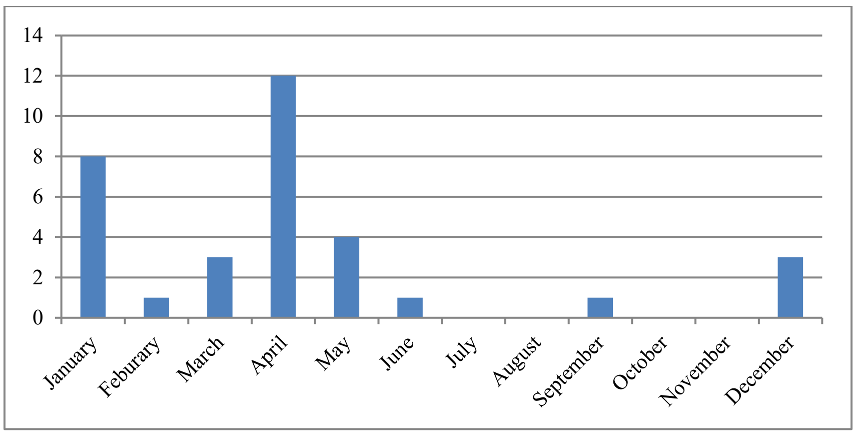


Figure 15 Number of reported sea ice-related besetting/drifting occurrences in different months - TSB reports in Canadian waters, 2009 to 2022

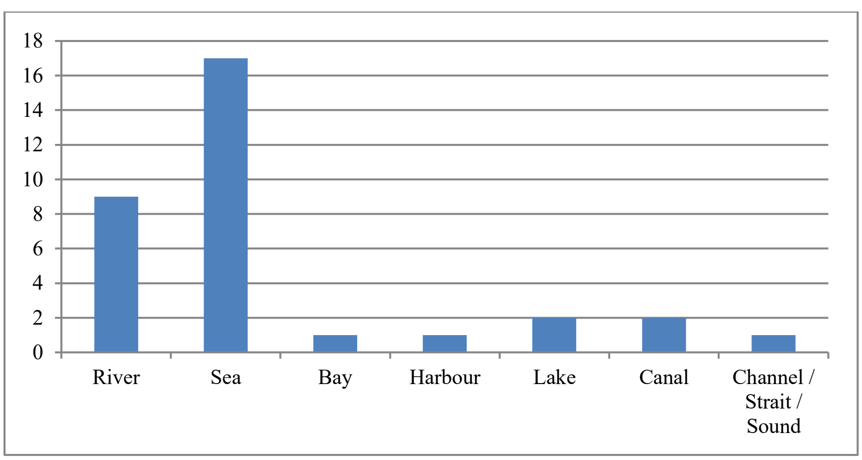


Figure 16 Number of reported sea ice-related besetting/drifting occurrences in different shipping areas - TSB reports in Canadian waters, 2009 to 2022

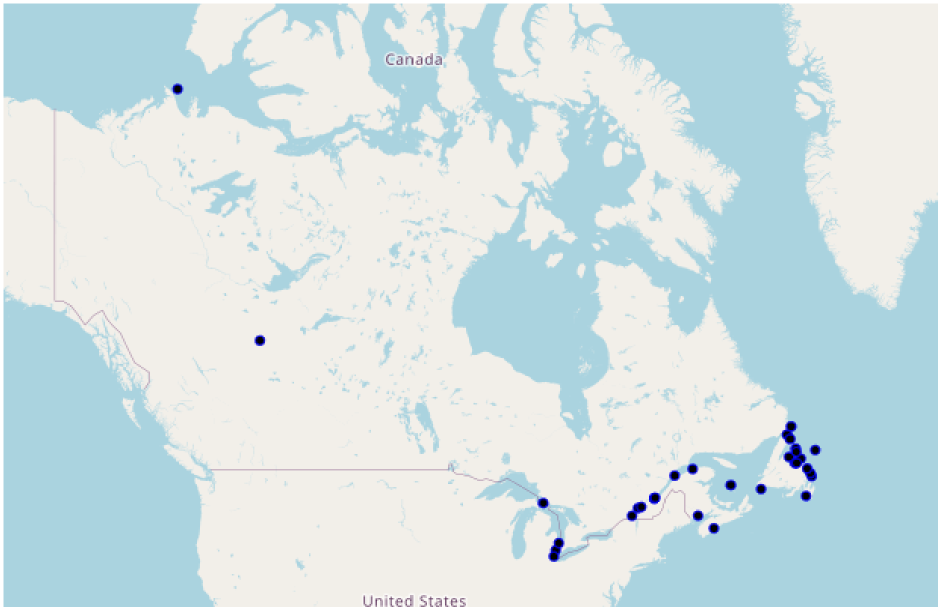


Figure 17 Locations of reported sea ice-related besetting/drifting occurrences - TSB reports in Canadian waters, 2009 to 2022

From the above data, the following information can be drawn:

- Most occurrences happened in April. Although the exact time of sea ice concentration reduction is not fixed and varies in different areas, April can be considered shoulder season for most occurrences in their relative area. This result supported the idea of exercising GIS analysis for the shoulder season.
- Most occurrences happened at sea. This result made the idea behind the limiting FRAM study to en route navigation. Although other scenarios are also worth studying, including them in the current study was impractical. Furthermore, there may be fundamental differences between them that require separate studies.
- Most occurrences happened in the areas where the presence of multi-year ice is unlikely. It shows that ice-related hazards are not necessarily limited to heavy ice conditions. Low-ice class ships need to maintain safe operations in lighter-ice conditions, as they are not

supposed to sail in highly concentrated multi-year ice. This data supported the idea of GIS analysis in the Hudson Bay area, where multi-year ice is unlikely.

- Most occurrences happened outside of the Northern Canada vessel traffic service zone (NORDREG Zone). Figure 18 shows the extent of the NORDREG Zone. The Canadian government has imposed more restricting regulations and procedures in this area. Higher latitudes are associated with harsher environments, which increases shipping costs and reduces navigation interest. Either lower traffic or more restrictive regulations can reduce the number of ice-related incidents in the NORDREG Zone; however, it can only be concluded firmly with more detailed investigations. This outcome implies the possibility of the effects of regional regulations on decision-making in icy waters (which is related to secondary research question 2).
- It is noticeable that most occurrences happened to cargo ships. It is not possible to draw any conclusion regarding ship type-related factors to the possibility of incidents; however, it boldened the idea that maybe mission and organizational aspects (which may be different in different sectors) can have some influence on navigators' decision-making (which is related to secondary research question 2).
- No ice-related occurrences are reported for the July months between 2013 and 2022 (the time scope of the historical POLARIS analysis-Also see section 4.3)

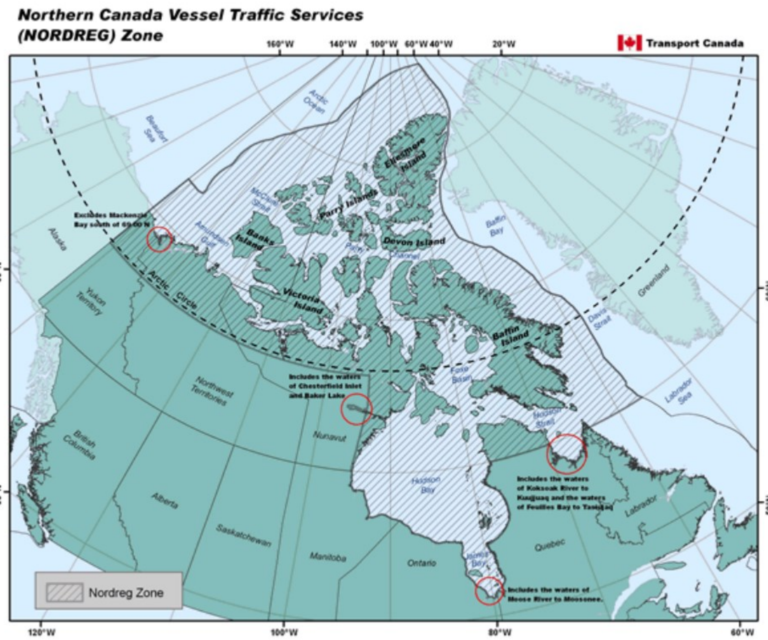


Figure 18 Northern Canada Vessel Traffic Service Zone [10]

Possible causes of occurrences can be investigated in more detail when other factors like overall shipping activity data are considered (also see section 6.6), which was outside of the scope of this study. The primary reason for occurrence review through a Safety-I approach in this research was to have a general idea of possible undesirable scenarios to discuss in the Safety-II part of the study.

4.2. FRAM

Among six volunteers, two did not have access to a reliable and reasonable internet connection. Four of the participants were interviewed. Table 6 shows the experience and background of them.

Table 6 Participants' experience

Participant	Experience as a captain	Experience as an ice navigator	Ice breaker experience	Training for navigation in ice	Current Job	Last time onboard
No. 1	25+ years	5 to 10 years	Yes	Yes	Retired/Consultant	2021
No. 2	1 to 5 years	1 to 5 years	Yes	Yes	Marine instructor	2019
No. 3	20-25 years	0	Yes	Yes	Consultant for route planning	2016
No. 4	10 to 15 years	5 to 10 years	No	Yes	Ice navigator and captain	Working at the time of the interview

After analyzing approved transcripts, the FRAM model shown in Figure 19 was created. Blue functions are new identified functions, and white functions are D. Smith et al. work [7]. Although the D. Smith et al. model [7] can, to some extent, be used for both strategic and tactical shipping activities, it was found that it is more suitable for tactical navigation. Some activities describing initial and strategic route planning, learning ship capabilities and organizational aspects of the navigation can be better determined by expanding some background functions in their model.

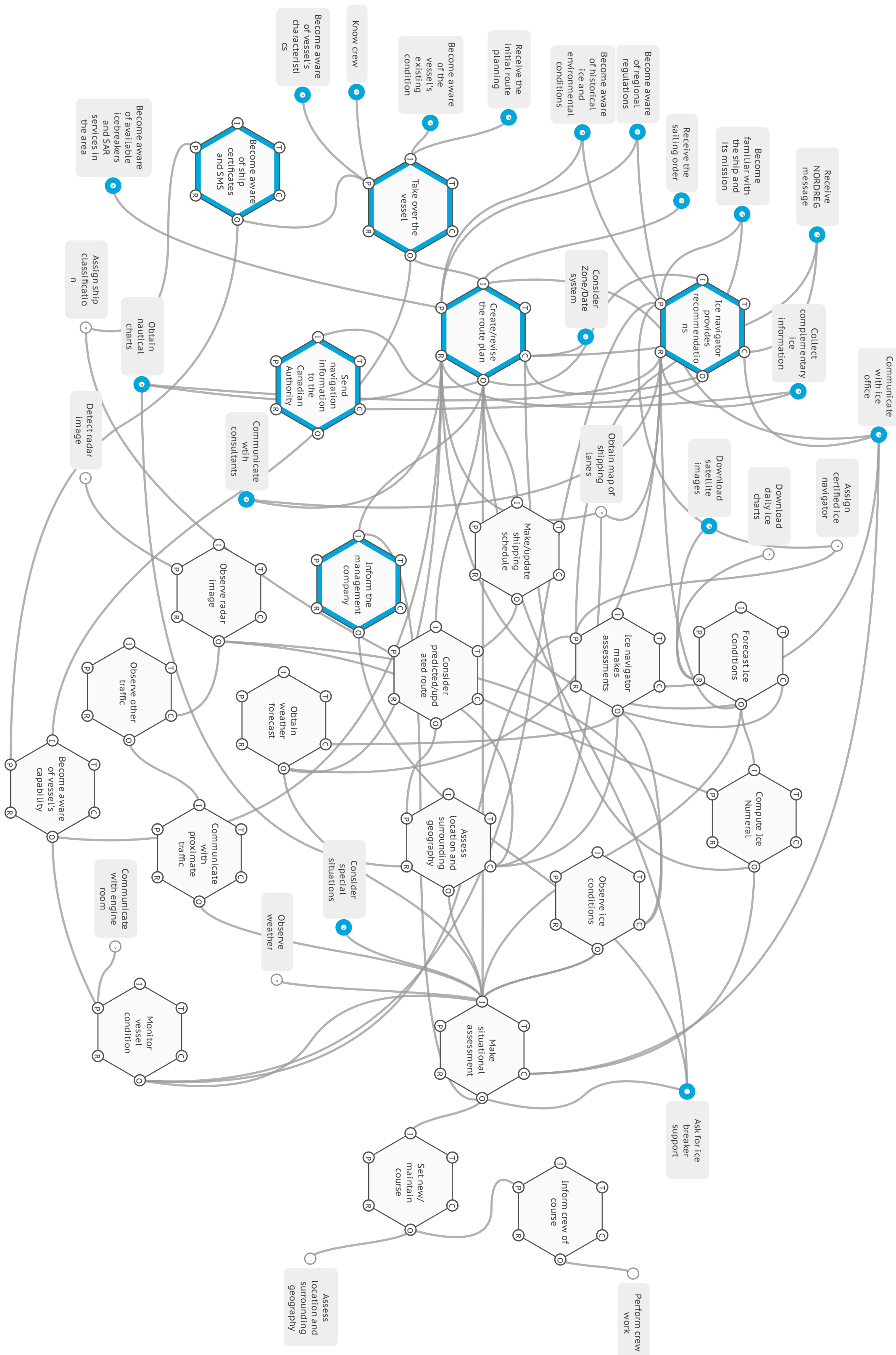


Figure 19 As-done icy water navigation FRAM model

New identified functions with their aspects from the interviews and new information on some functions from the D. Smith et al. [7] FRAM model are presented in the Table 7. Also, a discussion of possible variability raised during interviews is provided below each function. Additional information for functions from the D. Smith et al. [7] model collected during interviews are reflected in their description and variability discussions in *Italic* font. Functions from the D. Smith et al. work are marked with an asterisk (*). In all cases, variability discussion is only based on the study findings. Full details and variability discussions are provided by D. Smith et al. work [7]. Unidentified or insignificant aspects are called "Unidentified" in this report. These aspects may be described/identified in future investigations if new information is found. These aspects are removed from the tables in this chapter to keep the results concise, but a full table of the model can be found in the Appendix IV.

Table 7 As-Done FRAM model of navigation in Canadian icy waters

Note: Un-identified aspects are removed from this table; a full table of the model can be found in the Appendix IV.

Function Name	**Receive the sailing order**
Description	Captain receives a sailing order from the ship management company which provides general information about the vessel, mission, and itinerary.
Output	Sailing order received
Variability Discussion	The level of details may very between different companies and operations. This initial generic plan may be generated a year or six months or, in some cases, even much earlier in advance. It involves many factors and depends on the company's goals and procedures. The ship captain may be involved in developing it.
Function Name	**Become aware of regional regulations**
Description	Ship captain and ice navigator review regional regulations and consider them in their planning and operation.
Output	Aware of regulations
Variability Discussion	Regulations and official publications are available to captains, bridge teams, and ice navigators through the Canadian government's official website, onboard library, and safety management system. The ship management company provides updates according to their procedures. The frequency and depth of review depend on individuals' approach. They may refer to their memory and past information or experience. Ship management policies and procedures may regulate how and when updated regulations will be received by captains and ice navigators.
Function Name	**Become aware of historical ice and environmental conditions**
Description	Captain and ice navigator look at historical ice and weather conditions in the area to see the trend.
Output	Aware of historical data
Variability Discussion	There are enough sources available in Canada, including the Canada ice service website. The level of including them depends on the bridge team. This information should be used cautiously. Historical information may not be beneficial for short-term strategic planning due to drastic changes in weather and ice conditions. When getting closer to the sailing date, the bridge team and ice navigators look at and track the current ice and weather conditions rather than relying on historical information.
Function Name	**Receive the initial route planning**
Description	In some case when captains join the ship, there is a route planning already made. Captains receive this plan as part of take over procedure and consider it in their planning.

Output	A route plan is already prepared
Variability Discussion	
Function Name	**Become aware of the vessel's existing condition**
Description	Captain receives information about vessel's existing conditions through official reports and changeover processes and unofficial discussion and liaison with their colleagues onboard and in the shipping company.
Output	Vessel condition is communicated
Variability Discussion	There is an official procedure and checklists/forms to follow during the handover process for this purpose. They may include ship conditions, defects and deficiencies, available provisions, and stores. The actual condition of the ship may be different from what is communicated in the takeover process due to a lack of sufficient reporting and human perception, but it is not usually a major issue. In addition to official takeover procedures, the captain may walk around the ship and receive unofficial information about the vessel's operational condition from their predecessor. Ship navigators may keep some unofficial notes in addition or attached to their official documents for future reference. This information may be useful in audits and for changeovers. They may also liaise with the superintendents or department heads onshore. Some specifics that do not fit within official documents may be good information for navigators. Additionally, the visual condition of the vessel gives an impression of its structural strength and machinery condition. Captains may check some systems to verify their performance, especially after a maintenance period.
Function Name	**Know crew**
Description	Captain becomes familiar with their crew by reviewing their certificates and competencies available onboard or received from the company as well as communicating with them directly. Captain makes sure they are experienced enough.
Output	Become familiar with crew
Variability Discussion	Captains and officers may consider the competency and experience of the crew in their decision-making. They may ask the company to provide more experienced personnel if the voyage is challenging. They may assess crews' performance through discussion and/or based on their behavior. Captains consider the level of experience and competency of the crew in the planning and regulate their supervision accordingly to ensure the safe execution of the voyage plan and watchkeeping.
Function Name	**Receive NORDREG message**
Description	Ships receive a feedback or message from NORDREG including clearance into northern Canadian waters or other feedback regarding their location and routing plan
Output	NORDREG message received
Variability Discussion	Routing and regular messages the vessel sends to NORDREG is processed and feedback is sent to the vessel. The quality and details of message may regulate the route planning and decision-making during the navigation. The process and decision-making in NORDREG and Canadian authority may affect the message.
Function Name	**Become aware of vessel's characteristics**
Description	Navigators become aware of vessel's anecdotal performances.
Output	Aware of vessel characteristics
Variability Discussion	This anecdotal information may include the ship's dynamic stability and seakeeping, equipment performance, vessel and equipment responses to actions, or environment that are not necessarily a part of official documentation. The level of detail varies based on individuals' experience and approach. Navigators may have prior experience with the ship or similar ships they are taking over. Some characteristics can be found in the official documents of the vessel, but some information may not be included in the official documents as they are not required to be recorded by regulations. These characteristics may be communicated through discussion between the vessel's crew and bridge team.
Function Name	**Become aware of ship certificates and SMS**
Description	The navigators become familiar with safety management system (SMS) and certificates status during takeover process.
Output	Vessel Documents and records
Precondition	Ship classification assigned
Variability Discussion	Many fundamentals of safety management systems in shipping companies are similar; however, details of procedures and ship particular considerations may vary. Being familiar with SMS is particularly important when the navigator has little experience in the intended operation. The ship maintenance plan and procedures are also important to schedule voyages and tasks onboard. There may be a gap between the vessel's documented procedures and actual operations due to the impracticality of implementing official procedures or lack of attention.
Function Name	**Become aware of available icebreakers and SAR services in the area**
Description	Ship captains consider availability of icebreaking and search and rescue (SAR) services, ports of refuge or repair services in the area for possible contingencies.
Output	Aware of icebreakers and SAR

Variability Discussion	This is a part of contingency planning. It is important that icebreaker may not be available, so flexibility of the plan is an important factor. Support availability depends of the government and commercial supply in the area. Companies may provide commercial services for their fleet in their interest areas. In this case financial aspect of may be important.
Function Name	**Take over the vessel**
Description	The ship navigators receive information about the vessel and operation conditions when they join the ship. It includes but is not limited to operating conditions of systems, maintenance status, and safety management system. They may do unofficial communications, tests, and examinations to verify the reported condition.
Input	A route plan is already prepared Vessel condition is communicated
Output	Changeover process is completed
Precondition	Vessel Documents and records Become familiar with crew Aware of vessel characteristics
Variability Discussion	This function collects all inputs from different sources. It is important to note that this is a human team function. The whole or part of the bridge team and other crew may change during this procedure, and the level of communication, cooperation, experience, and enthusiasm regulates the extent and efficiency of the process.
Function Name	**Become familiar with the ship and its mission**
Description	Ice navigators get familiar with the vessel and its capabilities, management system, crew and operation.
Output	Familiar with the vessel and operation
Variability Discussion	General information about the ship and operation is communicated through the company, but most detailed information will be received onboard from the bridge team. The management company may have a procedure for briefing the bridge team and ice navigator and communicating information. The primary required information is ship ice class, power, maneuverability, and crew experience in icy waters. The level of detail and cooperation may vary depending on the bridge culture and individuals' approach.
Function Name	**Collect complementary ice information**
Description	Ice navigator and captains may collect information from different unofficial sources.
Output	Complementary information is collected
Variability Discussion	Ice navigators may collect information about the area, especially recent ice conditions, by communicating with their colleagues navigating in the area. They may look at AIS data to see how other vessels may navigate in the area. They do not refer to this unofficial information in their official reports; still, they consider them cautiously to have a clearer picture of the actual environmental condition in the area.
Function Name	**Consider Zone/Date system**
Description	Navigators can refer to Zone/Date to plan to enter a zone in NORDREG.
Output	Zone/Date system is considered
Variability Discussion	The Zone/Date system is not the only tool to decide to enter an area in the NORDREG Zone. Navigators may avoid an area due to heavy ice conditions despite the Zone/Date system. The Zone/Date system is not the best tool to decide to enter an area due to constant changes in ice patterns and the effects of global warming.
Function Name	**Create/revise the route plan**
Description	A route plan is created or the existing route plan is revised based on updated information and situation.
Input	Sailing order received Route planning should change Changeover process is completed Ice office comments
Output	Route plan is made Icebreaker support is required Inform the management company
Precondition	Aware of regulations Aware of historical data Aware of icebreakers and SAR
Resource	Weather forecast obtained Have shipping lane maps Obtained forecasted ice conditions Consultancy services Complementary information are collected Nautical charts are obtained

	Aware of vessel′s typical capability
Control	Ice navigator review/recommendations Ice Numeral computed Zone/Date system is considered NORDREG message received
Variability Discussion	The bridge team updates the route plan. They should constantly consider revising the voyage plan because of the changing situation. It is more important in icy waters due to more variability in environmental conditions and ice-related situations.
Function Name	**Ice navigator provides recommendations**
Description	Ice navigators review the route plan prepared by the bridge team and give feedback. If they are present at the time of planning they may provide feedbacks directly.
Input	Route plan is made
Output	Ice navigator review/recommendations Ice navigator makes sure the message is sent
Precondition	Ice navigator has been assigned Familiar with the vessel and operation Aware of historical data Aware of regulations
Resource	Have shipping lane maps Obtain forecasted ice conditions Weather forecast obtained Complementary information is collected Consultancy services Nautical charts are obtained
Control	Ice office comments NORDREG message received
Variability Discussion	Ice navigator provides experience-based judgment to the bridge. In cases where the captain or other officers have the ice navigator qualifications, it is not required to have another ice navigator onboard. This reduces the opinion and experience available for decision-making. In some cases, the qualified crew has little icy water experience or navigation experience in the area, which causes a lack of experience in overall performance.
Function Name	**Send navigation information to the Canadian Authority**
Description	In NORDREG, Eastern Canada Vessel Traffic Control, and Vessel Traffic Control Zones, ships' captains should send report of their ship information and navigation condition, and voyage planning to MCTS.
Input	Route plan is made
Control	Ice navigator makes sure the message is sent
Variability Discussion	Vessel entitled to [63], SOR/89-99 [64] and SOR/89-98 [65] should send the required information according to the respective regulations. The reporting requirements are different based on the situation and area. The Canadian authority may require additional information. The bridge team should also send their position reports to the regional operation center at least once a day. They also send their deviation report when they decide to change the voyage plan. Ice navigators review these reports and make sure of proper reporting to the authority. The authority provides the ship with feedback. The quality of observation and reporting affects the Canadian authority's feedback.
Function Name	**Obtain nautical charts**
Description	Bridge team obtains nautical charts and publications of the navigation area.
Output	Nautical charts are obtained
Variability Discussion	Canadian Hydrographic Service (CHS) provides nautical charts and publications for Canadian waters. Nautical charts are a major source for planning and operation. Bridge team should use updated version of them onboard. Availability of updated version of nautical charts and publications should be insured through safety management system. The quality and accuracy of nautical charts may vary in different areas, especially in remote areas.
Function Name	**Communicate with consultants**
Description	Bridge team and ice navigators consult with consultants onshore.
Output	Consultancy services
Variability Discussion	Some companies provide consultancy services for their ships either directly in their organizations or through commercial firms. Captains and ice navigators can be directly in contact with them and communicate their information and recommendations. They may also provide complementary environmental and sea ice information. The availability and efficacy of this consultation service depend on the shipping company's approach. Communication with onshore entities in remote areas may be challenging due to a lack of communication signals.
Function Name	**Communicate with ice office**

Description	Navigators have a communication with ice offices and are in consultation with them. They may consider their recommendations in their operation and route planning.
Output	Ice office comments
Variability Discussion	This communication is not essentially in the form of official correspondence. The Canadian Coast Guard provides ice offices in different months of the year, subject to ice conditions in different areas in Canadian waters. Ship and ice navigators may call or send an email to the respective ice offices and ask questions or request assistance. The availability and experience of the expert affect the process.
Function Name	**Inform the management company**
Description	The captain informs the shipping company about different situations, including but not limited to updated routing plans and schedules, available provisions, and operational conditions. They may ask the shipping company to arrange icebreaker support on their behalf.
Input	Inform the management company
Output	Icebreaker support is required
Variability Discussion	Management company policies, procedures, and working culture may affect ship operations. The company may push the bridge team to save fuel, voyage time, and other economic aspects of the operation.
Function Name	**Download satellite images**
Description	Bridge team downloads satellite images for the navigation area and compares them to other ice data.
Output	Satellite images are obtained
Variability Discussion	Satellite imagery like Moderate Resolution Imaging Spectroradiometer (MODIS) provides a picture of the area, but it only shows the presence of ice and, to some extent, ice concentration. However, the weather condition (cloud and fog) affects the images and, in some cases, make them unusable. Different ice data are released at different times of day. The bridge team may compare them to compensate for their temporal resolution and have a clearer understanding of the ice conditions in the area. There is more sophisticated imagery produced by radar/sensor detections. Some of this data can be found in the U.S. National Oceanic and Atmospheric Administration. The level of associating this complementary information depends on the individual's approach and SMS provisions, which are established by the ship management company.
Function Name	**Make*/update* shipping schedule***
Description	Expected departure and arrival times are determined.
Input	*Route plan is made*
Output	Shipping schedule made
Variability Discussion	*The captain may change the departure time and shipping schedule based on the vessel's actual condition and the updated plan.*
Function Name	**Consider predicted/updated route***
Description	Consider the current route you are transiting. This may be suggested by operational planners or adjusted by the navigator.
Input	*Route plan is made*
Output	Aware of the present route
Time	Shipping schedule made
Variability Discussion	
Function Name	**Become aware of vessel's capability***
Description	The navigator becomes aware of the vessel's capabilities. The navigational, structural and operational capabilities.
Input	*Changeover process is completed*
Output	Aware of vessel's typical capability
Precondition	*Vessel Documents and records*
Variability Discussion	*In icy water navigations, vessels' ice strengthening and maneuverability are important for navigators.* *Additionally, navigators may consider the ship's age as a parameter in capabilities. Depending on the ship type, assigned class, operational requirements, and visual condition of the vessel, navigators may or may not feel comfortable touching ice.*
Function Name	**Communicate with engine room***
Description	There is communication between the engine room and the bridge to discuss any issues or needed maintenance.
Output	Engine room maintenance/issues informed
Variability Discussion	*Dual fuel ships are required to change fuel type to achieve their best machinery responses when required. Availability of all maneuvering machinery is another important factor the bridge team should be aware of in icy waters. The effective and timely communication between the engine room and bridge regulates the availability of machinery and use of them in tactical navigation.*
Function Name	**Monitor vessel condition***
Description	The vessel's condition is monitored to understand the vessel's current capabilities.

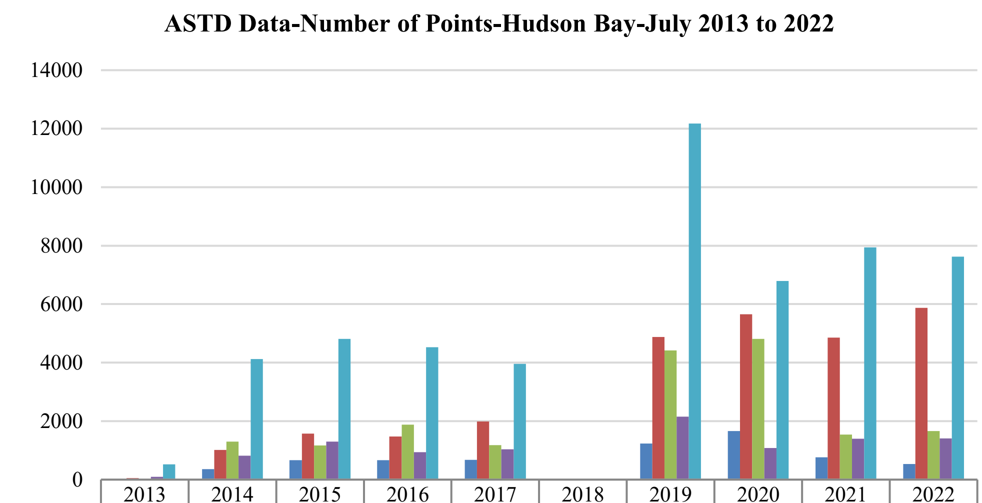
Output	Aware of apparent vessel condition
Precondition	Engine room maintenance/issues informed Aware of vessel's typical capability
Variability Discussion	*The range of monitor covers sensors, monitoring systems, routine and checklist-based maintenance, and regular visual observations. Some of them are established in SMS, but the level of execution may vary from person to person. Maintenance and inspections can be different in different cases as technological systems are different for different vessels.* *Also, the ship crew may change their monitoring approach in different operational conditions. For example, the captain may consider extra tank soundings if the vessel operates in icy waters. Also, navigators may make some guesses based on their feeling and intuitive understanding of the vessel's behavior and may take action to check the condition.* *When operating on ice, navigators monitor speed to avoid hull damage and make sure about the sea suction and hull appendage conditions relative to the draft.*
Function Name	**Ice navigator makes assessments***
Description	Ice navigator makes assessments of the conditions and upcoming tasks and shares experience with ships bridge team.
Output	Experienced visual assessment of ice Experience based ice forecast Improved knowledge of regional specific conditions Experienced based weather judgment
Precondition	Ice navigator has been assigned *Aware of apparent vessel condition* *Familiar with the vessel and operation*
Control	*Ice office comments*
Variability Discussion	
Function Name	**Forecast Ice Conditions***
Description	Obtain the forecasted ice conditions. This may be done by historical trends in area and/or tactical ice drift models
Output	Obtain forecasted ice conditions Daily ice chart observed
Resource	Ice charts downloaded *Satellite images are obtained*
Control	Experience based ice forecast
Variability Discussion	
Function Name	**Assess location and surrounding geography***
Description	Locate the vessel with respect to intended route, shipping lanes and regional geographic features.
Output	Geographical assessment made
Precondition	Aware of the present route
Resource	*Nautical charts are obtained*
Control	Have shipping lane maps Improved knowledge of regional specific conditions
Variability Discussion	
Function Name	**Observe ice conditions***
Description	Observe the current ice conditions. This can be done from the bridge or on deck, but also the conditions ahead can be observed via helicopter or aircraft.
Output	Ice conditions have been visually observed onboard Up route ice conditions assess with helicopter
Control	Experienced visual assessment of ice Radar image observed
Variability Discussion	*Ice observation may be done through communication with shore supports like lighthouses.* *Ice movement and pressure due to sea currents, geographical conditions, and tidal currents are also important factors navigators monitor during the operation.*
Function Name	**Observe weather***
Description	The current local (ship) weather conditions are observed. This can be from the bridge or on deck.
Output	Weather has been observed
Variability Discussion	*Air temperature is an important parameter that should be monitored. It may be required to preheat the engine room air and make sure of the correct condition of exposed systems like firefighting systems.* *Reduced visibility is another important environmental factor that affects decisions. Fog in the Arctic can appear suddenly. Navigators may reduce speed due to lack of visibility.*
Function Name	**Consider special situations**
Description	Some special conditions like medical emergencies, serious safety issues and problems in vessel operability may require special considerations that may cease or require deviation in the operation.

Output	Special situation happened
Variability Discussion	
Function Name	**Make situational assessment***
Description	The captain and bridge team make a situational assessment based on the available information at a given time.
Input	Weather forecast obtained Up route ice conditions assess with helicopter Obtained forecast ice conditions Geographical assessment made Weather has been observed Aware of apparent vessel condition Ice condition have been visually observed onboard Proximate traffic communicated with *Special situation happened*
Output	Complete or partial assessment made *Icebreaker support is required* *Route planning should change* *Inform the management company*
Control	Ice numeral computed *Ice office comments*
Variability Discussion	
Function Name	**Ask for ice breaker support**
Description	Commercial vessels may ask for icebreaker support directly or through their agents or company (owner). Ships can request via coastal radio station, and the owner or agent can call the ice operation center.
Input	Icebreaker support is required
Variability Discussion	
Function Name	**Set new/ maintain course***
Description	A decision is made to either maintain the current course or to make adjustments to course. *Navigators may decide to maintain or change speed.*
Input	Complete or partial assessment made
Output	Routing decision made
Variability Discussion	

Variability assessment of most functions is limited without a detailed investigation on different possible situations. This requires a separate study on government provided supports and their possible variability and a study on different ship management companies considering their policies and procedures. Also see discussions (Section 6) and future works (Sections 6.6)

4.3. Historical POLARIS analysis

Ship positions (from PAME-ASTD) in Hudson Bay were overlaid on weekly ice charts (from Canadian Ice Service) and POLARIS RIO was calculated for each Finnish-Swedish ice class. ASTD data for July 2018 did not include the ships ice class, so it was removed from the analysis. July 2018 statistics in Figure 20 to Figure 22 are zero due to the unavailability of data. Figure 20 shows the number of ship position points in ASTD data for each ship type.



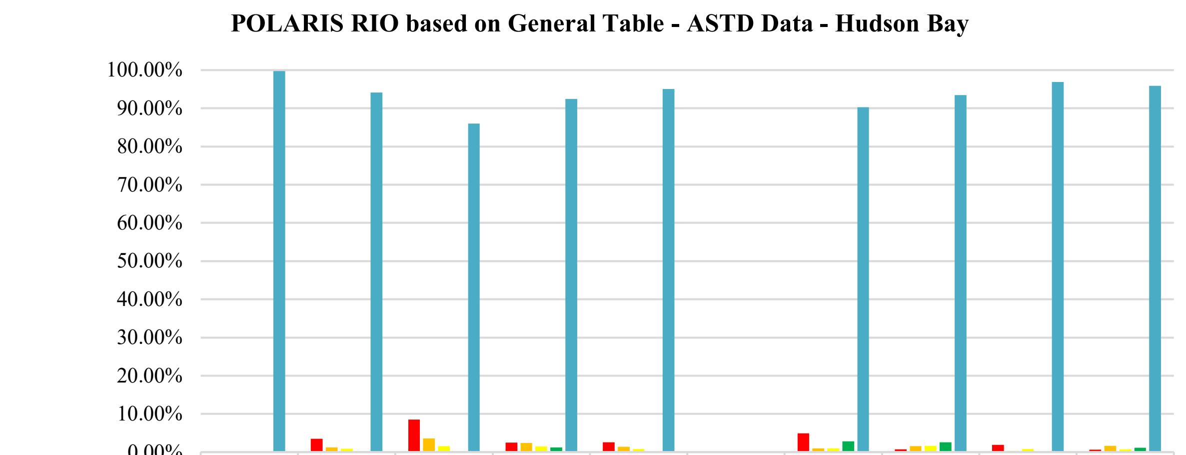
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
IAS	5	358	666	670	679	0	1237	1657	768	532
IA	51	1015	1578	1479	1991	0	4882	5655	4851	5873
IB	0	1300	1167	1880	1184	0	4423	4809	1535	1665
IC	95	816	1296	938	1032	0	2153	1076	1403	1409
NI	527	4124	4809	4527	3962	0	12177	6796	7940	7622

IAS= Finnish-Swedish Ice Class IA Super IA= Finnish-Swedish Ice Class IA IB= Finnish-Swedish Ice Class IB IC= Finnish-Swedish Ice Class IC NI=Non-Ice-Class ship

Figure 20 Number of ship position points in ASTD data for each ship type

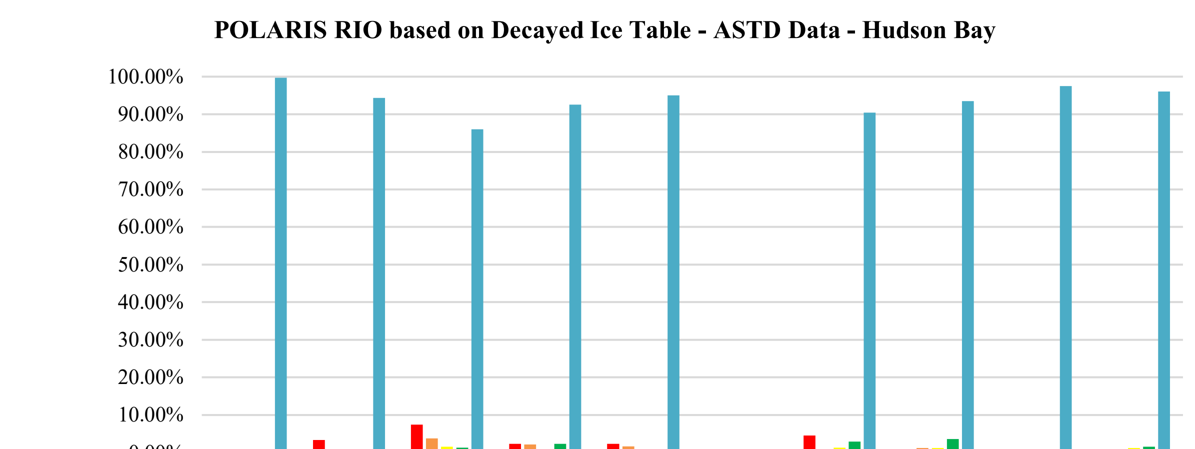
Decayed ice conditions are not reported in the weekly ice charts; on the other hand, it cannot be claimed only because sea ice is going to decrease in the area in July, so, it was decided to calculate POLARIS RIO based on both general and decaying ice.

POLARIS RIOs based on general and decayed ice RIV tables were calculated for each reported point and results are presented in the Table 8 and Table 9 and Figure 21 and Figure 22.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
-20<=RIO	0.15%	3.49%	8.51%	2.46%	2.61%	0.00%	4.88%	0.74%	1.92%	0.67%
-20<RIO<=-10	0.15%	1.22%	3.60%	2.42%	1.44%	0.00%	0.99%	1.58%	0.32%	1.64%
-10<RIO<=0	0.00%	0.88%	1.58%	1.44%	0.79%	0.00%	1.02%	1.65%	0.79%	0.70%
0<RIO<=10	0.00%	0.24%	0.26%	1.20%	0.12%	0.00%	2.79%	2.60%	0.06%	1.12%
RIO>10	99.71%	94.17%	86.04%	92.47%	95.04%	0.00%	90.32%	93.44%	96.91%	95.87%

Figure 21 POLARIS RIO based on general RIV table for different ice-class ships



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
-20<=RIO	0.15%	3.36%	7.41%	2.32%	2.32%	0.00%	4.54%	0.54%	0.90%	0.53%
-20<RIO<=-10	0.00%	0.87%	3.74%	2.12%	1.59%	0.00%	0.86%	1.20%	0.63%	0.65%
-10<RIO<=0	0.15%	0.70%	1.54%	0.62%	0.57%	0.00%	1.33%	1.19%	0.53%	1.21%
0<RIO<=10	0.00%	0.74%	1.26%	2.35%	0.49%	0.00%	2.87%	3.59%	0.45%	1.58%
RIO>10	99.71%	94.34%	86.04%	92.60%	95.04%	0.00%	90.40%	93.48%	97.48%	96.02%

Figure 22 POLARIS RIO based on decayed ice RIV table for different ice-class ships

Table 8 Distribution of POLARIS RIOs based on general RIV table for different ship ice classes

	-20<=RIO	-20<RIO<=-10	-10<RIO<=0	0<RIO<=10	RIO>10
IAS	37	0	155	34	6346
IA	252	254	652	178	26039
IB	30	5	169	33	17726
IC	31	101	57	169	9860
NI	2984	1329	225	1168	46778

Table 9 Distribution of POLARIS RIOs based on decayed ice RIV table for different ship ice classes

	-20<=RIO	-20<RIO<=-10	-10<RIO<=0	0<RIO<=10	RIO>10
IAS	0	0	38	159	6375
IA	57	245	361	673	26039
IB	6	26	171	10	17750
IC	10	28	94	226	9860
NI	2774	1125	501	1143	45222

According to the POLARIS, ships should avoid areas where their RIOs are less than zero for the planning purposes. Planning for following an icebreaker may add ten credits to the calculated RIOs and increase their risk index to higher than zero, but there still is a considerable number of reported points considered to be in undesired ice conditions based on POLARIS recommendations. Regardless of whether ice is decayed or not, there are a considerable number of points that are reported in relatively heavy ice conditions in the area. It is noteworthy that no ice-related hull damage or drift/besetting in ice was reported in the area within the interest period of this study in the occurrence analysis (section 4.1). This highlights the fact that POLARIS alone is not a enough to judge whether ships may have safe navigation in certain areas or not. These results are aligned with interviewees statements about the importance of experience and some other ship capabilities and specifications that are not directly addressed in POLARIS like maneuverability and power. Interviewees in the FRAM part of the study considered risk assessment tools (POLARIS and AIRSS) more useful tools for strategic planning in experienced hands, however, they do not rely on them in the field for tactical navigation in close range ice fields.

The ship position patterns on the ice charts shows that despite the possibility of encountering heavy ice based on the weekly ice charts, ships followed roughly the same routes in a week. Figure 23 shows an example of Hudson Bay area RIOs for non-ice-class ships for four weeks of July 2015. Black dots on the maps show the ships reported positions in the correlated week. It is apparent that non-ice-class ships' presence was increased with decreasing relative risk in the area based on POLARIS RIOs, yet a considerable number of ships navigated in areas where ice conditions were higher than what POLARIS recommended for them.

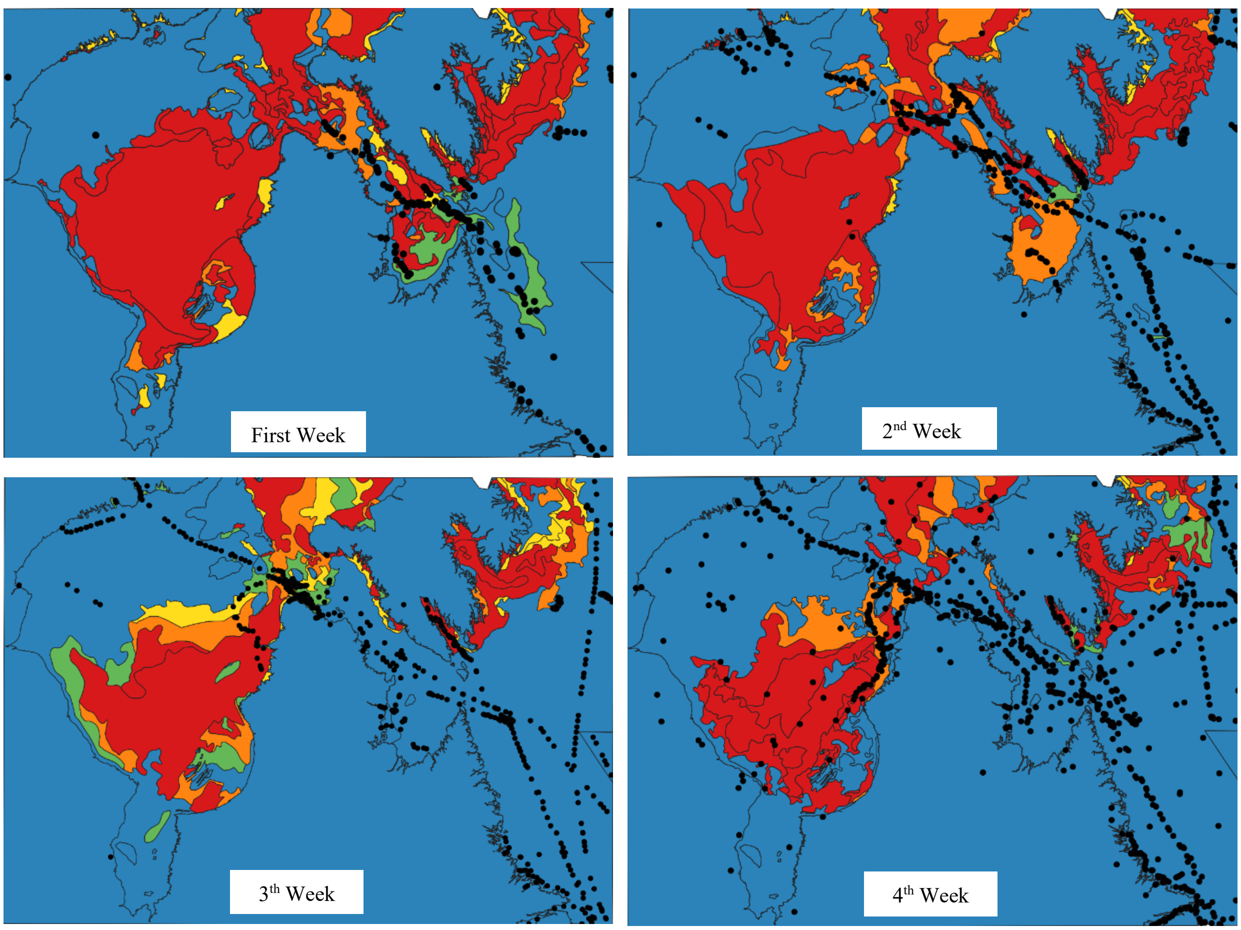


Figure 23 RIO in Hudson Bay July 2015 for non-ice-class ship

It should be noted that ice charts do not have enough temporal and geographical resolution to conclude with confidence that all these ships with calculated RIOs lower than zero certainly were in undesired ice conditions, but it can be concluded that it is likely that some ships navigated within areas in which they could encounter ice conditions higher than POLARIS recommendations. These conditions are recommended to be avoided in the planning phase, however, as noted by interviewees, the inaccuracy and low resolution of ice charts leads to situations where ships have to navigate in such areas.

The low temporal and geographical resolution of historical ice charts is also aligned with interviewees statements. The function "become aware of historical ice and environmental conditions" is a precondition for strategic route planning (see Figure 19). As highlighted in the variability discussion of the function in Table 7, navigators should use this information cautiously considering the possible drastic changes in ice conditions. As a result, the bridge team and ice navigator track the current ice condition given the known variability in historical ice charts.

4.4. Results Summary

Occurrence analysis showed that the most drifting and besetting and hull damage incidents due to sea ice between 2009 and 2022 in Canadian waters happened:

- at sea
- in southern parts of Canadian waters (out of NORDREG Zone), which low or non-ice-class ships may navigate in.
- in the first-year ice, which is a safety hazard for low-ice-class ships
- in shoulder seasons, which low or non-ice-class ships may experience
- for cargo ships

FRAM analysis provided a model for navigation in Canadian icy waters based on experts' knowledge. The model shows that:

- navigators use official sources like certificates and documents to understand officially reported ship capabilities. Navigators may rely on their knowledge and experience and unofficial discussions and casual notes to understand ship capabilities and characteristics. (“become aware of the vessel’s existing condition”, “become aware of ship certificates and SMS”, “become aware of vessel’s characteristics” and “take over the vessel” for ship bridge team and “become familiar with the ship and its mission” for ice navigators)
- navigators compensate for the lack of accuracy and resolution in environmental data and unpredicted changes in the environmental conditions in strategic planning by using different sources of information (resource aspects of the functions “ice navigator provides recommendation” and “create/revise the route plan”) and by experience-based and collective decision-making (through “ice navigator provides recommendations”, “communicate with ice office”, “communicate with consultants”).
- ship management companies have a considerable effect on navigation, especially strategic planning through preparing ships, providing and handling information (“become aware of ship certificate and SMS”), initial planning (“receive sailing order”) and supporting operations (“inform the management company” and “communicate with consultants).
- Canadian government affects ship operations by providing environmental and navigational information (“download daily ice charts”, “obtain map of shipping lanes”, obtain nautical charts”, become aware of historical ice and environmental conditions”, “obtain weather forecast”), regional regulations (Ice navigator requirements, “consider zone/date system”, “compute ice numeral”, and “send navigation information for the Canadian Authority”), and decision-making (“receive NORDREG message”, “communicate with ice office” and operational supports (“become aware of available icebreakers and SAR services in the area” and “ask for icebreaker support”).

Find functions in the parentheses above in Table 7.

Historical POLARIS analysis in Hudson Bay area based on weekly ice charts between 2013 and 2022 showed that:

- low and non-ice-class ships may have navigated in ice conditions that should have been avoided, at least at the planning level (Table 8 and Table 9).
- despite instances of low RIO, no ice-related ice damage to ships' hulls or drifting and besetting due to sea ice incidents were reported for the period of the study.

5. Research Answers

This section provides some answers to the research questions based on the results of the study. More discussion and details can be found in section 6. It should be noted that the safety of navigation in icy waters is unlimited to discuss and explore. Considering practicality, this study tried to investigate some aspects of it based on a systematic approach considering both classic (Safety-I) and proactive approaches (Safety-II).

RQ1: How ship navigators become informed of ship capabilities and assumed operating conditions?

There are different official and unofficial sources available and shown in the as-done FRAM model (section 4.2). Official sources are **certificates**, and **safety management documents**, and unofficial sources are **casual notes**, **peer discussions** and **liaisons**. Available data for ice navigator and captain may be different due to differences of their role and accessibility to the documents and resources, which may be determined in the ship safety management system to some extent. Navigators may have an understanding of ship characteristics and capabilities based on their experience and knowledge of ships in general and the specific ship they work on. Becoming aware of ship capabilities and conditions requires **teamwork**, which heavily depends on the **individual and team approach** and **experience**. The information transfer and its accuracy is influenced by the ship management system. Some capabilities like minimum temperature are determined clearly in certificates but some information, especially those that may change, like maneuverability and power in ice and structural strength for older ships can be vague. For non-ice-class ships, structural strength against sea ice is not determined. Hence, the importance of the functionality of the navigation system (including the ship itself, bridge team, and organizational supports) to avoid sea ice in the first place, and handle the vessel in icy waters is more prominent.

RQ2: How ship navigators consider ship capabilities and assumed operating conditions in their decision-making process in Canadian icy waters?

The as-done FRAM model (section 4.2) shows how navigators typically include ship capabilities and assumed operation conditions into their decision-making. Some capabilities and assumed operating conditions are not certain; navigators rely on their **experience** and **intuition** to include them in their decision-making. Aside from ship capabilities that are directly addressed in certificates, like **ship ice class**, navigators emphasize on the **power** and **maneuverability** of the ship as the most important factors in their decision-making in icy waters. The Canadian government provided supports through ice offices and the regulatory requirement to use advisory services of ice navigators, especially in the NORDREG zone, particularly for non-ice-class ships, provides **collective decision-making** in both strategic and tactical navigation based on ship capabilities and operating conditions.

RQ3: Are ships likely to experience more severe operating conditions than expected from operational and regulatory recommendations in planning navigation in Canadian icy waters?

Historical data (section 4.3) showed that ships **may have navigated** in the ice condition that should have been avoided according to one of the currently accepted risk assessment tools (POLARIS). No significant sea ice-related incident was reported for the period and area of historical data (section 4.1), so the evidence supports that ships **safely navigated** in sea ice conditions higher than what they are classified for. Ideally, this would be further investigated in future works considering ice breaker operations using ice data with higher resolution. According to the literature (section 2.5) and interviews, the current risk assessment tools (AIRSS and POLARIS) heavily rely on navigators' performance and experience and many practical parameters are not included in their assumptions. Interviewees considered them more useful tools for strategic planning in the experienced hands, however, they do not rely on them in the field for tactical navigation in close range ice fields (section 4.3). So, **it is possible** that ships encounter and navigate in ice conditions that are not recommended by POLARIS.

Secondary RQ1: How do Canadian regulatory and government provided supports affect non-ice-class ship navigation in Canadian icy waters?

The direct effects of the Canadian government on navigators' decision-making are shown in different functions in the as-done FRAM model (section 4.2) in the form of background functions. Government provided **navigational and environmental information** (section 6.1.1), **regulatory arrangements**, and **operational supports** (section 6.1.2) are noticeable contributors to non-ice-class ships' navigators' strategic planning. Regulatory requirements for training and experience for ice navigators/advisors onboard in different regions (inside and outside of the NORDREG zone) alter the minimum expertise required onboard for handling tactical navigation in non-ice-class ships intended to navigate in icy waters.

Secondary RQ2: How do ship management companies influence ship navigation planning in icy waters?

In addition to the overall effect of the management companies on the safety of navigation, the as-done FRAM model (section 4.2) showed their direct influence on the route planning through different functions by **policy making** (section 6.2.1**), preparing the ship**, **planning the operation** (section 6.2.2) and providing **support** for the operation (section 6.2.3).

6. Discussion

The FRAM model shows how ship navigators become aware and use ship capabilities in their decision-making for navigation in Canadian icy waters. The process includes many interconnected functions that different parties carry out. In this section, the discussion about the role of the Canadian government, ship management company, and navigators onboard is expanded to some extent based on the findings of this research.

6.1. Canadian Government

Figure 24 highlights the functions that are direct outcomes of government operations in the as-done FRAM model. Although political decisions and regulations (some appeared in the FRAM model) have an overall effect on most aspects of navigation and shipping safety, based on the findings from this study, the effectiveness of the marked functions in Figure 24 may have a more direct influence on the ship operation. The changes in the regulations are relatively infrequent, and the variability of the settled regulations is consequently very low.

6.1.1 Navigational and Environmental Information

The Canadian government provides navigational and environmental information, including daily and historical ice charts, nautical charts, shipping lanes maps, and weather forecasts (the orange marked functions in Figure 24). The accuracy, temporal, and geospatial resolution of the information causes variability that affects the decision-making at the functions “create/revise the route plan” and “make situational assessment” and, consequently, the overall outcome of the navigation. It should be noted that these two functions are the most critical functions in strategic and tactical navigation, respectively.

Interviewees emphasized on gathering as much information as possible and comparing them to have a clearer picture of the possible ice and weather conditions. It shows itself as variability in the functions “become aware of historical ice and environmental conditions”, “obtain nautical charts”, “obtain weather forecast”, “download daily ice charts”, “obtain map of shipping lanes”, and as separate functions “download satellite images” and “collect complementary ice information”.

The government provided information is available to all ship navigators in Canadian waters; however, the range of gathering more information from other sources varies in different situations and may vary for different individuals based on their personal approach, experience, and familiarity with the available sources. Also, shipping company procedures may increase navigators’ awareness of available information, which is discussed in 6.2. Each source of information may be available at different times of the day. Experienced navigators can use more information from different sources to compensate for accuracy and temporal resolution. So, they can dampen the variability of each source by considering others. For discussion about the effect of navigators’ experience, see 6.3.

It is shown in the historical AIS-ice analysis (4.3) that, in some cases, the ships’ reported positions were in the ice fields that should have been avoided in the planning phase according to POLARIS. Due to the low resolution of the weekly ice charts, it cannot be firmly concluded that ships encountered hazardous ice fields, but as weekly ice charts are one of the historical sources for strategic route planning, it is safe to say that navigators could have reduced the variability and compensate for the low resolution of historical ice charts by using daily and complementary ice information. It is discussed in the variability discussion under the function "become aware of historical ice and environmental conditions" in Table 7, "when getting closer to the sailing date, the bridge team and ice navigators look at and track the current ice and weather conditions rather than relying on historical information."

6.1.2 Regional Regulations and Support

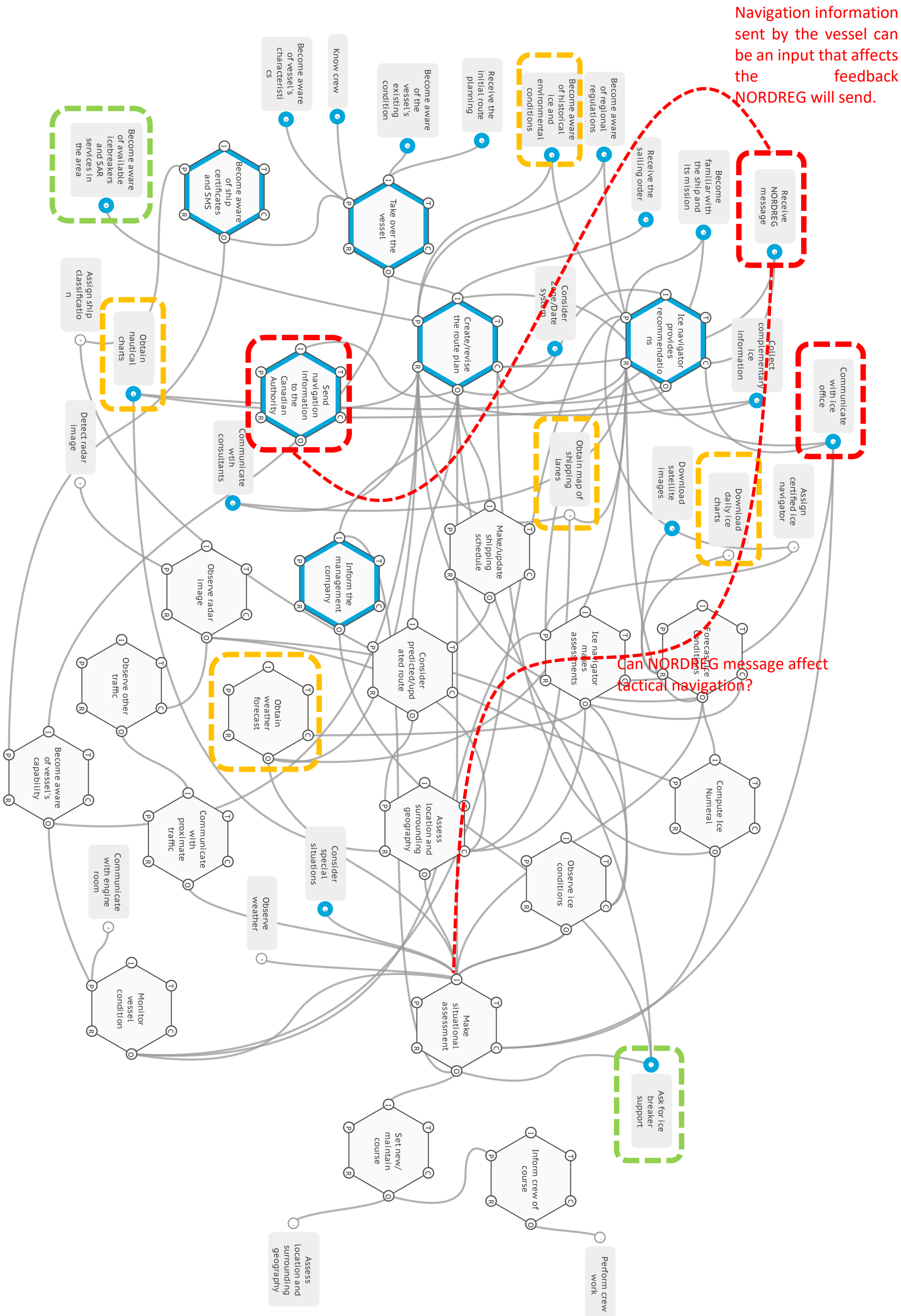
Reviewing the ice-related occurrences in Canadian waters revealed that most of these ice-related hull damage and drifting incidents/accidents happened outside of the NORDREG zone. As this study did not consider marine traffic, density, geospatial and environmental parameters, and many other factors for accident/incident analysis, we cannot draw any conclusion regarding the distribution of occurrences. However, a difference between regulatory requirements within the NORDREG Zone and outside of it is noticed during the literature review and interviews.

According to "Ice Navigation in Canadian Waters", in addition to general international and Canadian regulations regarding marine navigation, there are different regulations for Canadian icy waters. These regulations do not cover all shipping activities in the presence of sea ice in Canadian waters. Also, the difference between regulatory requirements within and outside the NORDREG zone is noticeable. Even though regulations cause minimal variability in everyday operations, the effect of the regulatory requirements in general and in different situations on navigators' decision-making should not be overlooked. Understanding the influence of regulatory differences in different Canadian water regions requires a separate study, which may include an FRAM analysis of the system.

Ships with 300 gross tonnage or higher and ships that carry dangerous cargo planning to navigate and navigating within the NORDREG Zone should follow a specific procedure for sending their voyage plans, location, and observations to the Canadian authority (NORDREG Canada) through Marine Communications and Traffic Services Centres (MCTS) [63]. They receive NORDREG Canada clearance or recommendations for navigating within the NORDREG Zone. Possible links for the function “receive NORDREG message” are shown in Figure 24, which require more investigation and system analysis in the internal operation of NORDREG in the Canadian authority. The message ships send in the function “send navigation information to the Canadian authority” can be an input to a function that produces an input for the function “Receive NORDREG message”. The variability of the sent message may propagate to the feedback the vessel receives from NORDREG and consequently affect the routing and possibly tactical navigation. As understanding these relations requires a study of the functionality of this process and involved organizations within the Canadian government, it is not included in this FRAM model.

Another government provided support in Canadian waters is ice offices in the Canadian Coast Guard (CCG). Navigators can ask questions and request assistance from them. The availability of services, however, are subject to ice conditions [66]. The variability of these communications may propagate in the navigators’ decision-making process and affect the overall outcome of the navigation. Similar to the NORDREG message, understanding this variability requires a detailed study of the governmental provisions for these supporting services.

The availability of the Canadian government search and rescue and icebreaking operations at sea can affect navigators' decision-making, as shown in Figure 24. The availability of these services may vary in different years and regions. The Canadian Arctic is vast, and providing the same level of support for all areas can be challenging. According to interviewees, the regulatory and government support and ice services are mostly effective and helpful in keeping operations safe; however, with the possible increase in shipping activity in the NORDREG zone, the effectiveness and resilience of governmental arrangements and support will be a concern.



Governmental supports (Red), Provided information (Orange), Operations at sea (Green)

Figure 24 Governmental functions for navigation in Canadian waters

6.2. Ship Management Company

The ship management company has an overall influence on navigation in almost every aspect, from selecting the correct vessel and crew for the operation to providing enough support for the vessel and crew to maintain the operation safely and efficiently. In the FRAM model, however, the ship management company effects appear only in some functions. Figure 25 highlights the management company's direct roles in the operation. The role of the ship management company in ship navigation can be discussed in three categories: policy making, preparing and planning, and support.

6.2.1 Policy making

The company's safety management system and operational procedures regulate how information is handled and how the ship is operated. The company designs a safety management system that governs many core activities onboard, including official communications, handover procedures, and maintenance. Understanding the variability and effects of company policies and procedures on navigation in icy waters requires a separate study that reviews a range of different companies to identify shared and specific characteristics and functions influencing documentation and operations onboard. From the FRAM model, the navigator becomes aware of the SMS in the taking-over process of the ship; however, the effects of in-place procedures for other functions should not be omitted.

According to the Polar Code, ship masters should be provided with sufficient ship operational capabilities and procedural information for decision-making in icy water through a document called the “Polar Water Operational Manual (PWOM)” [67]. Although the PWOM was expected to be the main source of information for captains to understand the ship’s capabilities for icy water navigations, interviewees stated that the PWOM is not necessarily a useful tool for them because of the quality of their content. Interviewees also stated that the SMS and official documentation do not necessarily reflect the vessel's actual conditions due to many factors like ship age, maintenance, and possible non-conformities in the management system. Accordingly, the company safety management system performance has possible impacts on many other functions in the navigation model that are not identified in this study.

Interviewees stated that the company culture and policies may put pressure on captains to plan their navigation in a more cost-efficient way. This does not mean that shipping companies are likely to risk the safety of the ship for more benefits. Still, as expected from every business, because they tend to make maximum financial benefit from their operations, they may unintentionally push vessels into unsafe situations. This may show itself as a variability in the functions "receive the sailing order" and "become familiar with the ship and its mission" or through other communications between the company and the captain for other purposes, which are not identified in the FRAM model. In either case, it is the responsibility of the captain to dampen the variability from functions and company pressure to maintain the voyage safe. The "control" role of the Canadian authority and ice navigators onboard in controlling the possible unsafe decisions made by captains due to company policies is significant in Canadian icy waters.

6.2.2 Preparing and Planning

Although the management company does not have a direct presence in the decisions made onboard for navigation, from the FRAM model, the effect of variability caused by the management company functions can be seen. The initial planning in the function "receive the sailing order", the ship itself and its mission, crew, and provision for the voyage, which are decided by the management company, can be considered a "given" from the very first step of the strategic planning. Although captains must plan the voyage based on the updated environmental and ship conditions and may revise the voyage if required, the sailing order and ship mission defines the purpose of the navigation, and captains have to plan to achieve them.

6.2.3 Support

The shipping company may provide shipping and environmental information as well as professional consultancy support in icy water navigations for their fleet. In addition, they may facilitate icebreaking services when required through the Canadian Coast Guard or other providers (the output of the function “inform the management company”). The management company also provides information required for icy waters navigation and assigns a certified ice navigator when required. Variability in company procedures and approaches to facilitate these services and supports also affects some background functions like “communicate with consultants” and “assign certified ice navigator” in the navigation model.

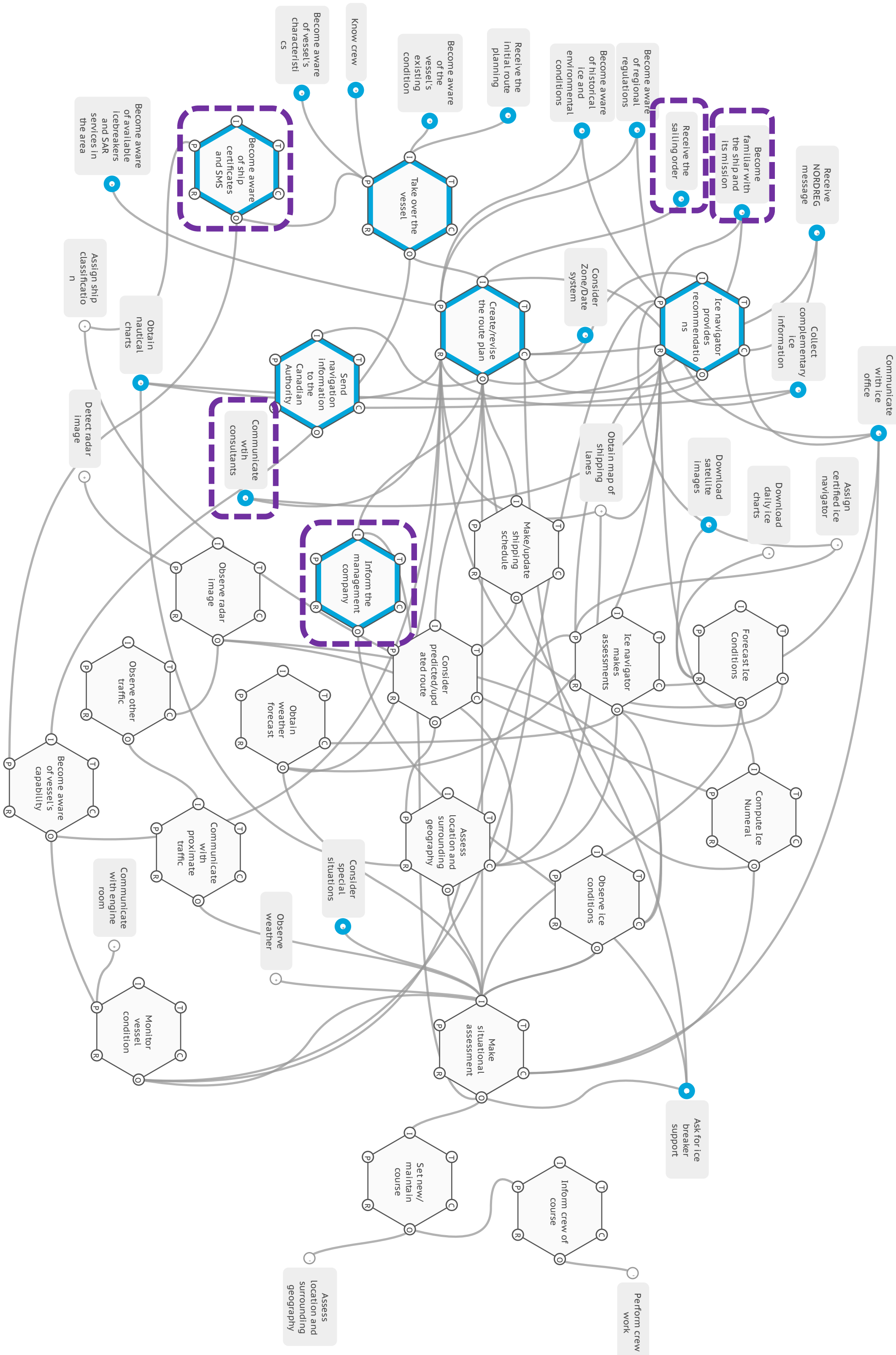


Figure 25 Ship management company functions in the FRAM model

6.3. Navigators

Navigators are shown to be the key players in the icy water navigation FRAM model. The most important and effective functions that determine the outcome of the system (safe navigation) are "make situational assessment" and "create/revise the route planning", which are carried out by navigators. In this study, navigators include the captain and officer of the watch on the vessel's bridge, who oversee and carry out these functions. It was shown that despite all efforts to regulate and organize information regarding vessel conditions through the ship safety management system, some information is communicated unofficially or understood intuitively.

Interviewees believed that experience has a significant role in icy water navigation. An experienced navigator processes the information and observations and can consider a projection of the possible futures in their decision-making. For ships operated by navigators with little experience in navigation in sea ice (more likely in non-ice-class ships), the role of the ice navigator/advisor and communication with ice offices and Canadian authority is more important. Ice navigators bring experience and knowledge to ships' bridges, and communication with ice offices provides additional informatory support for ship navigators for planning and operations. However, interviewees believed that the current requirements for training and competency do not appreciate the level of experience required in Canadian icy waters. Most ships (applied based on the ship size and cargo) navigating in the NORDREG Zone should use "Ice Navigators" for the navigation advisory [56], while some ships (applied to laden oil tankers and to tankers carrying liquid chemicals in bulk) in active Ice Control Zones should carry an "ice advisor" [68]. The competency requirements and duties of ice advisors and ice navigators are different. Also, according to [69], all Canadian passenger ships or ships engaged in the coasting trade of Canada when navigating in sea ice within economic zones of eastern Canada should carry an ice advisor.

The ice-navigation competency required for ice advisors for passenger ships, according to the Interim Standards for the Construction, Equipment & Operation of Passenger Ships in the Sea (1987) [69], is different than the requirement of Guidelines for the Control of Oil Tankers and Bulk Chemical Carriers in Ice Control Zones of Eastern Canada [68]. This is while other vessels are not required to use any sea ice experienced or trained operators onboard while navigating in icy waters.

Interviewees acknowledged the possible significant differences between forecasted and actual weather and ice conditions, especially in the Northern regions. The effect of navigators' experience in the region can be significant in reducing or dampening the variability resulting from environmental information. They also consider regional phenomena or patterns that they have experienced in an area in their assessment. Having experience in the region also facilitates communication with authorities and gathering information from different available sources.

The importance of teamwork cannot be overestimated. The bridge team handles a variety of information, from indicators and navigation technologies onboard, resources out of the ship, and observations of the surrounding environment. Navigators also rely on their colleagues onboard, especially from the engine room department, to provide them with most of the information required to understand the vessel's condition. Effective communication and teamwork seem vital for managing possible variability caused by changing conditions during navigation and deviations from official documentation. Ship navigators also consider their crew experience, attitude and working culture onboard in their approach to route planning and the level of oversight during operations. It can be seen in the FRAM model in the function "know crew".

The amount and details of the information the bridge team and ice navigator should process for their decision-making is significant, so they need to trade off between thoroughness and efficiency, which may be explained with the "Efficiency-Thoroughness Trade-Off" (ETTO) concept [49]. ETTO states that maximizing efficiency and thoroughness of the activity at the same time is impractical, so people and organizations balance their resources (time and effort) to achieve a level that satisfies their practical goals. In the icy waters navigation case, navigators balance the time and effort required to understand the ship and environmental conditions and determine the proper action in a practical manner to keep the operation safe. (Also see section 2.8) The ETTO may explain some variability in time and accuracy of outputs of the functions in the FRAM model if a detailed variability investigation on the FRAM model is carried out.

Interviewees believed that revising the route planning and contingency planning continuously are the most important parameters to keep the operation safe. The former showed itself as an output of the function "make situational assessment," which is an input for the function "create/revise the route planning". Both parameters may vary for different situations and for different people based on their approach, state of mind, and experience. This situation and individual-based parameters make the analysis of the variability of the mentioned functions very complex. These functions are currently carried out by human beings who balance all the upstream outputs and compensate for the variability in their decision-making and action to keep the operation safe and efficient.

6.4. A Hypothetical Functional Signature

In this section, a hypothetical functional signature of the FRAM model created in section 4.2 is provided. This example shows how the FRAM model can be used to record and describe the functionality of navigation in Canadian icy waters. It also shows a functional signature of strategic planning to create a route plan before starting the voyage. So, many functions in the tactical navigation (mostly obtained from D. Smith et al. work [7]) are not active in this example.

In this example, a hypothetical non-ice-class cargo ship with a gross tonnage of 20000 is scheduled to start her voyage on July 20th at 2 PM local time from the Port of Inukjuak in Hudson Bay to Nuuk, Greenland. A new captain and an ice navigator are assigned to join the ship on July 1st, 10 AM. Table 10 depicts the chronological events and details from assigning the captain and ice navigator to starting the voyage with their relative functions in the FRAM model (Table 7 and Figure 19). Although this example is not recorded from an actual operation, the event descriptions are tailored based on the interviewees' instances and explanations, so it can be considered a realistic example.

Table 10 A hypothetical functional signature of navigation in Canadian icy waters

NO.	Time	Function	Output(s) Description	Downstream Function(s)
1	January 15	Obtain nautical charts	The shipping company obtains updated Hudson Bay area nautical charts and publications	Resource for “Create/revise the route plan” (No.22)
2	February 12	Assign ship classification	The shipping company arranges the renewal survey of the ship, which is carried out by the classification society. The ship condition was found satisfactory, and certificates were renewed. The vessel is a non-ice-class ship.	Precondition for “Compute Ice Numerals” (No.16) Precondition for “Become aware of ship certificates and SMS” (No.10)
3	March 20	Receive the sailing order	The captain (who is not onboard) and ship receive a sailing order from the shipping company indicating the ship identification, port of departure (which is the same as the port the captain joins), destination, cargo, and list of crew and ice navigator.	Input for “Create/revise the route plan” (No.22)
4	March 20	Become aware of vessel’s characteristics	Captain sailed with similar ships several times. He sailed with the ship last summer. He refers to his personal notebook to recall his last voyage with the vessel.	Precondition for “Create/revise the route plan” (No.22) Precondition for “Take over the vessel” (No.18)
5	April 5	Assign a certified ice navigator	The ship management company made a contract with a Canadian ice navigator with over ten years of ice navigation and two years of icebreaking experience in Canadian waters. He holds the certification required under Canadian regulations.	Precondition for “Ice navigator makes assessment” (No.16) Precondition for “Ice navigator provides recommendations” (No.21)

6	May 15	Become aware of regional regulations	Captain is familiar with the regulations. He reviews latest updates on updates to see if there were changes in NORDREG zone requirements.	Precondition for “Create/revise the route plan” (No.22)
7	June 21	Become familiar with the ship and its mission	Ice navigator receives some information in the form of an email from the ship management company indicating the ship's specifications, her cargo, departure port, and destination.	Precondition for “Ice navigator makes assessment” (No.16) Precondition for “Ice navigator provides recommendations” (No.21)
8	July 19 5 PM	Download daily ice charts	The second officer downloads daily ice charts for Hudson Bay and Hudson Strait from the Canadian Ice Services website. Ice charts are released on June 19, 1 PM.	Resource for “Forecast ice conditions” (No.17)
9	July 20 8 AM	Know crew	Captain gets on the bridge. The predecessor captain, who is his friend, welcomes him onboard and introduces the bridge team to him. They have short chats when the predecessor captain shares some stories from their last voyage. He gives a hint about the third officer, who has little experience with this ship type.	Precondition for “Take over the vessel” (No.18)
10	July 20 9 AM	Become aware of ship certificates and SMS	Captain reviews the latest certificates, audit reports, and logbooks. He is familiar with the ship management system (SMS), so he does not check manuals.	Precondition for “Take over the vessel” (No.18) Precondition for “Become aware of vessel’s capability” (not active in this example)
11	July 20 9 AM	Obtain weather forecast	Second officer gathers updated weather forecasts from Canada weather and Windy.com and independent website.	Resource for “Create/revise the route plan” (No.22)
12	July 20 9:30 AM	Become familiar with the ship and its mission	The ice navigator gets on the bridge and holds a brief session with the bridge team. He asks about the ice navigation experience of the bridge team and the engine and steering system conditions. The captain tells him no one in the bridge team has ice navigation experience, so he requires him to attend the bridge if they encounter sea ice.	Resource for “Create/revise the route plan” (No.22)
13	July 20 9:45 AM	Become aware of the vessel’s existing conditions	Captain reviews the latest maintenance reports. He calls the ship superintendent at the shipping company to confirm the status of	Input for “Take over the vessel” (No.18)

			some modifications that were planned to be done during his last experience with the ship. He also discusses his concerns about a leak in the steering system with the chief engineer. The chief engineer tells him they are working on the issue and will resolve it before the scheduled departure time. He also suggests avoiding using more than 80 percent of engine power due to some technical issues observed before arriving at the current port, which is going to be addressed in the next port by a maintenance firm. The captain seeks his predecessor's opinion on the engine condition, and he confirms the chief engineer's suggestion.	
14	July 20 9:50 AM	Download Satellite images	Ice navigator downloads updated satellite imagery of Hudson Bay and Hudson Strait. Some parts of Hudson Strait are cloudy, and their image are not usable.	Resource for “Forecast ice conditions” (No.17)
15	July 20 9:55 AM	Collect complementary ice information	Ice navigator has a colleague that passed Hudson Bay Strait last night. He calls him and asks about ice condition. His colleague tells him ice fields are changing fast due to wind in southern areas of Nottingham Island.	Resource for “Ice navigator provides recommendations” (No.21)
16	July 20 10:15 AM	Ice navigator makes assessment	Ice navigator compares the Hudson Bays satellite imagery with ice charts and adjusts the second officer initial ice forecast.	Control for “Forecast ice conditions” (No.17)
17	July 20 9:55 AM	Forecast ice conditions	Second officer forecasts the ice conditions ahead of the initially planned route based on ice charts and ice navigators’ opinion.	Resource for “Create/revise the route plan” (No.22)
18	July 20 10:15 AM	Take over the vessel	Captains complete the handover process according to the company procedures. Predecessor captain shows locations of some dents on the waterline in the bow area to the captain.	Input for “Create/revise the route plan” (No.22) Input for Become aware of vessel’s capability (not active in this example)
19	July 20 11 AM	Compute ice numerals	Second officer computes Ice Numeral in different ice regimes in the initial route plan according to POLARIS.	Control for “Create/revise the route plan” (No.22)
20	July 20 11:10 AM	Consider Zone/Date system	Second officer knows from previous planning that according to the Zone/Date system they should not	Control for “Create/revise the route plan” (No.22)

21			navigate in the area this time of year; however, he rechecks the requirements. They can justify their navigation according to the ice numerals.	
21	July 20 11:15 AM	Ice navigator provides recommendations	Ice navigator provides recommendations to adjust details of planning to avoid possibly high concentrated icy fields. He insists to keep eye on the next ice charts, which are expected on 1 PM local time and may adjust the planning accordingly. He makes sure that the NORDREG report is prepared and sent properly.	Control for "Create/revise the route plan" (No.22) Control for "Send navigation information to the Canadian Authority" (No. 23)
22	July 20 12 PM	Create/revise the route plan	The captain reviews and confirms the route plan created by second officer.	Input for "Send navigation information to the Canadian Authority" (No.23)
23	July 20 12:30 PM	Send navigation information to the Canadian Authority	The captain sends the NORDREG report.	Input for government operations, which is outside the scope of this study.

Although this example does not represent every function the bridge team carries out to complete a planning task, it shows the significance of details and nuances in the human actions in almost all functions in the operation. The direct operational role and impact of the ship management company (functions No. 1, 2, 3, 5, 7, 13, and 18) and Canadian government (functions No. 6, 8, 20 and 23) can be seen. In addition, the shipping company has an overall impact on the quality of the maintenance and crew onboard. Regulatory requirements can be indicated in functions No. 2, 5, 6, 19, 20, and 23.

While a FRAM model should represent all possible scenarios in the system, it does not mean that all functions and their outputs should be active in every scenario. For instance, in this case, the bridge team did not use historical ice and environmental conditions for their planning purposes while they may consider them in other scenarios. The path a scenario takes in the FRAM model and the time and quality of each function's output differ in different scenarios. They form a history of outputs, which are called functional signatures. There is no practically approved methodology for classifying and analyzing functional signatures with different qualities; however, artificial intelligence seems a promising tool for this purpose. Collecting a large number of instances may provide a bank of functional signatures of actual operations to study and manage the operation in order to enhance efficiency and safety.

6.5. Limitations

6.5.1 FRAM

The FRAM model is generated for operations on commercial non-fishing ships of 300 gross tonnage and more. The navigation system, regulatory arrangement and operation in smaller vessels, personal yachts, military vessels, and ships intended to catch fish and other sea creatures are not considered. The FRAM model presented in this study may not be accurate for analyzing them.

The FRAM model provided a representation of general activities of icy waters navigation planning and execution and how they are interconnected to each other in everyday operations. So, occasional operations and duties like berthing and loading are not considered in the FRAM model. The FRAM model is created based on a previous study [7] and interviews with four experts in the field. The study could provide more details if knowledge elicitation could be continued to capture more data from more participants in the interviews, which was not practical for the time and resources of this research. Increasing the number of participants may also reduce the possibility of including interviewees personal preferences and biases in the study.

It should be noted that the FRAM model in this study is created based on bridge navigation viewpoints, so shipping companies' operational functions and Canadian government operational procedures and functions are not included in many details. Although these functions are not active in all decision-making instances onboard, their influence on bridge operations may be considered in future works.

6.5.2 Historical POLARIS Analysis

The historical POLARIS analysis was carried out based on the historical weekly ice charts. The temporal resolution of ice charts reduces the accuracy of historical ice conditions at the time of the ships' reported position. The local ice condition may have been different from what is reported as an average for the region in the ice charts. Also, the level of accuracy of ice charts imposes limitations on the analysis in this study. The Canadian Ice Service has provided a summary of historical changes in technology and accuracy of preparing regional ice charts. Despite all advancements, it is still possible that observational, mapping, and temporal errors can affect the accuracy of ice charts [70]. Although, these errors may affect historical ice charts used in this study, they are the best available source for these types of study.

The historical POLARIS analysis is carried out only for July 2013 to 2022 in the Hudson Bay area while the ship ice-class data for 2018 was not available. A broader geographical analysis may reveal more instances of low/non-ice class and sea ice encountering.

Another piece of information that could improve the historical POLARIS analysis is icebreaking operations. Ships intended to follow an icebreaker, can add ten credits in the planning phase to the calculated POLARIS RIO. So, if icebreaking and convoying information were available this analysis could be richer.

It is noteworthy that, POLARIS recommendations are only one of the criteria captains consider during their operations in icy waters. Other considerations like temperature, humidity, draft, and speed are not considered in this analysis.

6.6. Future Works

A variability observation using the FRAM model created in this study can show possible modes and functional signatures during icy waters navigation. The accumulated variability data can provide a basis for safety and efficiency management.

The FRAM model created in this study can be used for analyzing past and future events, especially for analyzing marine occurrences in the presence of sea ice in section 4.1. This type of investigation may show new functions or relations between functions in the FRAM model. It is particularly useful to find variability in exceptional instances that caused the occurrence happening. A detailed investigation on these occurrences may reveal some possible patterns as there are some occurrences that happened around the same location and time. For example, in almost two weeks, four bulk carriers experienced ice damage to their hulls in roughly the same region. (No.5 to 8 in the Appendix I-A) Also, ice damage to two cargo ships is reported over three days in the same region. (No.14 and 15 in Appendix I-A) Similar occurrences can be seen in besetting and drifting-related reports as well. (No.8 and 9; No.14 and 15, and No.27 and 28 in Appendix I-B). Also, ice conditions and RIOs values at the time of hull damage and besetting occurrences can be reviewed. Possible correlations between occurrences and seasonal traffic or ice conditions in the region can be studied as well.

It was shown that organizational functions carried out by ship management companies and the Canadian government can impact the decision-making and operation onboard. In this study they are deemed as background functions, which can be expanded through studies on functionality of government provided supports and operational and safety management practices of shipping companies.

The historical POLARIS analysis can be expanded by including icebreaking operations and using NORDREG Zone data. NORDREG data also provides additional information regarding details of route planning and deviations that can be investigated in relation to the sea ice and environmental conditions. This study also can be carried out in different times and geographical areas.

7. Conclusion

This research used a combination of Safety-I and Safety-II to create a model of ship navigation in Canadian icy waters. An accident analysis was carried out to understand possible ship-heavy ice incidents. It was found that most ice-related damages to ships' hull and besetting/drifting occurrences due to sea ice happened in shoulder seasons in southern parts of Canadian waters outside of the NORDREG zone. Results implied the possible role of regional regulatory requirements and organizational aspects of shipping on the safety of icy water navigations, which was further investigated in the next stages of the study.

Low and non-ice-class ships' AIS data was overlayed on their correlated historical ice charts in Hudson Bay area. This analysis showed that there were likely instances that ships navigated in the ice conditions that were not recommended by the currently accepted risk assessment tool, POLARIS. Although these instances should have been avoided in the first place, navigators managed to complete the voyage without significant incidents/accidents, as no ice-related accidents were reported for the period and area of the study. Results also highlighted the shortcomings of historical data for navigation strategic planning purposes.

A FRAM model of ship navigation in Canadian icy waters considering the regulatory requirements, the operation on the bridge, communication, and cooperation with entities onshore was created based on semi-structured interviews with experienced navigators. The FRAM model showed different sources of information for navigators to understand ship capabilities and the effects of teamwork to consider them in the decision-making process considering the recommended criteria in voyage planning and execution in a changing environment. It was shown that the safety management system affects how navigators understand the ships' capabilities. It was also found that navigators may collect information from unofficial or unrecorded sources, like colleague discussions and liaisons. The significance of Canadian regional regulations and governmental support, as well as ship management company processes in policy-making, planning, and support of ship operations, and their effects on decision-making on ships' bridges, were demonstrated. Some potential sources of variability and the necessity of in-depth variability investigation in governmental operations and ship management companies were discussed. Also, the importance of human factors, especially experience and teamwork, in dampening variability and keeping navigation safe was highlighted.

The FRAM model provides a basis for future investigations in work optimization and safety enhancement on the ship's bridge and in ship management companies. It also assists in understanding the influence of variability from upstream functions, especially in Canadian government operations, on individual ships' navigations in icy waters. A more detailed study on this data can reveal possible contributing factors and the variability of functions in the FRAM model that lead to encountering these undesired ice conditions and to what is required to support safe navigation in ice.

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Appendices

Appendix I	**Ice-related Incident Reports** **A) Hull Damages** **B) Besetting/Drifting**
Appendix II	**Imagined FRAM model References**
Appendix III	**Interview Documents** **A) Semi-structured Interview Guide** **B) Recruitment Email and Announcement** **C) Informed Consent Form** **D) Experience Form** **E) Research Ethics Approval**
Appendix IV	**Complete As-Done FRAM Model**

Appendix I - Ice-related Incident Reports

A) Hull Damages

No.	OccID	Ship Type	Date	Latitude	Longitude	Province
1	49747	Fishing	5/25/2022	56.25	59.43333	NEWFOUNDLAND AND LABRADOR (NL)
2	47796	Fishing	10/8/2020	48.73512	63.83312	QUEBEC (QC)
3	45779	Bulk Carrier	4/10/2019	43.18761	79.19941	ONTARIO (ON)
4	44378	Bulk Carrier	4/17/2018	48.39083	89.21333	ONTARIO (ON)
5	44365	Bulk Carrier	4/5/2018	46.04167	83.94417	Outside Provincial Boundaries
6	44363	Bulk Carrier	4/3/2018	44.97667	74.86833	Outside Provincial Boundaries
7	44334	Bulk Carrier	4/5/2018	46.04311	83.93698	Outside Provincial Boundaries
8	44331	Bulk Carrier	3/26/2018	45.29698	83.42117	Outside Provincial Boundaries
9	44276	Bulk Carrier	2/12/2018	48.00167	61.52833	QUEBEC (QC)
10	43765	General Cargo	9/2/2017	68.65	107.7	NUNAVUT (NU)
11	43345	Fishing	6/2/2017	49.53117	55.1115	NEWFOUNDLAND AND LABRADOR (NL)
12	43143	Ro-Ro Cargo	4/19/2017	47.55833	52.64833	NEWFOUNDLAND AND LABRADOR (NL)
13	43124	Fishing	4/25/2017	40.17633	52.576	NEWFOUNDLAND AND LABRADOR (NL)
14	43078	Cargo	4/6/2017	47.05	52.58333	NEWFOUNDLAND AND LABRADOR (NL)
15	43077	Cargo	4/3/2017	46.91667	52.73333	NEWFOUNDLAND AND LABRADOR (NL)
16	42842	Survey	12/16/2016	46.31367	72.55533	QUEBEC (QC)
17	42380	Fishing	6/26/2016	51.56667	55.2	NEWFOUNDLAND AND LABRADOR (NL)
18	42040	Cargo	5/10/2016	51.8	55.6	NEWFOUNDLAND AND LABRADOR (NL)
19	41781	Fishing	2/21/2016	62.55	59.03333	NUNAVUT (NU)
20	40845	Fishing	5/7/2015	50.03333	55.56667	NEWFOUNDLAND AND LABRADOR (NL)
21	40737	Passenger	3/28/2015	46.955	61.77667	QUEBEC (QC)
22	40730	General Cargo	3/24/2015	49.70917	65.72056	QUEBEC (QC)
23	40678	Bulk Carrier	2/14/2015	41.7174	87.45666	Outside Provincial Boundaries
24	39864	Bulk Carrier	4/19/2014	45.8	84.91667	Outside Provincial Boundaries
25	39854	Fishing	6/1/2014	50.16667	55.55	NEWFOUNDLAND AND LABRADOR (NL)
26	39699	Fishing	5/1/2014	50.01678	55.23788	NEWFOUNDLAND AND LABRADOR (NL)
27	39686	Fishing	4/20/2014	51.06667	50.33333	NEWFOUNDLAND AND LABRADOR (NL)
28	39677	Cargo	4/25/2014	42.97503	82.41145	ONTARIO (ON)
29	39639	Cargo	4/18/2014	45.83067	84.88117	Outside Provincial Boundaries
30	39619	Ferry	4/9/2014	46.81111	71.19583	QUEBEC (QC)
31	39582	Cargo	3/14/2014	47.58556	58.70167	NEWFOUNDLAND AND LABRADOR (NL)
32	39574	Ferry	3/10/2014	46.41667	60	NOVA SCOTIA (NS)
33	39475	Fishing	1/17/2014	45.40833	65.06	NOVA SCOTIA (NS)
34	39445	Cargo	1/12/2014	43.74556	81.72722	ONTARIO (ON)
35	38807	Fishing	7/2/2013	49.56495	58.28866667	NEWFOUNDLAND AND LABRADOR (NL)

36	38404	Bulk Carrier	3/27/2013	48.34167	89.15	ONTARIO (ON)
37	38393	Fishing	4/13/2013	51.18944	55.41944	NEWFOUNDLAND AND LABRADOR (NL)
38	37926	Cargo	7/13/2012	63.73889	68.51806	NUNAVUT (NU)
39	35934	Tug	6/28/2009	62.42833	70.49667	NUNAVUT (NU)
40	35682	Bulk Carrier	2/12/2009	50.20147	66.40038	QUEBEC (QC)

B) Besetting/Drifting

	OccID	Ship Type	Date	Latitude	Longitude	Province
1	49529	Bulk Carrier	4/8/2022	46.37833	84.225	Outside Provincial Boundaries
2	49431	Bulk Carrier	2/26/2022	48.55483	68.958	QUEBEC (QC)
3	47157	Passenger	3/27/2020	57.97311	117.1466	BRITISH COLUMBIA (BC)
4	45728	Bulk Carrier	3/22/2019	47.49833	58.89333	NEWFOUNDLAND AND LABRADOR (NL)
5	45571	Container Carrier	1/22/2019	45.96582	73.19991	QUEBEC (QC)
6	45201	Fishing	9/20/2018	70.50583	126.7398	NUNAVUT (NU)
7	44485	Fishing	4/13/2018	49.54212	54.88495	NEWFOUNDLAND AND LABRADOR (NL)
8	44184	Bulk Carrier	12/31/2017	46.74551	71.2907	QUEBEC (QC)
9	44156	Product/Chemical tanker	12/30/2017	46.74338	71.28821	QUEBEC (QC)
10	43365	Fishing	6/7/2017	49.97583	55.61858	NEWFOUNDLAND AND LABRADOR (NL)
11	43274	Oil Tanker	5/25/2017	49.508	54.93383	NEWFOUNDLAND AND LABRADOR (NL)
12	43273	Fishing	5/24/2017	51.63728	55.86887	NEWFOUNDLAND AND LABRADOR (NL)
13	43176	Fishing	5/8/2017	48.5	53.01667	NEWFOUNDLAND AND LABRADOR (NL)
14	43123	Fishing	4/25/2017	48.73675	53.15928	NEWFOUNDLAND AND LABRADOR (NL)
15	43121	Fishing	4/25/2017	49.8531	54.29425	NEWFOUNDLAND AND LABRADOR (NL)
16	43092	Fishing	4/17/2017	46.9495	53.6745	NEWFOUNDLAND AND LABRADOR (NL)
17	41747	Fishing	1/24/2016	50.60433	54.88533	NEWFOUNDLAND AND LABRADOR (NL)
18	40749	Bulk Carrier	4/3/2015	45.33883	73.8919	QUEBEC (QC)
19	40700	Bulk Carrier	3/4/2015	47.80833	62.41333	QUEBEC (QC)
20	39722	Fishing	5/6/2014	49.106	53.5475	NEWFOUNDLAND AND LABRADOR (NL)
21	39715	Fishing	4/14/2014	49.528	54.76983	NEWFOUNDLAND AND LABRADOR (NL)
22	39644	Fishing	4/15/2014	50.5	52.6	Outside Provincial Boundaries
23	39613	Product/Chemical tanker	4/3/2014	42.44	82.77667	Outside Provincial Boundaries
24	39499	Cable Ferry	1/27/2014	45.35	66.221	NEW BRUNSWICK (NB)
25	39471	Barge/Solid	1/19/2014	41.89667	83.00167	ONTARIO (ON)
26	39437	Cable Ferry	1/4/2014	44.29722	64.36111	NOVA SCOTIA (NS)
27	38397	Fishing	4/8/2013	50.36444	54.82	NEWFOUNDLAND AND LABRADOR (NL)
28	38395	Fishing	4/13/2013	51.31167	55.52694	NEWFOUNDLAND AND LABRADOR (NL)
29	38299	Cargo-Solid	1/28/2013	49.06333	66.84667	QUEBEC (QC)
30	38241	Work boat	12/19/2012	46.06495	72.8134	QUEBEC (QC)
31	37773	Fishing	4/28/2012	5.222222	55.4	NEWFOUNDLAND AND LABRADOR (NL)
32	37704	Ferry	1/12/2012	46.81	71.18833	QUEBEC (QC)
33	37051	Cargo-Solid	1/22/2011	43.04944	82.41722	

Appendix II - Imagined FRAM model References

NO	Name of Function	Ref.	Note
1	Obtain weather forecast	D. Smith et al	
2	Set new/maintain course	D. Smith et al	Speed considerations in POLARIS
3	Observe Ice conditions	D. Smith et al	
4	Forecast Ice conditions	D. Smith et al	
5	Assess location and surrounding geography	D. Smith et al	Ship actual location should be considered
6	Inform crew of course	D. Smith et al	
7	Assess location and surrounding geography	D. Smith et al	
8	Make situational assessment	D. Smith et al	
9	Perform crew work	D. Smith et al	This activity should be controlled by OOW (Safety of Navigation)
10	Observe weather	D. Smith et al	
11	Consider predicted/updated route	D. Smith et al	This function is output of plan appraisal (IMO A.893(21)). Upstream functions can be discussed.
12	Compute Ice Numeral	D. Smith et al	
13	Monitor vessel condition	D. Smith et al	
14	Assign ship classification	D. Smith et al	Carried out by Recognized Organizations according to rules and regulations.
15	Download daily ice charts	D. Smith et al	Means of obtaining ice charts may be addressed in PWOM.
16	Ice navigator makes assessments	D. Smith et al	
17	Obtain map of shipping lanes	D. Smith et al	
18	Observe radar image	D. Smith et al	
19	Observe other traffic	D. Smith et al	COLREG and local regulations. Radar Image is not the only means. Visual observation, AIS and Collision avoidance systems are also used.
20	Communicate with proximate traffic	D. Smith et al	
21	Communicate with engine room	D. Smith et al	
22	Assign certified ice navigator	D. Smith et al	This function is regulated by mandatory national and international regulations.
23	Detect radar image	D. Smith et al	
24	Become aware of vessel's capability	D. Smith et al	
25	Make shipping schedule	D. Smith et al	This function may be controlled by safety management system. It is an outcome of voyage appraisal. Other aspects, especially Inputs of this function can be discussed.
26	Provide PWOM	POLAR Code and Guide	Polar Waters Operational Manual (PWOM) ay be controlled by classification societies. PWOM is part

			of safety management system for SOLAS ships.
27	Consider ballast and loading conditions	POLAR Code and Guide	This function can be considered under the function "Become aware of vessel's capability" Note: Ballast Water Management and Intact Stability Code requirements may be considered.
28	Get live information from Ice load monitoring system	ABS Guide	This equipment is not mandatory, but some vessels may have such equipment. ABS has published a guide for Ice Loads Monitoring Systems in 2021.
29	Do visual inspection	Occurrence Analysis	There are many situations that may happen during voyage and give a sense of vessel condition to the navigator. Other senses may be involved. Let's start with visual inspections!
30	Consider Seachest Intake	POLAR Code and Guide	It is done by observing ice conditions May be considered in PWOM.
31	Consider safety of propeller and steering sys.	POLAR Code and Guide	It is done by observing ice conditions. May be considered in PWOM.
32	Become aware of available provision	POLAR Code/Appendix2/CH.4	The PWOM should provide information on any limitations on ship endurance such as fuel tankage, fresh water capacity, provision stores, etc. This will normally only be a significant consideration for smaller ships, or for ships planning to spend extended periods in ice.
33	Consider possible consequences		It can be investigated if navigators consider this factor during navigation or not.
34	Check zone/date table	Arctic Shipping Safety and Pollution Prevention Regulations	
35	Become aware of special areas restrictions	Polar Code 11.3-8 & Arctic Shipping Safety and Pollution Prevention Regulations (15)	Polar Code 11.3 “the master shall consider a route through polar waters, taking into account [...] 8. national and international designated protected areas along the route;” There are some restriction for special routes like rivers (see Navigation Safety Reg.) and some prohibition Arctic Shipping Safety and Pollution Prevention Regulations (15) Operations in polar waters must be taken into ac count in the Oil Records Books, the manuals, the ship board oil pollution emergency plan, and the shipboard marine pollution emergency plan when they are required to be carried by a vessel under the

			Vessel Pollution and Dangerous Chemicals Regulations.
36	Become aware of mammals in the region	Polar Code 11.3 -7	Polar Code 11.3 "the master shall consider a route through polar waters, taking into account [...] 7. current information and measures to be taken when marine mammals are encountered relating to known areas with densities of marine mammals, including seasonal migration areas"
37	Become aware of SAR availability	Polar Code 11.3-9	Polar Code 11.3 "the master shall consider a route through polar waters, taking into account [...] 9. operation in areas remote from search and rescue (SAR) capabilities"
38	Become aware of ice and temperature statistical information	Polar Code 11.3-4	Polar Code 11.3 "the master shall consider a route through polar waters, taking into account [...] 4. statistical information on ice and temperatures from former years;"
39	Record Radio communications	Navigation Safety Reg. (247)	
40	Watch radio communications continuously	Vessel Traffic Services Zones Regulations (5)	
41	Communicate with onshore supports	Arctic Shipping Safety and Pollution Prevention Regulations	Including but not limited to Communication Centres, CCG, Shipping Company, and Ports.
42	Assign qualified helmsman	Navigation Safety Reg. 133 (2)	
43	Ask for Icebreaker support		
44	Report the (new) route plan/maneuver/occurrence	Vessel Traffic Services Zones Regulations (6) (7) (8) and within NORDREG zone	
45	Observe Heading and track control system	Navigation Safety Reg. 133 (1)(2)(3)	
46	Record the voyage information	IMO A.916(22) and Navigation Safety Reg. (138)	Detail of records can be discussed. Other Inputs are possible.
47	Manage Incidents	Occurrence Analysis	There may be some standard actions that should be taken in different incident/accident scenario. They can be defined if bridge is involved.

Appendix III – Interview Documents

A) Semi-structured Interview Guide

<u>Semi-Structured Interview Guide</u>

Research Title: Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)

Note: Italic texts are for the interviewer information only.

Introduction

Thank you for participating in our study and sharing your experience of navigation in Canadian waters.

My name is {your name}, and I am {your affiliation and role in the project}. Here with me are /is {name and affiliation of other research team members in the meeting}

This interview is designed to learn from your knowledge and experience on ship operations in icy Canadian waters. Our research aims to understand some aspects of the safety of operation (specifically the decision-making process) of low/non-ice-class ships in Canadian waters, especially in the presence of sea ice. During this interview, we focus on how navigators consider ship capabilities and possible communications and consultations between them and their companies and authorities regarding the safety of navigation.

This interview is planned to take up to 2 hours. We will record this interview and send you a transcript in a few weeks. You can revise and add to your statements within a week after receiving the transcript. The revised version, and If you won't revise the transcript, the original one will be considered approved and used in the study, and the recording will be deleted.

Feel free to skip any questions if you are uncomfortable with answering them. These questions are not meant to test your knowledge or presence of mind. We try to learn from your experience as an expert in the field. Please let me/us know if you need a break during the interview or if you want to stop the interview.

Your identity and answers will be kept confidential. We may quote you anonymously in our reports; however, your identity will not be addressed in any report. You can withdraw from the study at any time until two weeks after transcript approval. We will not be able to remove your answers from the study after this time because the study may be completed. We have sent you a Consent Form and an experience form. Do you have any question?

Review the consent form if required and if the participant hasn't sent a signed copy yet.

Complete the Experience Form if the participant hasn't sent the completed form.

I need your consent to start recording and interview. Do I have your consent?

Start recording with the consent of the participant.

Recording is started now. Now we can start interview.

Before Getting Onboard

Let's start with the very first day you get normally involved in navigation. Assume you are not currently onboard.

How do you get informed of your assignment, ship particulars and voyage plan?

What kinds of information about the voyage and ship do you receive before getting onboard?

Potential follow up questions:

a) Voyage Plan? Are you involved in its development? If so, in what way?
b) Weather and ice forecast?
c) Ship specifications?
d) Ice navigator?

Is this information sufficient in your opinion or you think more information should be provided or less information would be more efficient?

What do you do normally before getting onboard after you have received the voyage plan and schedule? Do you make any contact or check information?

Is there anything else you can tell me about your role in planning before getting onboard?

After Getting Onboard and Before Starting the Voyage

In this study we do not consider occasional operations like berthing, loading, pilotage and anchoring and we focus on en route navigation and related activities.

What is the general process of taking over the ship? What information do you communicate?

Once you get onboard the vessel, what parameters of ship capabilities do you consider for planning? Provide Examples, parameter and criteria.

Potential follow up questions based on the ship capability they mention, ask for all parameters mentioned in the previous question.

a) Where do you get this information?
b) How much do you rely on information you have about ship capabilities?
c) In your opinion, does this information match with the actual ship conditions and capabilities?
d) Do you do assessments or examinations to make sure about this information?
e) Are there any criteria you use regarding this parameter? What criteria do you uses?
f) Where do these criteria come from?
g) How do you feel about the validity of the criteria?
h) In your opinion, is it possible to operate ships beyond these criteria?

If there are adjustments made to the plan before departing, how do uncertainties in forecasts and ship capabilities influence the adjustments?

Is there anything else you can tell me about your route planning before starting voyage?

During Navigation

What aspects, systems, or sub-systems of the ship do you monitor during voyage for making sure about the safety of ship during voyage? For example: hull condition, engine…

Potential follow up questions based on the aspects they mention:

a) How do you become aware of the condition of this aspect/system?
b) Do you do regular checks, or you feel changes in ship condition from ship behavior?
c) What operational or environmental factors do you consider when thinking of this aspect/system?
d) Do you have any criteria?
e) How uncertainties in this information from ship condition and environment can affect ship navigation?

In Special Circumstances

At what point would you consider adjusting the voyage plan (before and during voyage)? What is involved in that? What parameter do you consider? Can you provide an example?

Is it possible to change the route significantly or stop navigation if you think it is necessary? What is the procedure? Do you need confirmation from company or authorities?

What is the procedure if you need ice breaker support? Do you need company/authorities confirmation? Is the cost a big consideration?

POLARIS Question (or AIRSS)

Have you ever used POLARIS or AIRSS?

In your opinion, is POLARIS/AIRSS a proper tool for decision-making in icy waters or not? Do you rely on it? What are pros and cons?

How much do you rely on POLARIS/AIRSS during strategic and tactical navigation?

Have you experienced a situation that POLARIS outcomes were unsatisfactory for the situation? For example, POLARIS numerals were fine to navigate in an area but the ship suffered from ice damage, or you preferred to not to navigate in the area for other reasons or POLARIS numerals suggested to not to enter the area but you entered and navigated safely.

How do you estimate ice concentration and ice type? Do you feel confident while doing these estimations? How do you assess your approach in estimation: conservative, accurate, or adventurous?

Company, consultants and authorities

Do you get connected to consultancies, authorities, or other entities outside the shipping company before or during navigation?

What kinds of information do you communicate with them at each stage?

Do you get assistance or consultancy in planning? When, who and how?

Considering company arrangements, is it practical for you to change plan or schedule before and during?

Can company, authorities and consultant refuse/change your plan? In what situations?

General question and participant's preferences of getting information and support

Do you think current procedures and information are satisfactory for planning a safe voyage in Canadian waters?

How do you assess current criteria? Are you confident to use them?

How do you assess the current procedures, regulations, supports and criteria for decision making during navigation in Canadian waters? How do you assess them: insufficient, helpful, or too restrictive?

Do companies and authorities put ships in risky situations or they are too conservative in Canadian waters?

Is there anything else you want to add? Anything I haven't asked, and you think may be important?

This concludes our session. We will send you the transcript in a few weeks. Thank you very much for your participation.

For interviewers only

Below table shows some ship capabilities that have been addressed in the Imagined FRAM model. Do not mention them directly in the interview and do not limit the interview within them, but you may use it as a guide to capture more information about this parameters or learn other parameters based participant's answers.

Parameter	*Ship information*	*Forecast*	*Control (Live)*	*Criteria*	*Notes/References*
Structural Strength (Sea ice)	*Certificates* *PWOM*	*Ice Services*	*Visual* *Radar*	*Ice Numerals* *AIRSS, POLARIS, Zone/Date system*	*Arctic Shipping Safety and Pollution Prevention Regulations* *POLAR Code and Guide*
Power	*PWOM*		*Engine Gauges* *Shaft RPM Indicator* *Communication with Engine Room* *GPS* *Speed Log*		*POLAR Code and Guide*
Manoeuvre	*PWOM*		*Rudder Angle Indicator* *Turning Rate (swing) Indicator* *GPS*		*POLAR Code and Guide*
Temperature	*Certificate* *PWOM*	*NAVTEX* *Communication*	*Visual* *Onboard Measurements*		*Polar Code 11.3-4*
De-icing capabilities	*PWOM*				*POLAR Code and Guide*
Cooling System (Seachest Intake)	*PWOM*		*Communication with Engine Room* *Engine Gauges*		*From Incidents* *POLAR Code and Guide*
Under water appendages Steering and Propeller	*PWOM*				*From Incidents*
Stability, Ballast and Draft	*Stability Booklet* *PWOM* *Certificate*				*POLAR Code and Guide*
Endurance	*PWOM*		*Log Books*		*POLAR Code/Appendix2/CH.4*
Latitude	*Certificate*		*GPS* *Charts*		
Possible Consequences Emergency Response	*PWOM*				

B) Recruitment Email and Announcement

Subject: Recruiting Research Participants

Hello,

We are looking for volunteers who have experience with at least one ship voyage in the presence of sea ice in Canadian waters. Volunteers should be current or former ship masters, officers, ice navigators, and/or route planners.

We are trying to understand the decision-making process in successful ship route planning and navigation in icy waters.

Interviews will be held via videoconference and will take two hours maximum.

Research project details may be found in the attached recruitment letter. Here are some key points:

- Results will be used to understand bridge teams' decision-making factors and their positive impact on navigation resilience and maintaining safety in icy waters.
- Participation is completely voluntary.
- Interviews will be held and recorded via videoconference. After transcription approval by the participant, the recordings will be deleted.
- An Informed consent form and an experience form will be sent to the participants to fill in before the interview.
- Volunteers can withdraw from the study anytime without any consequence.
- Volunteers' anonymity will be protected.

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy.

Sincerely,

Amin Attarzadeh

Memorial University of Newfoundland

<u>Research Participants Recruitment</u>

Research Title: ***Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)***

We are looking for volunteers among current or former ship masters, officers, ice navigators, and route planners who have experienced or have been involved in at least one ship voyage in the presence of sea ice in Canadian waters to participate in an interview about route planning and execution in Canadian waters.

My name is Amin Attarzadeh, and I am a master's student in Ocean and Naval Architectural Engineering at the Memorial University of Newfoundland. I am conducting a research project titled "Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)" as a part of my master's thesis under the supervision of Dr. Doug Smith and Dr. Bruce Quinton. This study aims to understand the safety of ship navigation in Canadian waters by identifying different activities and their relationships required for making decisions for route planning and navigation before and during an actual operation.

I am inviting volunteers to participate in an interview in which they will be asked to discuss sequences and requirements of activities usually done for planning, execution, and monitoring ship navigation in Canadian waters in different situations, especially in the presence of sea ice. Results will be used to understand bridge teams' decision-making factors and their positive impact on navigation resilience and maintaining safety in icy waters. Participants will be asked to provide their free consent and their navigation experience in forms that will be send to them before the interview. Interviews will be held and recorded via videoconference. Interview transcripts will be sent to participants for review/approval. Once the transcript is approved, the recording will be deleted. Interviews are expected to be two hours maximum (15min briefing, 90min interview, 15min closing), and the transcript review will be approximately one hour.

If you are interested in participating in this study or have any questions about me or the projects, please contact me, Amin Attarzadeh, by Email at a.attarzadeh@mun.ca.

If you know suitable people who may be interested in participating in this study, please give them a copy of this information.

If you choose to participate in this research, you can withdraw at any time without providing any reasons, and there will not be any consequences for you. Research is designed to protect the anonymity of participants, and your participation in this study will not affect your employment. The research report can be shared with participants when the study is complete.

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as your rights as a participant, you may contact the Chairperson of the ICEHR at icehr.chair@mun.ca or by telephone at 709-864-2861.

Thank you in advance for considering my request,

Amin Attarzadeh

C) Informed Consent Form

Informed Consent Form

Title: *Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)*

Researcher: *Amin Attarzadeh, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, (709) 219-0606, aattarzadeh@mun.ca*

Supervisors: *Dr. Doug Smith, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, (709) 864-8470, d.smith@mun.ca*

Dr. Bruce Quinton, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, (709) 864-7925, bruce.quinton@mun.ca

Member of Supervision Committee: *Dr. Thomas Browne, Research officer, National Research Council Canada (NRC), c26tmb@mun.ca*

You are invited to take part in a research project entitled "Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)."

This form is part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. It also describes your right to withdraw from the study. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is the informed consent process. Take time to read this carefully and to understand the information given to you. Please contact the researcher, Amin Attarzadeh, if you have any questions about the study or would like more information before you consent.

It is entirely up to you to decide whether to take part in this research. If you choose not to take part in this research or if you decide to withdraw from the research once it has started, there will be no negative consequences for you, now or in the future.

Introduction

I, Amin Attarzadeh, am a Master's student in Ocean and Naval Architectural Engineering at the Memorial University of Newfoundland. As a part of my Master's thesis, I am conducting research under the supervision of Dr. Smith and Dr. Quinton. Dr. Smith is an assistant professor of Ocean and Naval Architectural Engineering in the Faculty of Engineering and Applied Science at the Memorial University of Newfoundland. Dr. Quinton is an associate professor and the deputy head of Ocean and Naval Architectural Engineering in the Faculty of Engineering and Applied Science at the Memorial University of Newfoundland. Dr. Thomas Browne, member of supervisory committee, is a research officer at National Research Council. This study is a part of the research project "Capabilities of low- and non-ice class vessels in ice" funded by NSERC CRD, DND (DRDC Atlantic), Gov. NL (IET), ABS, Vard Marine Inc.

This study aims to understand the safety of ship navigation in Canadian waters by identifying different activities required to complete safe operations. We plan to elicit the knowledge and experience of ship masters, officers, ice navigators, and route planners to understand actual considerations in shipping in Canadian waters. Acknowledging the positive impact of human decisions on safety and the differences between what is imagined of an ideal shipping operation and what is required to be done in actual operations, this study will provide a basis for discussing influencing factors on the safety of shipping in the real world. This research focuses on planning and execution of en route shipping of a typical none or low-ice-class ship in the presence of sea ice; however, other factors will be considered to have a broader picture of possible affecting parameters on operations.

Purpose of study

The purpose of this study is to understand the process and influencing factors on decision-making before and during typical ship navigation in Canadian waters, especially in the presence of sea ice. Outcomes will provide a descriptive model of ship navigation, which will be a useful means for safety management based on requirements and considerations in an actual operation.

What you will do in this study

In this study, during your pre-scheduled interview, you will be asked to describe activities you do from the first moment of being in charge of a ship navigation in Canadian waters in terms of planning, appraisal, execution, and monitoring. Interviews will be conducted in the form of videoconference meetings, which will be held on Cisco Webex. Videoconference information will be sent to you via Email.

Interviews will start with a 15 min briefing followed by a discussion on activities during ship navigation planning and execution. During the briefing time, researchers will provide introductions to the study and data collection and your rights to withdraw and confidentiality of your information. If you are satisfied with the terms, you will indicate your free and informed consent verbally. You can provide your consent by signing the form which should be sent to your email at least a day before your scheduled interview time for your review. Afterward, you will be asked to complete an Experience Form, which is designed to collect information about your experience related to the research scope. This form will be sent to you along with the consent form a day before the interview which you can fill out and email to the research coordinator. If you email the completed experience form to the research coordinator before the interview, this part will be escaped. This information will give researchers a better understanding of participants' backgrounds gives them insight into the extent of their research.

After completing the Experience Form, with your free will, video and audio recording will be started. You will be asked to describe activities you usually do from the first moment you become involved in ship navigation in Canadian waters. You will be asked to explain:

- What do you do in each step of your job regarding ship navigation?
- What do you require to do this activity, and how do you obtain them?
- What are the typical outcomes of activities, and how may an activity affect others?
- What do you consider for making decisions at each step?

The interview is semi-structured. As a result, in addition to the above typical questions, researchers may ask other aspects of the activity if they feel it may show possible scenarios. You will not be asked to reveal information about exact occurrences; researchers intend to capture typical activities you, as an expert in the field, do in your job and the possible outcomes you expect. Please note that you will not be tested or judged based on the information you provide, so feel free to tell researchers if you have any reservations or if you cannot recall any part of the navigation process during the interview.

At the end of the meeting, you can provide any relevant information that has not been discussed during the interview. You can provide researchers with feedback and comments on the study. After this, the recording will be stopped, and the session will be completed. The research team will review the transcription of the recorded meeting and will remove identifiable information to protect your anonymity rights. This anonymized transcription will be sent to your Email for you to review a few weeks after the interview. You can revise, delete, or add information to the transcription. If researchers do not receive the revised transcription within one week, they will consider it approved. Once the transcription is approved, the recording will be deleted. Only revised and approved transcriptions will be used in the study.

Researchers will identify each function discussed in interviews and its relation with upstream and downstream activities. Aggregated information from participants will give a descriptive model of activities and considerations required to complete ship navigation in Canadian waters in different situations from ship navigators' and planners' points of view, which will be used in studying the safety of operation.

Length of Time

You will be asked to attend one videoconference. The expected length of the session is two hours maximum. A few weeks after the meeting, the transcription of the recorded interview will be sent to your Email for your review. The required time for the review varies, but it is expected to be around one hour.

Withdrawal from the study

You can withdraw from the study at any point during your participation, including reviewing transcription, without any consequences. In such a case, all data collected from you will be destroyed. To withdraw from the study, please inform the research coordinator, Amin Attarzadeh. Once your data is destroyed, you will be informed via Email. If you choose to withdraw after data collection has ended, your data can be removed from the study up to two weeks after transcription approval; because data will be summarized with data collected from other participants, and aggregated data may be published. The transcription approval date will be a week after the research team sends you an anonymized transcript of your interview for your review/edit. If researchers do not receive the revised transcription within one week, the transcription will be considered approved.

Possible Benefits

The outcomes of this study can be used to analyze and manage the safety of shipping operations in Canadian waters. Your participation may fill the gap between imagined and actual navigation requirements and provides a basis for enhancing safety and environmental protection. Maritime and scientific communities may benefit from your participation as it will contribute to safety studies and improve safety knowledge in the field.

Possible Risks

Some people may feel embarrassed if they feel they cannot answer researchers' questions adequately. Please note that you will not be tested or judged based on the information you provide, so feel free to tell researchers if you have reservations or cannot recall any part of the navigation during the interview. You also have the opportunity to revise your answers when you receive the transcription. To reduce possible stress, you can have breaks during interviews if you need to. You can skip any question if you feel uncomfortable or do not want to answer. Researchers will terminate the interview at any point if you feel uncomfortable. In case of getting upset during the interview, you are encouraged to seek professional help and/or contact 1-866-585-0445 or provincial and territorial mental health supports and in emergency cases call 911. Further information can be found on https://www.canada.ca/en/public-health/services/mental-health-services/mental-health-get-help.html

Confidentiality

The ethical duty of confidentiality includes safeguarding participants' identities, personal information, and data from unauthorized access, use, or disclosure. The information gathered from your participation will only be used for research purposes. Only researchers in this study will have access to the raw information you will provide.

The data from this research project will be published and may be presented at conferences; however, your identity will be kept confidential. Although we may report direct quotations from the interview, you will be given a pseudonym, and all identifying information will be removed from our report. Maritime is a relatively small community. Although names and identifications will be removed from documents and public reports, it may still be possible for people to identify some information or events. Researchers encourage you to refrain from discussing your participation in this study with your co-workers and colleagues. Participation in this study is not a requirement of your employment and will not be reported to your colleagues, supervisors, or employers.

Anonymity

Anonymity refers to protecting participants' identifying characteristics, such as name or description of physical appearance. Interview participation is not anonymous because it will be recorded; however, the recording will be deleted once the anonymized transcription is approved. All participants in the study will be assigned an alphanumerical code. This coding system makes documentation possible, while forms and transcriptions will not carry your identity. The key for the coding will be kept separate from other anonymized documents. Only anonymized information will be used in the study, and publications from this study will not carry any direct identifiers from participants.

Because the participants for this research project have been selected from a relatively small group of maritime professionals, all of whom may know each other, it is possible that you may be identifiable to other people based on what you have said.

Recording of Data

You will be asked to provide some information about your experience and expertise in the Experience From. This data includes the level of education or training and experience in shipping operations in Canadian waters and ice navigation. Also, interviews will be video and audio recorded. You will receive a transcription of this recording and can revise it. Once the transcription is approved, the recording will be deleted.

Use, Access, Ownership, and Storage of Data

The research team will collect the data that is required for this study. Forms and documents containing your name, identity, and contact information and video and audio recordings will be kept in a locked office and on a password-protected computer and separate from anonymized data at Memorial University by the research coordinator, Amin Attarzadeh. After completing the study, anonymized data will be stored in the Ocean Engineering Research Center (OERC) for future studies.

Data will be kept for a minimum of five years, as required by Memorial University's policy on Integrity in Scholarly Research. After this time, data will be destroyed permanently according to the "Procedure for Shredding and Disposal of Confidential Materials - St. John's Campus" at Memorial University.

Third-Party Data Collection and/or Storage

Videoconference interviews will be conducted and recorded using Cisco Webex software. As a result, data collected from you as part of your participation in this project will be hosted and/or stored electronically by Cisco Webex and is subject to their privacy policy, and to any relevant laws of the country in which their servers are located. Therefore, anonymity and confidentiality of data may not be guaranteed in the rare instance, for example, that government agencies obtain a court order compelling the provider to grant access to specific data stored on their servers. If you have questions or concerns about how your data will be collected or stored, please contact the researcher and/or visit the provider's website for more information before participating. The privacy and security policy of the third-party hosting data collection and/or storing data can be found at: https://www.cisco.com/c/en/us/about/legal/privacy-full.html.

Reporting of Results

Data will be published in aggregated form and may include anonymized quotations. This study is a part of a Master's Thesis and after completion will be available online on the Memorial University Research Repository at: https://research.library.mun.ca/view/theses_dept/FacEngineering.html.

Sharing of Results with Participants

A report will be provided when the study is completed. If you wish to receive the report in your Email, please inform the research coordinator, Amin Attarzadeh. Also, the thesis will be publicly available on the Memorial University Research Repository.

Questions

You are welcome to ask questions at any time before, during, or after your participation in this research. If you would like more information about this study, please contact: Amin Attarzadeh (aattarzadeh@mun.ca).

ICEHR Approval Statement

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as a participant, you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

Consent:

Your signature on this form means that:

- You have read the information about the research.
- You have been able to ask questions about this study.
- You are satisfied with the answers to all your questions.
- You understand what the study is about and what you will be doing.
- You understand that you are free to withdraw participation in the study without having to give a reason, and that doing so will not affect you now or in the future.
- You understand that if you choose to end participation during data collection, any data collected from you up to that point will be destroyed.
- You understand that if you choose to withdraw after data collection has ended, your data can be removed from the study up to two weeks after transcription approval. Once your received the interview transcription, you can revise or add to it. The revise transcription is considered approved. If researchers will not receive your answer in a week they consider the transcription approved.
- You agree to be audio and video-recorded.
- You agree to the use of direct quotations.
- You agree data collected from you to be archived in in the Ocean Engineering Research Center (OERC) for future studies.

By signing this form, you do not give up your legal rights and do not release the researchers from their professional responsibilities.

Your Signature Confirms:

☐ I have read what this study is about and understood the risks and benefits. I have had adequate time to think about this and had the opportunity to ask questions and my questions have been answered.

☐ I agree to participate in the research project understanding the risks and contributions of my participation, that my participation is voluntary, and that I may end my participation.

☐ A copy of this Informed Consent Form has been given to me for my records.

X ____________________

Click or tap here to enter text.

Signature of Participant *Date*

Researcher's Signature:

I have explained this study to the best of my ability. I invited questions and gave answers. I believe that the participant fully understands what is involved in being in the study, any potential risks of the study and that he or she has freely chosen to be in the study.

X ____________________

Click or tap here to enter text.

Signature of Principal Investigator *Date*

6 of 6

D) Experience Form

Experience Form

Research Title: Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)

This form is provided to record the experiences of participants in the study. This form will be kept anonymous and your answers are confidential.

Please answer the below questions. If anything is unclear or you have any concerns, please contact the research coordinator. Please return the completed form by Email to the research coordinator, Amin Attarzadeh: aattarzadeh@mun.ca

Interview Date: Click or tap here to enter text.

Participant No.: Click or tap here to enter text.

1- What is the highest degree or level of training you have achieved?
   Click or tap here to enter text.

2- Have you passed Ice Navigation training or any other training regarding sea ice?
   Click or tap here to enter text.

3- What role have you had in ship navigation in Canadian waters and how much experience do you have in it?

Role	Less than 1 year	1-5 years	5-10 years	10-15 years	15-20 years	20-25 years	More than 25 years	Last time in the role
Ship Master (Captain)	☐	☐	☐	☐	☐	☐	☐	....
Ship Officer (Last Rank ....)	☐	☐	☐	☐	☐	☐	☐	....
Ice Navigator	☐	☐	☐	☐	☐	☐	☐	....
Ship Route Planner	☐	☐	☐	☐	☐	☐	☐	....

   If your role is not mentioned above please describe:
   Click or tap here to enter text.

4- What kind of ships have you had experience with, and how long?
   Click or tap here to enter text.

5- Do you have experience in ice breaking or ice management? If yes, please explain your roles and level of experience.
   Click or tap here to enter text.

6- When was the last time you were involved in ship navigation in Canadian waters?
   Click or tap here to enter text.

7- Please describe your current or the latest role in maritime industry.
   Click or tap here to enter text.

E) Research Ethics Approval

MEMORIAL UNIVERSITY

Interdisciplinary Committee on
Ethics in Human Research (ICEHR)

St. John's, NL Canada A1C 5S7
Tel: 709 864-2561 icehr@mun.ca
www.mun.ca/research/ethics/humans/icehr

ICEHR Number:	**20231740-EN**
Approval Period:	May 25, 2023 – May 31, 2024
Funding Source:	NSERC [RIS# 20180705]
Responsible Faculty:	Dr. Doug Smith, Department of Ocean and Naval Architectural Engineering
Title of Project:	*Understanding the safety of low/non-ice-class ships navigation in Canadian waters using functional resonance analysis method (FRAM)*

May 25, 2023

Mr. Amin Attarzadeh
Department of Ocean and Naval Architectural Engineering
Faculty of Engineering and Applied Science
Memorial University

Dear Mr. Attarzadeh:

Thank you for your correspondence addressing the issues raised by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) for the above-named research project. ICEHR has re-examined the proposal with the clarifications and revisions submitted, and is satisfied that the concerns raised by the Committee have been adequately addressed. In accordance with the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans (TCPS2)*, the project has been granted *full ethics clearance* for **one year**. ICEHR approval applies to the ethical acceptability of the research, as per Article 6.3 of the *TCPS2*. Researchers are responsible for adherence to any other relevant University policies and/or funded or non-funded agreements that may be associated with the project. If funding is obtained subsequent to ethics approval, you must submit a Funding and/or Partner Change Request to ICEHR so that this ethics clearance can be linked to your award.

The *TCPS2* **requires that you strictly adhere to the protocol and documents as last reviewed by** ICEHR. If you need to make additions and/or modifications, you must submit an Amendment Request with a description of these changes, for the Committee's review of potential ethical concerns, before they may be implemented. Submit a Personnel Change Form to add or remove project team members and/or research staff. Also, to inform ICEHR of any unanticipated occurrences, an Adverse Event Report must be submitted with an indication of how the unexpected event may affect the continuation of the project.

The *TCPS2* **requires** that you submit an Annual Update to ICEHR before **May 31, 2024**. If you plan to continue the project, you need to request renewal of your ethics clearance and include a brief summary on the progress of your research. When the project no longer involves contact with human participants, is completed and/or terminated, you are required to provide an annual update with a brief final summary and your file will be closed. All post-approval ICEHR event forms noted above must be submitted by selecting the *Applications: Post-Review* link on your Researcher Portal homepage. We wish you success with your research.

Yours sincerely,

James Drover, Ph.D.
Vice-Chair, Interdisciplinary Committee on
Ethics in Human Research

JD/bc
cc: Supervisor – Dr. Doug Smith, Department of Ocean and Naval Architectural Engineering
Director, Research Initiatives and Services

Appendix IV - Complete As-Done FRAM Model

Functions from the D. Smith et al. work are marked with an asterisk (*). In all cases, variability discussion is only based on the study findings. Some additional information for functions from D. Smith et al. model were collected during interviews are reflected in their description and variability discussions in *Italic* font. Full details and variability discussions in D. Smith et al. work can be found in their paper [7]. Unidentified or insignificant aspects are called "Unidentified" in this report.

Function Name	**Receive the sailing order**
Description	Captain receives a sailing order from the ship management company which provides general information about the vessel, mission, and itinerary.
Input	Unidentified
Output	Sailing order received
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	The level of details may very between different companies and operations. This initial generic plan may be generated a year or six months or, in some cases, even much earlier in advance. It involves many factors and depends on the company's goals and procedures. The ship captain may be involved in developing it.
Function Name	**Become aware of regional regulations**
Description	Ship captain and ice navigator review regional regulations and consider them in their planning and operation.
Input	Unidentified
Output	Aware of regulations
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Regulations and official publications are available to captains, bridge teams, and ice navigators through the Canadian government's official website, onboard library, and safety management system. The ship management company provides updates according to their procedures. The frequency and depth of review depend on individuals' approach. They may refer to their memory and past information or experience. Ship management policies and procedures may regulate how and when updated regulations will be received by captains and ice navigators.
Function Name	**Become aware of historical ice and environmental conditions**
Description	Captain and ice navigator look at historical ice and weather conditions in the area to see the trend.
Input	Unidentified
Output	Aware of historical data
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	There are enough sources available in Canada, including the Canada ice service website. The level of including them depends on the bridge team. This information should be used cautiously. Historical information may not be beneficial for short-term strategic planning due to drastic changes in weather and ice conditions. When getting closer to the sailing date, the bridge team and ice navigators look at and track the current ice and weather conditions rather than relying on historical information.
Function Name	**Receive the initial route planning**

Description	In some case when captains join the ship, there is a route planning already made. Captains receive this plan as part of take over procedure and consider it in their planning.
Input	Unidentified
Output	A route plan is already prepared
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Become aware of the vessel's existing condition**
Description	Captain receives information about vessel's existing conditions through official reports and changeover processes and unofficial discussion and liaison with their colleagues onboard and in the shipping company.
Input	Unidentified
Output	Vessel condition is communicated
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	There is an official procedure and checklists/forms to follow during the handover process for this purpose. They may include ship conditions, defects and deficiencies, available provisions, and stores. The actual condition of the ship may be different from what is communicated in the takeover process due to a lack of sufficient reporting and human perception, but it is not usually a major issue. In addition to official takeover procedures, the captain may walk around the ship and receive unofficial information about the vessel's operational condition from their predecessor. Ship navigators may keep some unofficial notes in addition or attached to their official documents for future reference. This information may be useful in audits and for changeovers. They may also liaise with the superintendents or department heads onshore. Some specifics that do not fit within official documents may be good information for navigators. Additionally, the visual condition of the vessel gives an impression of its structural strength and machinery condition. Captains may check some systems to verify their performance, especially after a maintenance period.
Function Name	**Know crew**
Description	Captain becomes familiar with their crew by reviewing their certificates and competencies available onboard or received from the company as well as communicating with them directly. Captain makes sure they are experienced enough.
Input	Unidentified
Output	Become familiar with crew
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Captains and officers may consider the competency and experience of the crew in their decision-making. They may ask the company to provide more experienced personnel if the voyage is challenging. They may assess crews' performance through discussion and/or based on their behavior. Captains consider the level of experience and competency of the crew in the planning and regulate their supervision accordingly to ensure the safe execution of the voyage plan and watchkeeping.
Function Name	**Receive NORDREG message**
Description	Ships receive a feedback or message from NORDREG including clearance into northern Canadian waters or other feedback regarding their location and routing plan
Input	Unidentified
Output	NORDREG message received
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Routing and regular messages the vessel sends to NORDREG is processed and feedback is sent to the vessel. The quality and details of message may regulate the route planning and decision-making during the navigation. The process and decision-making in NORDREG and Canadian authority may affect the message.
Function Name	**Become aware of vessel's characteristics**
Description	Navigators become aware of vessel's anecdotal performances.
Input	Unidentified
Output	Aware of vessel characteristics

Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	This anecdotal information may include the ship's dynamic stability and seakeeping, equipment performance, vessel and equipment responses to actions, or environment that are not necessarily a part of official documentation. The level of detail varies based on individuals' experience and approach. Navigators may have prior experience with the ship or similar ships they are taking over. Some characteristics can be found in the official documents of the vessel, but some information may not be included in the official documents as they are not required to be recorded by regulations. These characteristics may be communicated through discussion between the vessel's crew and bridge team.
Function Name	**Become aware of ship certificates and SMS**
Description	The navigators become familiar with safety management system (SMS) and certificates status during takeover process.
Input	Unidentified
Output	Vessel Documents and records
Precondition	Ship classification assigned
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Many fundamentals of safety management systems in shipping companies are similar; however, details of procedures and ship particular considerations may vary. Being familiar with SMS is particularly important when the navigator has little experience in the intended operation. The ship maintenance plan and procedures are also important to schedule voyages and tasks onboard. There may be a gap between the vessel's documented procedures and actual operations due to the impracticality of implementing official procedures or lack of attention.
Function Name	**Become aware of available icebreakers and SAR services in the area**
Description	Ship captains consider availability of icebreaking and search and rescue (SAR) services, ports of refuge or repair services in the area for possible contingencies.
Input	Unidentified
Output	Aware of icebreakers and SAR
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	This is a part of contingency planning. It is important that icebreaker may not be available, so flexibility of the plan is an important factor. Support availability depends of the government and commercial supply in the area. Companies may provide commercial services for their fleet in their interest areas. In this case financial aspect of may be important.
Function Name	**Take over the vessel**
Description	The ship navigators receive information about the vessel and operation conditions when they join the ship. It includes but is not limited to operating conditions of systems, maintenance status, and safety management system. They may do unofficial communications, tests, and examinations to verify the reported condition.
Input	A route plan is already prepared Vessel condition is communicated
Output	Changeover process is completed
Precondition	Vessel Documents and records Become familiar with crew Aware of vessel characteristics
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	This function collects all inputs from different sources. It is important to note that this is a human team function. The whole or part of the bridge team and other crew may change during this procedure, and the level of communication, cooperation, experience, and enthusiasm regulates the extent and efficiency of the process.
Function Name	**Become familiar with the ship and its mission**
Description	Ice navigators get familiar with the vessel and its capabilities, management system, crew and operation.
Input	Unidentified
Output	Familiar with the vessel and operation
Precondition	Unidentified

Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	General information about the ship and operation is communicated through the company, but most detailed information will be received onboard from the bridge team. The management company may have a procedure for briefing the bridge team and ice navigator and communicating information. The primary required information is ship ice class, power, maneuverability, and crew experience in icy waters. The level of detail and cooperation may vary depending on the bridge culture and individuals' approach.
Function Name	**Collect complementary ice information**
Description	Ice navigator and captains may collect information from different unofficial sources.
Input	Unidentified
Output	Complementary information is collected
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Ice navigators may collect information about the area, especially recent ice conditions, by communicating with their colleagues navigating in the area. They may look at AIS data to see how other vessels may navigate in the area. They do not refer to this unofficial information in their official reports; still, they consider them cautiously to have a clearer picture of the actual environmental condition in the area.
Function Name	**Consider Zone/Date system**
Description	Navigators can refer to Zone/Date to plan to enter a zone in NORDREG.
Input	Unidentified
Output	Zone/Date system is considered
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	The Zone/Date system is not the only tool to decide to enter an area in the NORDREG Zone. Navigators may avoid an area due to heavy ice conditions despite the Zone/Date system. The Zone/Date system is not the best tool to decide to enter an area due to constant changes in ice patterns and the effects of global warming.
Function Name	**Create/revise the route plan**
Description	A route plan is created or the existing route plan is revised based on updated information and situation.
Input	Sailing order received Route planning should change Changeover process is completed Ice office comments
Output	Route plan is made Icebreaker support is required Inform the management company
Precondition	Aware of regulations Aware of historical data Aware of icebreakers and SAR
Resource	Weather forecast obtained Have shipping lane maps Obtained forecasted ice conditions Consultancy services Complementary information are collected Nautical charts are obtained Aware of vessel′s typical capability
Control	Ice navigator review/recommendations Ice Numeral computed Zone/Date system is considered NORDREG message received
Time	Unidentified
Variability Discussion	The bridge team updates the route plan. They should constantly consider revising the voyage plan because of the changing situation. It is more important in icy waters due to more variability in environmental conditions and ice-related situations.
Function Name	**Ice navigator provides recommendations**

Description	Ice navigators review the route plan prepared by the bridge team and give feedback. If they are present at the time of planning they may provide feedbacks directly.
Input	Route plan is made
Output	Ice navigator review/recommendations Ice navigator makes sure the message is sent
Precondition	Ice navigator has been assigned Familiar with the vessel and operation Aware of historical data Aware of regulations
Resource	Have shipping lane maps Obtain forecasted ice conditions Weather forecast obtained Complementary information is collected Consultancy services Nautical charts are obtained
Control	Ice office comments NORDREG message received
Time	Unidentified
Variability Discussion	Ice navigator provides experience-based judgment to the bridge. In cases where the captain or other officers have the ice navigator qualifications, it is not required to have another ice navigator onboard. This reduces the opinion and experience available for decision-making. In some cases, the qualified crew has little icy water experience or navigation experience in the area, which causes a lack of experience in overall performance.
Function Name	**Send navigation information to the Canadian Authority**
Description	In NORDREG, Eastern Canada Vessel Traffic Control, and Vessel Traffic Control Zones, ships' captains should send report of their ship information and navigation condition, and voyage planning to MCTS.
Input	Route plan is made
Output	Unidentified
Precondition	Unidentified
Resource	Unidentified
Control	Ice navigator makes sure the message is sent
Time	Unidentified
Variability Discussion	Vessel entitled to [63], SOR/89-99 [64] and SOR/89-98 [65] should send the required information according to the respective regulations. The reporting requirements are different based on the situation and area. The Canadian authority may require additional information. The bridge team should also send their position reports to the regional operation center at least once a day. They also send their deviation report when they decide to change the voyage plan. Ice navigators review these reports and make sure of proper reporting to the authority. The authority provides the ship with feedback. The quality of observation and reporting affects the Canadian authority's feedback.
Function Name	**Obtain nautical charts**
Description	Bridge team obtains nautical charts and publications of the navigation area.
Input	Unidentified
Output	Nautical charts are obtained
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Canadian Hydrographic Service (CHS) provides nautical charts and publications for Canadian waters. Nautical charts are a major source for planning and operation. Bridge team should use updated version of them onboard. Availability of updated version of nautical charts and publications should be insured through safety management system. The quality and accuracy of nautical charts may vary in different areas, especially in remote areas.
Function Name	**Communicate with consultants**
Description	Bridge team and ice navigators consult with consultants onshore.
Input	Unidentified
Output	Consultancy services
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Some companies provide consultancy services for their ships either directly in their organizations or through commercial firms. Captains and ice navigators can be directly in contact with them and

	communicate their information and recommendations. They may also provide complementary environmental and sea ice information. The availability and efficacy of this consultation service depend on the shipping company's approach. Communication with onshore entities in remote areas may be challenging due to a lack of communication signals.
Function Name	**Communicate with ice office**
Description	Navigators have a communication with ice offices and are in consultation with them. They may consider their recommendations in their operation and route planning.
Input	Unidentified
Output	Ice office comments
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	This communication is not essentially in the form of official correspondence. The Canadian Coast Guard provides ice offices in different months of the year, subject to ice conditions in different areas in Canadian waters. Ship and ice navigators may call or send an email to the respective ice offices and ask questions or request assistance. The availability and experience of the expert affect the process.
Function Name	**Inform the management company**
Description	The captain informs the shipping company about different situations, including but not limited to updated routing plans and schedules, available provisions, and operational conditions. They may ask the shipping company to arrange icebreaker support on their behalf.
Input	Inform the management company
Output	Icebreaker support is required
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Management company policies, procedures, and working culture may affect ship operations. The company may push the bridge team to save fuel, voyage time, and other economic aspects of the operation.
Function Name	**Download satellite images**
Description	Bridge team downloads satellite images for the navigation area and compares them to other ice data.
Input	Unidentified
Output	Satellite images are obtained
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	Satellite imagery like Moderate Resolution Imaging Spectroradiometer (MODIS) provides a picture of the area, but it only shows the presence of ice and, to some extent, ice concentration. However, the weather condition (cloud and fog) affects the images and, in some cases, make them unusable. Different ice data are released at different times of day. The bridge team may compare them to compensate for their temporal resolution and have a clearer understanding of the ice conditions in the area. There is more sophisticated imagery produced by radar/sensor detections. Some of this data can be found in the U.S. National Oceanic and Atmospheric Administration. The level of associating this complementary information depends on the individual's approach and SMS provisions, which are established by the ship management company.
Function Name	**Obtain map of shipping lanes***
Description	Prior to shipping through an area it is good practice to obtain maps of the shipping lanes. The shipping lanes typically has more reliable soundings and have been practiced over the years.
Input	Have shipping lane maps
Output	Unidentified
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Assign ship classification***
Description	The ship is assigned a classification. In particular, this classification here pertains to the category that will be used to compute the ice numeral.
Input	Unidentified
Output	Ship classification assigned

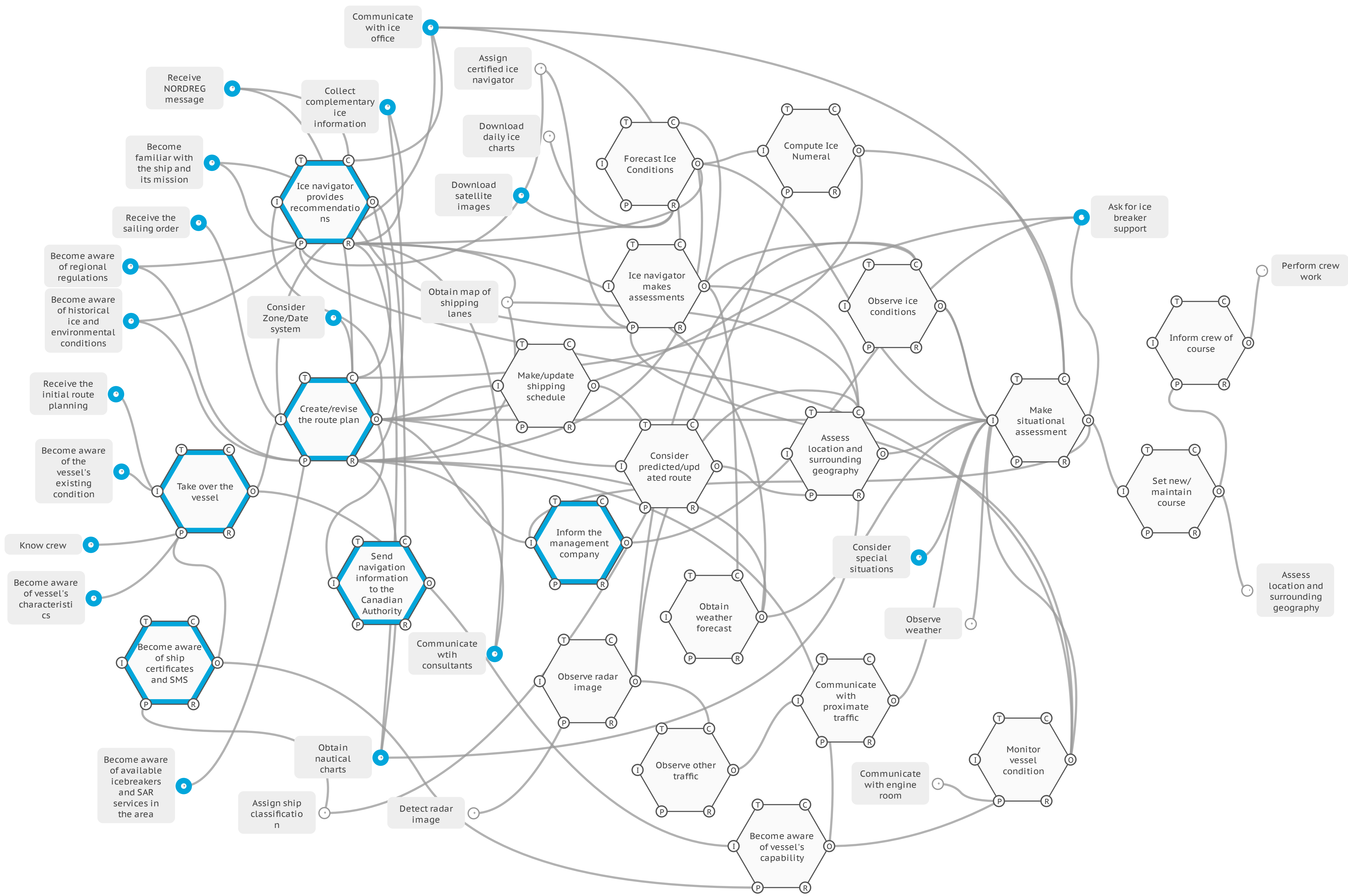
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Make*/update* shipping schedule***
Description	Expected departure and arrival times are determined.
Input	*Route plan is made*
Output	Shipping schedule made
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	*The captain may change the departure time and shipping schedule based on the vessel's actual condition and the updated plan.*
Function Name	**Consider predicted/updated route***
Description	Consider the current route you are transiting. This may be suggested by operational planners or adjusted by the navigator.
Input	*Route plan is made*
Output	Aware of the present route
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Shipping schedule made
Variability Discussion	
Function Name	**Download daily ice charts***
Description	Download the daily ice chart(s) that are applicable to your region. These charts are produced by Canadian Ice Services (CIS) in Canada.
Input	Unidentified
Output	Ice chart downloaded
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Detect radar image***
Description	Radar signal has been sent from ships radar and is ready to receive any signals that bounce back from objects
Input	Unidentified
Output	A radar signal has been detected by ships radar
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Assign certified ice navigator ***
Description	To assign an ice navigator to assist with navigation of the vessel. This is required for Navigation in the Canadian Arctic.
Input	Unidentified
Output	Ice navigator has been assigned
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Observe radar image***
Description	The radar image is observed and then should be visually inspected to determine what caused the radar image to be produced
Input	Unidentified
Output	Radar image observed
Precondition	A radar signal has been detected by ships radar
Resource	Unidentified
Control	Unidentified

Time	Unidentified
Variability Discussion	
Function Name	**Observe other traffic***
Description	Observe any other shipping traffic that may be in the area
Input	Unidentified
Output	Other traffic observed
Precondition	Unidentified
Resource	Unidentified
Control	Radar image observed
Time	Unidentified
Variability Discussion	
Function Name	**Become aware of vessel's capability***
Description	The navigator becomes aware of the vessel's capabilities. The navigational, structural and operational capabilities.
Input	*Changeover process is completed*
Output	Aware of vessel's typical capability
Precondition	*Vessel Documents and records*
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	*In icy water navigations, vessels' ice strengthening and maneuverability are important for navigators.* *Additionally, navigators may consider the ship's age as a parameter in capabilities. Depending on the ship type, assigned class, operational requirements, and visual condition of the vessel, navigators may or may not feel comfortable touching ice.*
Function Name	**Communicate with engine room***
Description	There is communication between the engine room and the bridge to discuss any issues or needed maintenance.
Input	Unidentified
Output	Engine room maintenance/issues informed
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	*Dual fuel ships are required to change fuel type to achieve their best machinery responses when required. Availability of all maneuvering machinery is another important factor the bridge team should be aware of in icy waters. The effective and timely communication between the engine room and bridge regulates the availability of machinery and use of them in tactical navigation.*
Function Name	**Monitor vessel condition***
Description	The vessel's condition is monitored to understand the vessel's current capabilities.
Input	Unidentified
Output	Aware of apparent vessel condition
Precondition	Engine room maintenance/issues informed Aware of vessel's typical capability
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	*The range of monitor covers sensors, monitoring systems, routine and checklist-based maintenance, and regular visual observations. Some of them are established in SMS, but the level of execution may vary from person to person. Maintenance and inspections can be different in different cases as technological systems are different for different vessels.* *Also, the ship crew may change their monitoring approach in different operational conditions. For example, the captain may consider extra tank soundings if the vessel operates in icy waters. Also, navigators may make some guesses based on their feeling and intuitive understanding of the vessel's behavior and may take action to check the condition.* *When operating on ice, navigators monitor speed to avoid hull damage and make sure about the sea suction and hull appendage conditions relative to the draft.*
Function Name	**Communicate with proximate traffic***
Description	Communicate with proximate traffic. This can be done via lights, horns or radio.
Input	Other traffic observed
Output	Proximate traffic communicated with
Precondition	Unidentified
Resource	Unidentified

Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Ice navigator makes assessments***
Description	Ice navigator makes assessments of the conditions and upcoming tasks and shares experience with ships bridge team.
Input	Unidentified
Output	Experienced visual assessment of ice
	Experience based ice forecast
	Improved knowledge of regional specific conditions
	Experienced based weather judgment
Precondition	Ice navigator has been assigned
	Aware of apparent vessel condition
	Familiar with the vessel and operation
Resource	Unidentified
Control	*Ice office comments*
Time	Unidentified
Variability Discussion	
Function Name	**Obtain weather forecast***
Description	Obtain weather forecast from meteorological organization or department
Input	Unidentified
Output	Weather forecast obtained
Precondition	Unidentified
Resource	Unidentified
Control	Experience based weather judgment
Time	Unidentified
Variability Discussion	
Function Name	**Forecast Ice Conditions***
Description	Obtain the forecasted ice conditions. This may be done by historical trends in area and/or tactical ice drift models
Input	Unidentified
Output	Obtain forecasted ice conditions
	Daily ice chart observed
Precondition	Unidentified
Resource	Ice charts downloaded
	Satellite images are obtained
Control	Experience based ice forecast
Time	Unidentified
Variability Discussion	
Function Name	**Compute Ice Numeral***
Description	Compute the ice numeral as per Canadian regulatory requirements.
Input	Daily ice chart observed
Output	Ice numeral computed
Precondition	Ship classification assigned
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Assess location and surrounding geography***
Description	Locate the vessel with respect to intended route, shipping lanes and regional geographic features.
Input	Unidentified
Output	Geographical assessment made
Precondition	Aware of the present route
Resource	*Nautical charts are obtained*
Control	Have shipping lane maps
	Improved knowledge of regional specific conditions
Time	Unidentified
Variability Discussion	
Function Name	**Observe ice conditions***
Description	Observe the current ice conditions. This can be done from the bridge or on deck, but also the conditions ahead can be observed via helicopter or aircraft.
Input	Unidentified
Output	Ice conditions have been visually observed onboard

	Up route ice conditions assess with helicopter
Precondition	Unidentified
Resource	Unidentified
Control	Experienced visual assessment of ice Radar image observed
Time	Unidentified
Variability Discussion	*Ice observation may be done through communication with shore supports like lighthouses.* *Ice movement and pressure due to sea currents, geographical conditions, and tidal currents are also important factors navigators monitor during the operation.*
Function Name	**Observe weather***
Description	The current local (ship) weather conditions are observed. This can be from the bridge or on deck.
Input	Unidentified
Output	Weather has been observed
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	*Air temperature is an important parameter that should be monitored. It may be required to preheat the engine room air and make sure of the correct condition of exposed systems like firefighting systems.* *Reduced visibility is another important environmental factor that affects decisions. Fog in the Arctic can appear suddenly. Navigators may reduce speed due to lack of visibility.*
Function Name	**Consider special situations**
Description	Some special conditions like medical emergencies, serious safety issues and problems in vessel operability may require special considerations that may cease or require deviation in the operation.
Input	Unidentified
Output	Special situation happened
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Make situational assessment***
Description	The captain and bridge team make a situational assessment based on the available information at a given time.
Input	Weather forecast obtained Up route ice conditions assess with helicopter Obtained forecast ice conditions Geographical assessment made Weather has been observed Aware of apparent vessel condition Ice condition have been visually observed onboard Proximate traffic communicated with *Special situation happened*
Output	Complete or partial assessment made *Icebreaker support is required* *Route planning should change* *Inform the management company*
Precondition	Unidentified
Resource	Unidentified
Control	Ice numeral computed *Ice office comments*
Time	Unidentified
Variability Discussion	
Function Name	**Ask for ice breaker support**
Description	Commercial vessels may ask for icebreaker support directly or through their agents or company (owner). Ships can request via coastal radio station, and the owner or agent can call the ice operation center.
Input	Icebreaker support is required
Output	Unidentified
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified

Time	Unidentified
Variability Discussion	
Function Name	**Set new/ maintain course***
Description	A decision is made to either maintain the current course or to make adjustments to course. *Navigators may decide to maintain or change speed.*
Input	Complete or partial assessment made
Output	Routing decision made
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Assess location and surrounding geography***
Description	Locate the vessel with respect to intended route, shipping lanes and regional geographic features.
Input	Routing decision made
Output	Unidentified
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Inform crew of course***
Description	Inform crew of any change of course if necessary.
Input	Unidentified
Output	Responsible crew member notified
Precondition	Routing decision made
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	
Function Name	**Perform crew work***
Description	The crew will perform their necessary work to maintain course or adjust their work to accommodate any changes.
Input	Responsible crew member notified
Output	Unidentified
Precondition	Unidentified
Resource	Unidentified
Control	Unidentified
Time	Unidentified
Variability Discussion	



Communicate with ice office
Assign certified ice navigator
Receive NORDREG message
Collect complementary ice information
Download daily ice charts
Become familiar with the ship and its mission
Ice navigator provides recommendations
Forecast Ice Conditions
Compute Ice Numeral
Download satellite images
Receive the sailing order
Ask for ice breaker support
Become aware of regional regulations
Ice navigator makes assessments
Observe ice conditions
Perform crew work
Become aware of historical ice and environmental conditions
Consider Zone/Date system
Obtain map of shipping lanes
Inform crew of course
Receive the initial route planning
Make/update shipping schedule
Create/revise the route plan
Make situational assessment
Assess location and surrounding geography
Consider predicted/updated route
Become aware of the vessel's existing condition
Take over the vessel
Set new/ maintain course
Inform the management company
Know crew
Send navigation information to the Canadian Authority
Consider special situations
Obtain weather forecast
Become aware of vessel's characteristics
Assess location and surrounding geography
Observe weather
Communicate wtih consultants
Become aware of ship certificates and SMS
Observe radar image
Communicate with proximate traffic
Observe other traffic
Monitor vessel condition
Obtain nautical charts
Become aware of available icebreakers and SAR services in the area
Communicate with engine room
Assign ship classification
Detect radar image
Become aware of vessel's capability