



**IAMU 2015 Research Project**  
**(No. 20150304)**

**Application of Formal Safety Assessment  
in Polar Maritime  
Transportation: Namely Routeing,  
Emergency Procedures and  
Human Factors (FORSASS.POMARTRA)**

**By**

**Fisheries and Marine Institute, Memorial University (FMIMUN)**

**August 2016**

**IAMU**  
**International Association of Maritime Universities**

This report is published as part of the 2015 Research Project in the 2016 Capacity Building Project of International Association of Maritime Universities, which is fully supported by The Nippon Foundation.

The text of the paper in this volume was set by the author. Only minor corrections to the text pertaining to style and/or formatting may have been carried out by the editors.

All rights reserved. Due attention is requested to copyright in terms of copying, and please inform us in advance whenever you plan to reproduce the same.

The text of the paper in this volume may be used for research, teaching and private study purposes.

No responsibility is assumed by the Publisher, the Editor and Author for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in this book.

### **Editorial**

IAMU Academic Affairs Committee (AAC)

Head of Committee : Piotr JĘDRZEJOWICZ

Rector, Gdynia Maritime University (GMU)

Editorial committee : Bogumil LACZYNSKI (GMU)

Bill DAVIDSON (CSUMA)

NGUYEN Thanh Son (VMU)

---

Published by the International Association of Maritime Universities (IAMU) Secretariat

Meiwa Building 8F, 1-15-10 Toranomom, Minato-ku,

Tokyo 105-0001, JAPAN

TEL : 81-3-6257-1812    E-mail : [info@iamu-edu.org](mailto:info@iamu-edu.org)    URL : <http://www.iamu-edu.org>

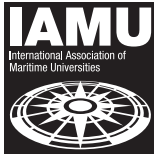
Copyright ©IAMU 2016

All rights reserved

ISBN978-4-907408-15-2

---





**IAMU 2015 Research Project**  
(No. 20150304)

**Application of Formal Safety Assessment  
in Polar Maritime  
Transportation: Namely Routeing,  
Emergency Procedures and  
Human Factors (FORSASS.POMARTRA)**

By

**Fisheries and Marine Institute, Memorial University of Newfoundland (FMIMUN)**

Contractor : Glenn BLACKWOOD, Vice President, FMIMUN

Research Coordinator : James R. PARSONS, FMIMUN

Research Partner : Vladimir E. KUZMIN, AMSU-MIS

Elizabeth K. CLOUTER, FMIMUN

# Table of Contents

ABSTRACT .....	2
LIST OF FIGURES .....	4
List of Tables .....	5
LIST OF ACRONYMS .....	6
1.0 FORMAL SAFETY ASSESSMENT LITERATURE REVIEW .....	8
1.1 INTRODUCTION .....	8
1.2 FORMAL SAFETY ASSESSMENT IN REVIEW .....	8
1.3 FSA IMPACTS .....	9
1.4 FSA DEFICIENCIES .....	10
2.0 FORMAL SAFETY ASSESSMENT .....	21
2.1 INTRODUCTION TO RISK MANAGEMENT IN ARCTIC MARITIME TRANSPORTATION .....	21
2.2 SCOPE .....	22
2.3 FSA STEP 1: HAZARD IDENTIFICATION .....	22
2.4 FSA STEP 2: RISK ANALYSIS .....	28
2.5 FSA STEP 3: RISK CONTROL OPTIONS .....	40
2.6 FSA STEP 4: COST BENEFIT ANALYSIS .....	43
2.7 FSA STEP 5: RECOMMENDATIONS FOR DECISION-MAKING .....	44
3.0 CONCLUSIONS .....	45
4.0 RECOMMENDATIONS FOR THE USE OF FSA IN ARCTIC SHIPPING .....	46
References .....	48

Appendix A: Requirements for Vessels and Arctic Navigators as per IMO	
Requirements .....	57
Appendix B: Publications Required or Recommended by Transport Canada to be	
Carried on Vessels Sailing in the Canadian Arctic .....	63
Appendix C: Standard of Competence for Ice Navigation .....	65
Appendix D: Project Correspondence .....	71





**Application of Formal Safety Assessment in Polar Maritime  
Transportation: Namely Routeing, Emergency Procedures and  
Human Factors (FORSASS.POMARTRA)**

**by**

**Fisheries and Marine Institute, Memorial University, Canada (Contractor)**

**and**

**James R. Parsons (Research Coordinator)**

**Research partners:**

**James R. PARSONS**

*Captain, Academic Director, School of Maritime Studies, Marine Institute, Memorial University, Newfoundland,  
Canada [Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)*

**Vladimir E. KUZMIN**

*Associate Professor, Admiral Makarov State University of Maritime and Inland Shipping, Saint-Petersburg,  
Russia [vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)*

**Elizabeth K. CLOUTER**

*Instructor, School of Maritime Studies, Marine Institute, Memorial University, Newfoundland, Canada  
[eclouter@mi.mun.ca](mailto:eclouter@mi.mun.ca)*

## Abstract

Global attention towards the Arctic is increasing, especially in the exploitation of its waters and hence in maritime transportation. Some of the main drivers of this increase include a decline in the coverage and thickness of multi-year ice, longer open water periods during the Arctic summer, increase in demand for renewable and non-renewable resources in the area, improvements in technology, potential gains in business efficiency via shorter shipping routes, and population growth of native and non-native people requiring greater consumer choice and more services. Regardless of the global growth in interest, the Arctic remains a very challenging environment in which to safely and effectively operate as it is a remote, isolated, geographically vast, sparsely populated, environmentally sensitive, climatically harsh, poorly charted and meagerly serviced region with extensive periods of total darkness and waters that are ice covered or ice-infested.

The Arctic presents many hazards and risks to maritime transportation and thus effective risk management is a vital component of safe and successful business operations. To help drive the need for risk management, the International Maritime Organization (IMO), through its International Safety Management (ISM) Code, requires ship owners to establish safeguards against all identified risk. To expand on the work of the IMO in the area of risk management, a Formal Safety Assessment (FSA) concept has been developed and credited with prompting numerous initiatives and regulatory changes. The goal of the FSA is to predetermine need so that measures can be established in an attempt to prevent tragedy. The FSA methodology has several of the characteristics common to many risk management approaches and is a five step process with feedback loops. The steps include hazard identification, risk assessment, risk control options (RCOs), cost-benefit assessment (CBA), and decision-making recommendations. While the FSA methodology is not without its critics, it is felt that with appropriate application tailored to numerous challenges, it is a suitable risk management tool for use in Arctic maritime transportation.

The Canadian Transportation Safety Board (TSB) database was utilized to gain insight on the circumstances surrounding the 157 reported marine occurrences in Canadian waters north of 60°N between the years 2000 and 2014. Of the 157 reported occurrences four were fully investigated and reported on by the TSB. Three of the four reports were completed and released to the public prior to 14 March 2016; the fourth report was released on 15 March. Although the fourth report was not incorporated into the FSA, a review determined that the report's findings as to causes and contributing factors of the vessel grounding were similar to two of the three earlier reports in which vessel grounding was the outcome. In these three vessel grounding events the TSB reported that poor bridge resource management was practiced, safety management systems were lacking, bridge equipment was not effectively used, and crew were fatigued. In comparing Canadian Arctic shipping statistics with those of other Arctic nations, it was found that the biggest risk to vessels sailing in Arctic ice covered water was related to vessel damage as a result of contact with ice or grounding. Throughout the research, it was observed that there is room for improvement in the way that data are collected and presented both in Canada and elsewhere. With respect to gaps in the current education and training requirements stipulated by the IMO through various Conventions and Codes, there appear to be none that would have contributed to the four occurrences investigated by the TSB as noted above. In addition, it was noted from interviews with industry advisors, all having experience working in Arctic waters, that the current status of IMO education and training requirements for Arctic water navigation is sufficient. However, it was stressed that experience and mentoring were critical to safe and efficient shipping operations in Arctic ice covered waters. Also, it was noted that industry will benefit from an IMO model course with more detailed curriculum on ice navigation. Current training mostly address



deck officers while training of engine officers should also be a part of the ship readiness to operate in polar waters. It is expected that an IMO Polar Code ice navigation course will be in effect as of 2018.

While there were limitations with respect to available data, time, and resources, the FSA recommended three RCOs for adoption and implementation. These included an ice navigation training course, ice radar system, and high power searchlights suited for extreme weather conditions for a total combined cost of approximately USD \$134K. The FSA did not calculate the probability of a vessel grounding in the Arctic prior to or after the implementation of the RCOs and made the assumption that implementation of the RCOs would prevent an oil spill. In the event that an oil spill, independent of size, were to occur in the Arctic, a 2016 net present value of the cleanup cost was calculated based on a 5% annual interest rate, a 2009 global average total spill cost of USD \$67,275, and a 2006 North American average cleanup cost of USD \$24K/tonne, and that cleanup costs in the Arctic could be in the range of ten times that in the south. Using these figures and hypothetical assumptions, the NPV could be estimated approximately between USD \$400K and \$950K per tonne.

Several recommendations are provided for the application of FSA in Arctic shipping. Not all of these recommendations were applied to the FSA as some challenges were insurmountable in light of the time and resources available. While the recommendations are not listed in an overall order of importance, they highlight that a FSA for Arctic shipping will be a time-intensive venture which, depending on its nature and extensiveness, could take several years. In addition, due to the vast diversity and sensitivity of the entire Arctic region, regional focus is critical.

**Keywords:** Risk, Arctic, Maritime, Navigation, FSA

## List of Figures

Figure 1. Proposed Viable Trans-Arctic Shipping Routes.....	21
Figure 2. The Five Steps of an FSA. ....	22
Figure 3. Bayesian Network of the 28 Potential Hazards and Possible Connections.....	24
Figure 4. Shipping occurrences by year from 2000 to 2014.....	29
Figure 5. Shipping occurrences by month from 2000 to 2014.....	30
Figure 6. Shipping occurrences by subtype from 2000 to 2014.....	30
Figure 7. Shipping occurrences by category from 2000 to 2014.....	31
Figure 8. Marine occurrences in Canadian waters north of 60° between January 2000 and November 2014.....	31
Figure 9. Shipping accidents north of 66° pan-Arctic by year from 1995 to 2014.....	32
Figure 10. Shipping accidents north of 66° pan-Arctic by month from 1995 to 2014.....	32
Figure 11. Shipping accidents north of 66° pan-Arctic by reason from 1995 to 2014.....	33
Figure 12. Raw plot on ArcMap? of all 450 recorded major shipping incidents in the Arctic region sourced from LMIU.....	33

## List of Tables

Table 1. Main Hazards Associated with Shipping in Greenland Waters .....	25
Table 2. Probability of a Hazardous Event Occurring in the Waters off Greenland.....	25
Table 3. Dangerous Situations Posing a Real Threat to Ships Sailing in Greenland Waters.....	26
Table 4. Hazards to Shipping in the Canadian Arctic.....	26
Table 5. Reasons for Accidents and Possible Consequences in the Baltic Sea .....	27
Table 6. FSA Frequency Index .....	38
Table 7. FSA Severity Index .....	38
Table 8. FSA Risk Index .....	39
Table 9. Risk Index for Vessel Damage in Arctic Waters .....	39
Table 10. Sigma S6 Ice Radar Cost and Specifications .....	41
Table 11. Seematz Searchlight Specifications .....	42
Table 12. GCAF and NCAF for all RCOs.....	43



## List of Acronyms

AIS – Automated Information System  
ALARP – As Low As Reasonably Practicable  
BN – Bayesian Networks  
BRM – Bridge Resource Management  
CAD – Canadian Dollars  
CBA – Cost Benefit Assessment  
CHS – Canadian Hydrographic Service  
CREAM – Cognitive Reliability and Error Analysis Method  
DNV - Det *Norske Veritas*  
ETA – Event Tree Analysis  
FI – Frequency Index  
FMA – Finnish Maritime Administration  
FMEA – Failure Mode and Effect Analysis  
FRAM – Functional Resonance Analysis Method  
FSA – Formal Safety Assessment  
FTA – Fault Tree Analysis  
GBS – Goal Based Standards  
GCAF – Gross Cost of Averting a Fatality  
HAZID – Hazard Identification  
HAZOP – Hazard and Operability  
HE – Human Error  
HEAP – Human Element Analysing Process  
HEP – Human Error Probability  
HRA – Human Reliability Assessment  
IMO - International Maritime Organization  
IOPCF – International Oil Pollution Compensation Fund  
ISM – International Safety Management Code  
K – Thousand  
LMIU – Lloyd’s Maritime Intelligence Unit  
MARPOL – The International Convention for the Prevention of Pollution from Ships  
MCDA – Multi-criteria Decision Analysis  
MED – Marine Emergency Duties  
MEPC – Marine Environmental Protection Committee  
MI – Marine Institute  
MSC – Maritime Safety Committee  
NCAF – Net Cost of Averting a Fatality  
NMTC – Northern Marine Transportation Corridors  
NORDREG - Northern Canada Vessel Traffic Services Zone  
NOTSHIP – Notice to Shipping  
NPW – Net Present Value  
NWP – Northwest Passage  
PC – Polar Code  
P&I – Protection and Indemnity

QSEP – Quality Safety and Environmental protection  
RA – Risk Assessment  
RCO – Risk Control Option  
RCT – Risk Contribution Tree  
RI – Risk Index  
SDC – Ship Design and Construction  
SI- Severity Index  
SMS – Safety Management System  
SOLAS – Safety of Life at Sea  
STCW- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers  
Swedish Maritime Administration  
TC – Transport Canada  
TSB – Transportation Safety Board of Canada  
TSC – Total Spill Cost  
UK – United Kingdom  
USD- United States Dollars

## 1.0 Formal Safety Assessment Literature Review

### 1.1 Introduction

The significance of maritime initiatives such as the Formal Safety Assessment (FSA) aligns with the irrefutably fundamental role of maritime shipping on the world stage. According to Det Norske Veritas (DNV) [1], although vulnerable to the ebb and flow of the global economy, maritime shipping stands tall in the supply chain, accounting for 90% of world trade as measured by volume, with the caveat of using only 7% of all the energy consumed by transport activities [2]. Furthermore, despite economic fluctuations, the forecast for shipping appears positive, with both seaborne trade and world fleet capacity expected to grow well into the next decade [1]. In addition to experiencing what is generally accepted as exponential growth, the shipping industry has also seen a marked drop in maritime accidents worldwide in recent decades [3-4]. Nevertheless, as evidenced by the recent Costa Concordia tragedy for example, the shipping industry continues to be exposed to significant inherent risk [5-6] despite carefully planned and implemented safety procedures [3,6-7].

This framework is the backdrop to a momentous thrust in the industry to establish efficient, accurate guidelines regarding risk assessment and prevention that not only acknowledge the industry's "increased maritime traffic" [8] (p. 107) and profound global presence but also the rapid changes due to technology which have in turn necessitated closer review of aspects such as ship design, including the notably robust increase in container ship size, the introduction of "large" lifeboats, and the use of liquefied natural gas and other gases as a fuel in many ship types, to name a few [5-6]. In tandem, new ship design is associated with operational and safety issues. Moreover, the emergence of the Arctic corridor as a shipping route presents a new and exciting focus in maritime shipping and efficiency, but brings with it unique challenges to maritime safety considerations, as recognized by the establishment of the Polar Code (PC) due to take effect in 2017 and in plans such as the Northern Marine Transportation Corridors [NMTC] initiative [9]. Therefore, notwithstanding the improvements in maritime safety and the assertion that it can indeed be achieved [10], room for heightened awareness and further improvement still exists [11]. Although the concept of risk assessment is not new in the marine industry, formal and standardized methodologies for conducting them are a relatively recent focus [6] and, as Eswara [12] points out, their presence is vital as effective regulations and assessment tools greatly contribute to disaster prevention.

To that end, this review examines the FSA, which embodies the guidelines set forth by the International Maritime Organization [13] for a proactive vs reactive risk-based decision making approach aimed at "enhancing maritime safety" (p. 1). It reviews the evolution of the FSA, identifying both noteworthy accomplishments and deficiencies as well as how the IMO has responded to these concerns. The review indicates current trends in the FSA and that, despite various shortcomings, with appropriate modification tailored to that unique environment, it is a suitable tool for use in Arctic maritime transportation.

### 1.2 Formal Safety Assessment in Review

Historically, marine industry guidelines and regulations were notably stagnant, as evidenced by Sheehan's 1987 comment following the *Herald of Free Enterprise* investigation, that "the 1960 Safety Convention Regulations...do not take into account evolution in ship design and advances in knowledge over about the past 50 years" [14] (p. 49). Furthermore, the predominant maritime regulatory body itself, the IMO, came into being only in 1959. Likewise, cornerstone safety codes and



conventions such as SOLAS, MARPOL, and STCW'95 arose largely in response to tragedies which occurred over the course of the 20<sup>th</sup>-21<sup>st</sup> centuries.

The FSA concept was partially developed in 1988 in response to two European maritime disasters: the explosion of the *Piper Alpha* platform in the North Sea and the sinking of the British vessel, *Herald of Free Enterprise*, off the Belgian coast which together claimed 360 lives. These tragedies led to ensuing studies such as the 1992 Lord Cullen Report [15] which questioned the sufficiency of safety considerations in ship design and related regulations, especially with regard to developing technology. As well, related discussion arose concerning the need for proactive risk assessment in the approach to shipping governance [16-18] noteworthy progression in maritime safety analysis since the 1990s ensued [5], eventually leading to the adoption of the 1997 Interim FSA Guidelines by the IMO Maritime Safety Committee (MSC), followed by the official Guidelines in 2002 (see MSC/Circ. 1023-MEPC/Circ. 392) as endorsed by the MSC and the Maritime Environmental Protection Committee (MEPC), a first round of amendments (MSC 83/INF.2) in 2007, and the most recent 2013 Revised Guidelines (MSC-MEPC.2/Circ.12).

The goal of the FSA as an assessment tool is to pre-determine need so as to in turn guide the establishment of regulations, designs, and operational criteria, etc., in an effort to prevent tragedy. Some see this goal as a complement to the IMO's Goal-Based Standard (GBS) philosophy [6,11,19] in moving away from a prescriptive-based approach to safety, also mirrored in the UK Parliament's 1992 recommendation for goal-based safety standards for commercial vessels [7], for evaluating existing ones, as well as for improving and developing classification rules. The FSA is therefore intended to balance technical and operational concerns as well as safety and costs while also considering the human element, all of which are central to the conducting of the entire FSA process as outlined in MSC-MEPC. 2/Circ. 12 [20] through five consecutive steps:

1. Hazard identification (HAZID)
2. Risk assessment (RA)
3. Risk control options (RCOs)
4. Cost-benefit assessment (CBA)
5. Recommendations for decision-making

### ***1.3 FSA Impacts***

Notwithstanding some valid criticism, it appears that, overall, the FSA is indeed being used [5] and has shown itself to have a strong voice in the shipping industry. It has been credited with prompting numerous initiatives and regulatory changes such as in cargo ship safety [21], in the overturning of the Double Side-Skin (DSS) hull provision [22] as set out in MSC 76-78, in the MSC ruling on Helicopter Landing Areas (HLAs) on passenger ships [23-24], in new protocol governing bulk carrier safety at MSC 76 [25] as well as in the establishment of better defined Environmental Risk Evaluation Criteria as set forth in MEPC 62-64 [26].

Additionally, the FSA has promoted studies on various vessels such as container ships [27], Liquefied Natural Gas (LNG) [27], cruise and Ro-Pax vessels [28-29] as well as general cargo ship safety [21]. These and similar focuses have contributed to new regulations and improvements in areas such as simulation training [5] as well as in very specific types of RCOs such as Electronic Chart Display and Information System (ECDIS) as referenced in MSC 85 and 88 [30-31] as well as in the 2015 amendment requiring that RCOs not only specify an RCO's application but also be submitted in

specific, measurable, achievable, realistic, and time-bound (SMART) terms [32]. The FSA has also played a role in enhancements to shipping management best practices such as evidenced in the International Association of Classification Societies' (IACS) study into the watertight integrity on the fore end of bulk carriers which revealed the need for a more detailed assessment at both the onboard and shore side operations level [33]. As well, there have been movements forward in organizational and technological measures such as in the transport of dangerous goods interacting with water or CO<sub>2</sub> as outlined at the 91st MSC [34]. The FSA process has also been instrumental in developments advancing the risk-based approach to the ship design process such as exploration of the use of autonomous vehicles as illustrated in the 2013 model for novel ship design as presented in Kang, Yang, Choi, Lee, and Lee [35], in Rodseth and Burmeister's 2015 Marine Unmanned Ships Through Intelligence in Networks Project (MUNIN) project [36], as well as in the recent European Maritime Safety Agency (EMSA) [37] study on risk assessment as pertains to damage stability.

The presence of the FSA in the governance of the shipping industry has also led to the identification of areas in need of further research and development such as consideration of ship sizes, fast speed craft, and recognition of wider context issues including concerns with operations and operational environments [5]. For example, as per document NCSR 3/INF.3, routing measures and mandatory ship reporting systems were the focus of the sub-committee on Navigation, Communications, and Search and Rescue [38]. Fire and evacuation safety as well as general ship safety and traffic collision, improved and refined crew training and competency parameters, in addition to significant focus in the area of piracy and maritime security or Anti-Terrorism Anti-Piracy (ATAP) are also under ongoing examination with the Arctic gaining ground as another "new dimension" in FSA trends [5,39], for example, research into oil and oil dispersants in ice and cold water is progressing and showing positive outcomes [40]. Research is also continuing on FSA methodology itself with particular focus on risk estimation within a wider context in decision-making and cost-benefit analysis [5].

FSA studies have also been credited with prompting and/or continuing current trends which include the advancement of the use of uncertainty modelling techniques in risk quantification where insufficient historical data is present as well as in the development of Human Element Analysing Process (HEAP) [41] and Human Reliability Assessment (HRA) [34] methods for better evaluation of the ever-present human element in risk assessment. Similarly, further studies reinforce the continued inclusion of Bayesian Networks (BNs), fuzzy logic, Monte Carlo (MC) simulation, Markov chains, etc. [42-43,5]. Despite what appears to be significant positive impact, however, the FSA process is not without criticism.

#### ***1.4 FSA Deficiencies***

Important to note is that the maritime system is fundamentally a "people" system [3, 44-45] comprising technology, organization, and the environment - all of which ultimately depend upon humans to be managed and maximized. As such, the FSA is dependent upon numerous variables, including the individual(s) conducting the assessment [46,11]. Bearing in mind this fundamental aspect and notwithstanding the presence of views that of its inherent deficiencies prevent it from being an appropriate tool for use in the marine industry [47], the FSA appears to be considered overall as having merit as a "suitable proactive tool in the maritime environment" [48-50, 10], albeit with flaws [5,51-52] as outlined below.

## ***1. Hazard identification***

Numerous studies have been conducted on the importance of accurate hazard identification (HAZID), considered by Dourmas, Nikitakos, and Lambrou [53] as not only the first step in the FSA process but also “the most important step in a risk assessment” since it has the potential “to introduce more error into the overall risk estimate” (p. 1). FSA studies have been criticized for confusing cause and effect [51] and failing to determine root cause, as noted by Germany in MSC 86 [54]. Collisions and groundings, for example, are consequences which, if incorrectly categorized as “initiating events” [51,47] at this first critical stage, can result in the entire FSA study and its ensuing RCO recommendations being mis-channeled away from the FSA’s proactive goal of addressing risk prevention, and instead placing heavier focus on accident mitigation [5,51]. In turn, this can compromise recognition of the big picture perspective of the problem [46]. Methods to mitigate this shortcoming have been put forth and include, for example, the use of Bayesian Network modeling [3,8,11,55] as well as use of the HRA model [56] to better capture the problem in a broader context. The IMO has acknowledged the validity of such modeling in its 2013 Revised Guidelines, and it has since been applied in recent studies such as that of Abramowicz-Gerigk and Hejmlich [42].

Studies [5,51] indicate that root-cause data is typically not available in the databases used in the FSA process and contend that to proceed with the FSA study in the absence of root cause data compromises the FSA’s safety mandate. Additionally, Yang et al. [5] assert that to better enable FSA studies to accurately identify and emphasize root cause, development of databases with more root cause information is necessary. They also note that the IMO has scrutinized historical data and risk analysis aspects subsequent in particular to significant investigation into general cargo ship safety casualty reports leading to the addition of quantitative analysis per ship type to large failure databases such as noted in MSC 86/17/1 [54].

Of note as well is that only risks identified in the first steps of the FSA process are dealt with in the remaining steps. That is to say, if a risk such as a root cause were missed or inaccurately presented, resulting RCOs and ensuing regulations will be compromised as evidenced, for example, in studies on container vessels such as those represented in documents MSC 83/21/2 and MSC 83/INF.8 [27]. Similarly, a cruise ship FSA [28] used fatality data from ferries and Ro-Pax vessels to determine worst-case scenarios for cruise vessels even though some scenarios possible on these vessels would not be possible on cruise ships [51], inevitably compromising appropriate HAZID focus and in turn the validity of the overall study’s risk assessment.

Another noted HAZID related problem in some FSAs has been their failure to deal with related factors such as port infrastructure, noted as early as 1998 by Zec, Zorovic, and Vranic [57] as well as by Wang and Foinikis in 2001 [58] who argued for risk evaluation of port facilities that interact with the vessel, acknowledging that variations in port facilities impact vessel risk exposure. Later FSA studies such as that of Trbojevis [59] reinforced such needs and were recognized in the IMO’s 89<sup>th</sup> session in 2011. Recent studies further reinforce these earlier observations such as that by Koponen [60] which asserts that simulator training is an especially appropriate consideration in new port design, clearly an inevitable part of maritime Arctic development where infrastructure is largely underdeveloped. Koponen [60] also strongly recommends that such training certification should be a requirement of Polar Code training for deck officers operating in the Arctic. It is perhaps also fair to assume that such training may need to be extended to the broader, increasingly global, ship crew community. The value of training through simulation was equally noted in findings that risk-based evacuation and simulation

as well as fire modelling were sources of increased safety concerns in passenger vessels, for example [5]. Also, need exists in Search and Rescue (SAR) operations for trained personnel who, unlike supplies and equipment, cannot necessarily be pre-positioned [61]. The IMO [30] enlisted a Correspondence Group to complete what is termed as a Strategy Implementation Plan (SIP) (refer to MSC 85/26/Add.1) to identify tasks required to effectively apply e-navigation successfully in numerous high risk areas, including polar and remote, demonstrating the intention that marine navigation systems and supporting shore services be harmonized in recognition that port infrastructure development should consider sound e-navigation interface, a point which is certain to have Arctic relevance.

Various analysis methods exist at the HAZID stage including Hazard and Operability (HAZOP), Event Tree Analysis (ETA) and Fault Tree Analysis (FTA) [12,17,62] as supplement to the expert judgement associated with this step of the FSA process [53] where historical data is limited, such as in the Arctic. Current IMO guidelines recognize the place of these methods to standardize subjectivity amongst expert views at this stage; however, they do not require their use where adequate historical data is present [20].

## ***2. Database insufficiency***

Current FSA guidelines remain largely based on quantitative historical data in hazard identification and risk analysis [20]. However, it has been argued that reliance upon historical data is a reactive approach and thus fundamentally contradictory to the core of the proactive FSA principle [11,63]. Haapsaari et al. [8] also suggest its use is inherently biased as it does not reflect, for example, new technologies which, as Balleisio [6] notes, typically lack historical experience which could in turn result in other risks, reinforcing the view that historical data's intrinsic dependence upon existing studies does not adequately account for change, implemented or otherwise. In essence, as noted by Anand [64] "critical system interdependencies" (p. 7), can lead to both variability in performance as well as to unintended outcomes. Further, Akhtar and Utne [3] affirm that overall, maritime databases insufficiently supply "the level of detail necessary to conduct a thorough risk analysis with respect to human and organizational factors (HOF)" (p. 2). Moreover, historical data cannot adequately deal with unknowns such as those which will inherently be present in the Arctic, where historical data exists but with limitations such as transits of container ships or oil tankers. Compounding this, databanks often fail to provide data reflective of an implemented change, such as a new design or work practices and procedures [65] where "even a small increase in complexity in models often leads to an exponential growth in data requirements" [3]. Furthermore, it is important to note that databases are not just dependent on the establishment and maintenance of a database but rely upon the actual occurrence of an event in order to acquire data [66,11]. Indeed, incident and near miss reporting in shipping is felt to be overall deficient [67].

Still more problems with reliance on databanks have been noted. For example, concerns surround discrepancies in the data banks themselves, some of which are not available for third party review, and can therefore lead to inconsistent interpretation and conclusions [51,11,47]. Such opportunity for inconsistency has been argued to directly contradict the scientific principle which requires that data used must be available to anybody wishing to replicate the assessment, as per recommendations by Psaraftis [51] as outlined in Yang et al. [5] and earlier delineated by Devanney [47]. Therefore, "the database issue is very serious ...and should be looked at with a high sense of urgency" [51] (p. 401) as insufficient or inaccurate data will inevitably affect the integrity of the entire FSA study.

The problems associated with databanks and the ability to uphold the scientific method have been duly recognized by the IMO when, at its 91<sup>st</sup> MSC session in November 2012, for example, IMO data as well as significant databases such as Lloyd's Maritime Information Unit (LMIU) and Lloyd's Register Fairplay (LRFP) were reviewed. At this time, the IMO also endorsed the need to offset subjectivity by use of probabilistic methodologies as outlined below. As well, documents such as the MSC 83/INF.2, Annex Sect. 9.2.1 [48] addressed the fundamental need to enable the scientific principle to be upheld, albeit Psaraftis [51] claims studies have indicated this is "seldom followed or respected in full" (p. 401). IMO's revised guidelines highlight the need for "special consideration" in cases where the validity of historical data may be skewed due to recent changes, for example (refer to MSC-MEPC.2/Circ. 12). However, Yang et al. [5] notes that a global database to fully address this issue remains an overall existing need for which international input and coordination is essential, as reinforced in recommendations by the November 2015 Ship Design and Construction (SDC) sub-committee that casualty data be uploaded to the Global Integrated Shipping Information System (GISIS) database and therefore be made more accessible [68]. Juxtaposed to this is the additional point emphasized by Jalonen et al. [50] that development of an FSA for winter navigation-specific contexts is a very "long-term" project of 3-5 years minimum, due in part to "[the significant effort required to develop sufficient databases, not to mention adequate experimentation and the design and development of effective theoretical tools]" (p. 163) that an Arctic-focused FSA would clearly require.

Bayesian Networks (BNs) are promoted as a well-founded option for estimating event probability in the absence of abundant data [55] as reinforced by Wang [17] as well as by Kontovas and Psaraftis [11]. FSA studies supporting the use of probabilistic methodologies to improve HAZID and risk analysis exist. For example, Montewka, Goerlandt, & Kujala's [46] 2014 "systematic, transferable and proactive" (p. 143) BN-based model outlines accurate risk analysis for an open sea collision involving a Ro-Pax vessel. Similar confirmations of the usefulness of probabilistic modelling in risk identification and assessment are evident in the use of the HRA model [56], the Markov modelling extrapolated upon by Mennis, Platis, and Nikitakos, and Fontaine [69] as well as by Zhang, Yan, Yang, and Wang [70] in their accident-based approach for congestion risk assessment of inland waterways. Additional approaches include application of fuzzy logic and Failure Mode and Effect Analysis (FMEA) to Automated Information System (AIS) data to assess ship collision safety in the Malacca Straits as in the 2015 study by Zaman, Santoso, Kobayashi, Wakabayashi, and Maimun [71] and similarly in Goerlandt, Hanninen, Stahlberg, Montewka, and Kujala's 2012 study [72] on tanker collisions in the Gulf of Finland as well as in Akhtar and Utne's 2014 study [3] involving the role of fatigue in marine safety.

Psaraftis [51] has also noted the need to access and utilize the "huge source of data available inside the seafaring community which up to now remains mainly untapped" (p. 401). This view is supported by the sub-committee for 2013's NAV 59 [as cited in 73] which found that FSA cost figures "did not match the experience of ship owners who have fitted comparable equipment" (p. 1). Such may have particular relevance in Arctic maritime considerations as regards the use of the FSA tool and aligns with the suggestion for shipping crews and their administrations to, at minimum, outline problems and best practices at the end of each season given the seasonality of the Arctic corridor's seasonal nature [74].

### ***3. Varying methodology and criteria***

The FSA process is dependent upon numerous variables, including the individual(s) conducting the assessment [46,11]. Therefore, careful execution of the five-step, technically systematic FSA process does not ensure FSA goals are met as the way(s) in which those steps are conducted by the assessment team can lead to varied and often inaccurate results [51]. Current FSA guidelines [20] afford FSA analysts considerable latitude in their choice of which FSA methodologies to use. For instance, while the use of computer modeling is an acceptable risk assessment method, the accuracy of the historical data employed as well as the model's algorithms on which that data is based can produce differing results [46]. In other words, the same problem could be handled differently by different analysts and produce equally different results. A related problem appears to be incomplete or "lopsided" FSAs such as those focusing on HAZID and RA steps while failing to provide equivalent detail at the RCO and CBA stages [5]. Clearly, such haphazard characteristics stand to weaken the FSA in general.

It could therefore be argued that if nothing is set in stone and analysts can use any method they can justify or can arbitrarily distribute focus to particular FSA portions, then the role of the entire FSA is undermined and arguably negated. On the other hand, however, in cases like the Arctic where unknowns are plentiful, this latitude could prove essential in order to combat data insufficiency and to highlight critical needs perhaps significantly less evident in the far more developed south. Revised FSA guidelines [20] include increased objectivity in the data review process and paragraphs 3.2.3 and 3.2.4 indicate recognition of the need to standardize the subjectivity associated with differing expert opinion.

### ***Expert opinion, transparency, and doubt***

Analysts' latitude in choice of methodologies and criteria is further compounded by discrepancy in the expert opinions associated with the FSA process from as early as the initial HAZID step as evidenced in the HAZID step of the navigational safety study in Oresund [Ramboll, 2006, as cited in 73]. As Kontovas and Psaraftis [11] point out, the brainstorming component of the HAZID stage, which relies heavily on expert input, is crucial as it lends a proactive component to the process, affording it a breadth of perspective that extends beyond the confines of past-only hazards. All of these factors have the potential to lead to the manipulation of data, thus introducing bias and compromising both the FSA's goal of being transparent as well as the integrity of the entire process [51]. Indeed, Devanney [47] puts forth that, "anyone facile in FSA methodology can manipulate it to produce any result desired" (p. 1). In combination, these elements have been the source of significant FSA criticism such as was prompted by the IMO's contentious May 2004 reversal of its previous ruling requiring double side-skin hulls (DSS) on bulk carriers [22,51]. This decision, based on an FSA study by Greece whose findings did not unequivocally demonstrate that DSS design increased safety, spawned recommendations contradictory to those of two previous FSA studies submitted by the United Kingdom and Japan which supported a DSS mandate. Significant is that all three studies were described as "comparable" [51] (p. 46) and based on the same methodologies, casting doubt on whether the ensuing ruling reversal was scientifically justifiable or actually more rooted in political considerations, which in turn generated questions regarding the role of stakeholder interests in the FSA process [51].

The DSS decision served to exacerbate an existing doubt in the FSA process, previously prompted by the equally debated Helicopter Landing Area (HLA) ruling in 1997 where the IMO overturned a prior ruling requiring all passenger ships to be equipped with HLA [23-24]. Other studies have fueled



similar doubt such as the investigation into LNG carriers [76] (Refer to MSC 83/21/1 and MSC 83/INF.3) which likened probability estimates to those of passenger ships. Comparably, questions were raised as to whether the probability estimates used in a study on cruise ships [28] (see MSC/17/1 and MSC 85/INF.2) were justifiable vs merely convenient and lead to the 2012 query by Psaraftis [51] as to how the “experts” arrived at this equation as well as to concern regarding the overall outcome of the study and ensuing regulations.

Uncertainty as to what actually constitutes expert qualification serves to reinforce the debate over the validity of expert opinion, with Psaraftis [51] contending that expert opinion should potentially not even be used on the basis that in circumstances where data is simply not present or irrefutable, then it should not be “concocted” (p. 401), a point previously vociferously echoed by Devanney [47]. This is a potential noteworthy Arctic consideration, again due to the limited banks of marine-related historical data in that region.

Although inherent issues remain, the IMO [77] has acted on the contentious expert opinion aspect of the FSA at the 83<sup>rd</sup> MSC in MSC/Circ. 1180-MEPC/Circ. 474 where it was recommended to utilize an Expert Group to review unresolved issues with regard to inconsistent FSA results as well as to clarification of the technology used in the FSA process. However, it could be surmised that qualifications and variation amongst this very group will lead to criticisms similar to those they are attempting to circumvent. Therefore, recommendations for use of a “concordance coefficient” to measure the extent of agreement among experts using methods such as Delphi or Bayesian principles to avoid “thin air” solutions [51] (p. 393) have been recognized by the IMO albeit on an as needed vs mandatory basis at this time. Notable here is that despite the IMO’s recognition of the usefulness of such methods in conjunction with expert opinion alone, Psaraftis [51] asserts that they are “rarely followed” (p. 393). This observation notwithstanding, however, following IMO’s [54] endorsement of their use in the review process, Expert Groups (see MSC 86/26, para. 17.23.1) were enlisted to investigate numerous pertinent points such as FSA methodology, sufficiency of scenarios used in arriving at assumptions, transparency validity, reasonableness of FSA scope size, and expert group qualification sufficiency [51]. Notable as well is the conjecture by Kontovas and Psaraftis [11] that, ultimately, dissension amongst experts can be beneficial if the result is a strengthening of the overall FSA tool through clearer identification of areas in need of action combined with effective administration and enforcement of those actions.

Although also representative of other shortcomings in the FSA, such as too wide a scope, yet another problem associated with expert opinion in an FSA study is the length of time often linked to the achievement of concordance and the dissemination of its results [11]. Such factors would appear to not only challenge FSA efficiency but also, arguably, weaken the entire FSA process. The IACS’ FSA study on bulk carriers, for example, took in excess of two years to be completed [11] and still more time for related modifications and regulatory changes to be implemented. Appropriate scope size in arriving at concordance and providing timely results was recognized in MSC/Circ. 1180; MEPC/Circ. 474 [77] and has since been demonstrated in the 2016 EMSA [37] study assessing passenger ship risk levels related to damage stability as well as in studies such as that on general cargo ships as noted in Yang et al. [5] who also suggest the need for “fresh eyes” in the expert opinion process as a way to identify risk aspects from a non-routine perspective where a back to basics approach may be a means to identify risks experts may overlook. Again, this consideration which mirrors that of utilizing the seafaring community may have value as regards Arctic FSA development.

## 5. Assessing and managing risk

Risk management is a core tenet of any industry's sustained profitability as well as vital in achieving the IMO's FSA objective. Successful risk management is largely dependent on the effective analysis of the cause(s) and consequence(s) of hazards for all activities carried out within that industry [12,78]. Sage projection of what may happen in future by assessing associated risks and uncertainties is vital to choosing among alternatives for managing them [46].

To this end, the IMO's very definition of risk has been criticized, with some calling for a re-evaluation of terminology [46,11]. The standard definition of the word risk [79] in risk analysis combines the *probability* of occurrence and severity of consequence whereas the IMO frames risk as the *frequency* of occurrence and severity of consequence (FSA Risk Index = Frequency and Severity), noted as erroneously equating frequency and probability, in addition to not lending itself to environmental issues [11]. For example, Kontovas and Psaraftis [11] also remark that "[zero accidents in a harbor do not equate to zero probability of an accident occurring]" (p. 48), asserting that to base studies on such logic is, therefore, fundamentally flawed.

Further, Montewka, Goerlandt, and Kujala [46] suggest that the IMO's definition of risk is too narrow to represent actual FSA content and is subject to change "depending on the context" (p. 77). They propose instead a more accurate representation of big picture issues through a broader and more systematic approach that blends accident scenario possibilities with the potential likelihood of undesirable root causes along with clearly articulated event consequences and defined uncertainty. This, following the 2012 MSC where Expert Groups, albeit with particular focus on ATAP FSA development, did support the concept and development of systematic risk-analysis methodologies in conjunction with "novel supporting risk-modelling and decision-making methods" [5] (p. 270). Studies such as the novel ship design safety assessment model put forth by Kang et al [35] as well as the collision probability model of risk analysis for tanker collisions in the Gulf of Finland as discussed by Goerlandt, Hanninen, Stahlberg, Montewka, and Kujala [78] further illustrate the usefulness of such BN approaches which are felt to reinforce the expert opinion that is used heavily at the ship design phase [35] with exploration of probability analysis and risk estimation proving to be an ongoing trend in FSA studies and refinement [5]. Work of forerunners such as Merrick and van Dorp [80] and Hu et al. [10] have been continued in investigations by Goerlandt et al. [72] in the use of BNs in ship collision probabilities as well as in navigational risk estimation [70]. In addition, the MSC 91 [34] proposed a more holistic, two strand approach to the definition of probability, designed to capture the role of both Objective (frequency-based) and Subjective (Bayesian-based) aspects of the probability concept, a notable change in terminology [5] and a seemingly relevant consideration for Arctic maritime FSA development.

The IMO's Risk Index has also been criticized for lacking official risk acceptance criteria to adequately quantify societal risk in terms of actual frequencies and probabilities, emphasizing instead frequent but low consequence events [11]. Since limited resources or feasibility as well as physical impossibility may make elimination of all risk impossible, acceptance criteria is used to define levels of acceptable risk and to arrive at adjustments on those determined to be "at an intolerable or unacceptable level" [8] (p. 107). The FSA normally recommends risk be reduced to an As Low As Reasonably Practicable (ALARP) level; however, ALARP parameters have been questioned. For example, Psaraftis [51] proffers that to calculate ALARP for a particular risk on an overall annual basis is less accurate and effective than expressing risk according to appropriate "exposure variables"



(p. 401) such as annual ship trips, sea miles travelled, tons of oil moved, etc., as in the airline industry [81,51] contends such an approach, which would appear to be a relevant consideration for Arctic FSA development as well, offers a more realistic foundation that more adequately meets FSA objectives.

Montewka, Goerlandt, and Kujala [46] also point out the need to recognize imprecise knowledge in risk assessment, noting in particular those associated with operational concerns. They promote the combined use of quantitative and qualitative methods to better define both the risk and areas of knowledge or understanding in need of further research, outlining that an understanding of traditional systems rests on a combination of the knowledge and understanding of the analyzed system, technology, etc., and its behavior, highlighting that some risk is far from static since knowledge of a system is never fully complete and is therefore impossible to fully characterize in exact terms. Indeed, “According to the guys in the know, machinery failure is [actually] getting worse, not better” [47] (p. 3). Furthermore, the emergence of remote sensing and automation poses still another challenge with regard to machinery and systems in shipping operations and is expected to result in an increased reliance on systems and on the engineers needed to interpret their data [82]. Subsequently, seafarer training will need to reflect this new sphere in shipping operations.

Moreover, as asserted by Eswara [12] risk prediction will continue to be difficult due to numerous factors which include not only inaccurate data and changing circumstances, but also the human element. As earlier noted, the complex socio-technical maritime system is ultimately a human one where individuals heavily interface with ship machinery and operations [64,3,45]. However, Parsons [as cited in 81] points out that, while society has “very smartly engineered out many of the risks associated with the maritime industry” (p. 1), ensuing over-reliance on technology should be avoided as studies show that a staggering 80-90% of recorded maritime accidents are still traceable to human error as the direct cause [64,84]. Further, the maritime system is comprised of a decidedly global workforce with a wide range of language, traditions, and culture where variations in training, notwithstanding IMO standards, may be inconsistent and lead to variations in competence. Human error (HE) opportunities are argued to be further aggravated by attempts to reduce operational costs through approaches such as minimizing crewing levels, for example, such that human factor risks like fatigue are significant causes of accidents [3,44]. The importance of system knowledge and understanding in combination with the closely related human factor in risk analysis and management is upheld by Anand [64] and Abramowicz et al [65], as well as by the 2012 *DNV Report: Shipping 2020* [1]. However, studies on HE still focus largely on qualification analysis with focus on training and enforcement of associated “prescriptive” regulations [5]. Numerous techniques for effective risk analysis in light of the HE have been explored, including Human Risk Assessment (HRA) [12,85] as well as Swain and Guttman’s [86] 1983 Technique for Human Error Rate Prediction model, FTA, ETA, and the resulting Risk Contribution Tree (RCT) all of which are widely used in other industry sectors including air, health, and electronic. Of note is that studies such as El-Laden and Turan [87] suggest use of such approaches in Human Error Probability (HEP) analysis in the maritime industry has not kept pace with other industries such as the nuclear and process areas. The significance of Human Element Analysing Process (HEAP) in Risk Assessment was the subject of MSC 91/16 and is reflected in FSA Revised Guidelines [20] and continues to be a trending subject in maritime safety as evidenced in recent models such as Functional Resonance Analysis Method (FRAM) [64] and Akyuz and Celik’s [88] 2015 Cognitive Reliability and Error Analysis Method (CREAM).

In addition, Haapasaari et al. [8] point out that “most FSA studies” fail to adequately address risk associated with a “particular sea area” (p. 108), instead focusing more broadly on typical hazards associated with particular ship types. Equally has been noted the downfall in most FSA studies’ adherence to generic ship principles to represent all ships of a specific class whereas design variations and changes in regulations may negatively impact vessels with differences [89], a shortcoming also noted by Psaraftis [51] who points out as well the absence of appropriate quantitative criteria in these instances. Use of Multi-criteria Decision Analysis (MCDA) as a ranking method [53] is one way to deal with probability assessment in such cases. Recent studies concerning the determination of more accurate probabilities and which move the focus away from generic include that of Zaman et al. [71] who suggest the use of AIS data in probability calculation on ship collision in Malacca Straits as well as Goerlandt et al. [72] who also use AIS data in their model of risk analysis for tanker collisions in the Gulf of Finland. Further, affirmation of the need for Bayesian and other risk-based modeling tools in uncertainty conditions come from studies such as those by Abramowicz-Gerigk et al. [65] as well as from 2012’s *DNV Report: Shipping 2020* [1]. It is fair to assume that similar applications may have significant value in the Arctic shipping sector as well.

## **6. Determining options and costs**

In alignment with accepted risk management principles set out in Qin, Chen, & Zeng [90], for example, the final step of the FSA process, Recommendations for Decision-making, hinges heavily on the identification of viable Risk Control Options (RCOs) whose advantages, through Cost Benefit Analysis (CBA), have been determined to exceed the cost of implementation so as to make risk ALARP, that is to say significant risk reduction for acceptable cost. To quote Kontovas and Psaraftis [11] “CBA is a vulnerable step” (p. 51) involving nebulous variables since the consequences of accidents and related costs for stakeholders such as marine insurers, ship owners, and government bodies may vary substantially [89], and ultimately, at some point, cost of implementation will exceed an RCO’s economic viability.

The CBA stage involves identifying and comparing benefits and costs associated with RCO implementation. Costs of implementing safety features is relatively easy to determine whereas estimating benefits is trickier. Expressed in a monetary unit, *cost* derives from the initial and running costs of an RCO over its lifetime. On the other hand, *benefit* can encompass reduction in fatalities, environmental protection, prevention of ship loss, etc. Nevertheless, *benefit* is typically assigned a monetary value to enable a common denominator [11], thereby introducing a contentious aspect in this significant segment of the FSA process. Because residual risk inevitably remains no matter the risk control measures taken, economic criteria are established to measure acceptable risk level. While FSA guidelines do not provide a set standard for risk tolerance by which to compare RCOs [20], studies such as that of Psaraftis [51] show that two criteria are typically used in the FSA process: Gross Cost of Averting a Fatality (GCAF) which focuses on additional safety and Net Cost of Averting a Fatality (NCAF) directed at also capturing economic benefits [90]. While some studies attest to their appropriateness [5,51]. Psaraftis [51] also contends that use of GCAF or NCAF as evaluation criteria at the CBA step is a significant FSA shortcoming and “not sensible for evaluating the CBA of RCOs” (p. 266) as they are ratio criteria and can be used interchangeably by the analyst, potentially producing different rankings - particularly with regard to areas of the FSA dealing with fatalities and environmental criteria. Moreover, Psaraftis [51] suggests that, even in cases where alternate approaches may have been more appropriate, because the IMO has “gone at great lengths” (p. 395) to promote their use as criteria in CBA, the vast majority of FSA studies use them as benchmark criteria

such that they have become virtually synonymous with the CBA stage. For example, as of Psaraftis' 2012 study, only two documents (MSC 87/18/1 and MSC 87/INF.2), which concerned dangerous goods transport with open-top containerships, were noted to have used the GCAF/NCAF as *secondary* criteria only despite the fact that other measurement tools exist. For example, differences rather than ratios can be used to depict the absolute scale of an RCO's cost-benefit impact [51] or, alternatively, the use of scales employing both ratios and differences as suggested in MEPC 62/18/2 by Japan can be utilized [51]. Further, it has been noted that these approaches combined with sensitivity analyses have resulted in *some* rankings vs none as has notably been the case with use of GCAF and NCAF exclusively [11].

In short, following GCAF and NCAF alone can possibly hide better options [11] in what is recognized by Klimczak [as cited in 74] as a high stakes process where, especially in the changeable Arctic environment, "The cost of claims may be very difficult to estimate and, looking at the history of the most expensive shipping accidents, may be significantly underestimated" (p. 27). In addition, it has been questioned whether the most cost-effective option is actually the superior one or whether different methodologies and presentation of data would result in identification of the wider problem and in turn redirect RCOs to alternate target points where the combining of RCOs may have merit [11]. This approach would appear to have worth with regard to Arctic applications since numerous questions are as yet unanswered, particularly regarding crew training, suitability, and potential clean-up [Kinsey, as cited in 74]. Despite many safety and environmental issues being recognized in the Polar Code, Arctic conditions are notoriously non-uniform; winter darkness, extreme cold, remoteness, unpredictable weather, and ice in many forms present uncertainty factors in a region where disaster would equate to severe environmental consequences and quite probably higher RCO costs [93], reinforcing the need to consider the potential value of combining RCOs.

Society's concern about high consequence index events and the social risk acceptance criteria employed to limit the risk of catastrophes affecting many people at the same time is an ongoing important chapter in FSA review [11]. All parameters may be equally weighted but where a human life is concerned, this has proven to be very difficult to quantify. For instance, similar to what appears a default use of GCAF and NCAF criteria, the threshold value of USD 3 million, supported by DNV [1] is used "time and again" [5] (p. 395) in FSA studies as an appropriate human life value, leading to criticisms such as Devanney's [47] that the FSA essentially equates the life of a tanker man with 50 tons of spillage. As a result, Yang et al. [5] point out the vital importance of an internationally agreed-upon method of determining the value of human life, taking into consideration economic, political, and social trends. This is typically accomplished in combination with expert opinion where the concordance coefficient is used to determine where weights lie amongst the entire group. Likewise, establishment of specific tolerance guidelines remains understandably difficult given that societal and individual risk perceptions will not only fluctuate but also involve considerable uncertainty in estimates. For example, oil spill costs extend well beyond that of the actual oil spilled, encompassing damage to natural resources, flora and fauna, effects on other industries such as fishing, tourism, aquaculture, etc. [75], all of which are clearly considerations for Arctic FSA development as well.

A related CBA complication arises from failure to consistently implement FSA guidelines. For example, a study done on the Baltic Sea did not conduct uniform uncertainty/sensitivity analysis of model parameters, resulting in a very general cost assessment which failed to adequately highlight the

severe impact spills would have with respect to the most sensitive and vulnerable sea areas [75] and in turn arguably compromised the usefulness of the entire FSA.

The IMO has responded to the various problem areas associated with the RCO and CBA stages. At the 89<sup>th</sup> MSC in 2011, the importance of sensitivity and uncertainty analysis was highlighted as was the need to develop the definition and explanation of both. Although Revised Guidelines still do not contain a specific set of risk tolerance levels, they now acknowledge that risk tolerance and acceptance criteria should be better defined and evaluated and that qualification at the RCO recommendation for consideration stage should be through peer review [20], as further upheld by EMSA [37]. Also noteworthy is the 2015 amendment (see paragraph 9.3.3) calling for recommended RCOs to be submitted in SMART terms in addition to specifying an RCO's application [32].

With regard to new designs, goal-based new ship construction standards for use in the rule making process as well as the outlining of generic guidelines for GBS development were also addressed at the May 2011 MSC [19,94]. Also, it was established that where historic casualty data is not present and risk model development is required, methods for the development and application of risk models as well as ways to acknowledge and accommodate new design and ensuing changes must be provided.

Progress has also been made in the environmental criteria area. Despite significant divergence of opinion, it was decided that, although spill volume would remain the determining variable in oil spill cost estimates, other determinants of oil spill accident severity were to be recognized, including oil type, location, weather conditions, season, shoreline features, remoteness, and the lack of supporting infrastructure and clean-up resources, all of which are recognized to influence “scatter” in estimates. Other movements forward include discussion regarding the volume-dependent non-linear oil spill cost function using the International Oil Pollution Compensation Fund (IOPCF) function as recommended by the MEPC 62 delegation of nations as well as the latitude of FSA analysts to use other formulae accompanied by documentation to support their use. Moreover, current negotiations include the adoption of a cross-disciplinary approach linking safety and environmental aspects extending beyond oil pollution and inclusive as well of emissions, for example. In addition, the MEPC 62 [26] endorsed the use of a consolidated database to be placed in public domain for use in environmental assessments.

## 2.0 Formal Safety Assessment

### 2.1 Introduction to Risk Management in Arctic Maritime Transportation

As a result of declining ice coverage and thickness, an increase in smarter technology, greater access to more information, increasing societal demands, and human curiosity, interest in Arctic shipping has grown in recent years. One of the major benefits from availing of Arctic transportation is the potential for shorter shipping routes between certain ports in Europe, Asia and the east coast of North America. Figure 1 highlights some of the more commonly discussed Arctic shipping routes. While interest in the Arctic is increasing, it is still a very challenging environment and presents significant operational risk to maritime transportation. As part of a safety management culture the IMO expects that vessel operators planning to work in or transit through Arctic waters will “establish safeguards against all identified risks” [95]. One way to ensure the fulfillment of this requirement is by carrying out a FSA. As with any risk management undertaking, large volumes of statistical information are critical to successful outcomes. Herein lies a challenge with conducting a thorough risk management study focused on maritime transportation in Arctic waters. While shipping has been occurring in the Arctic for centuries, the amount of activity is minute when compared to global shipping. In addition, the overall environment, conditions and circumstances in which contemporary shipping is taking place in the Arctic are in many ways different from decades ago. Some examples of these differences can be found in the application of technologies towards advancements in shipbuilding, communications, and data collection. Other differences are associated with varying climatic and environmental conditions. More specifically, ships are better equipped for safe navigation in Arctic waters where the ice coverage itself is declining and thinning.

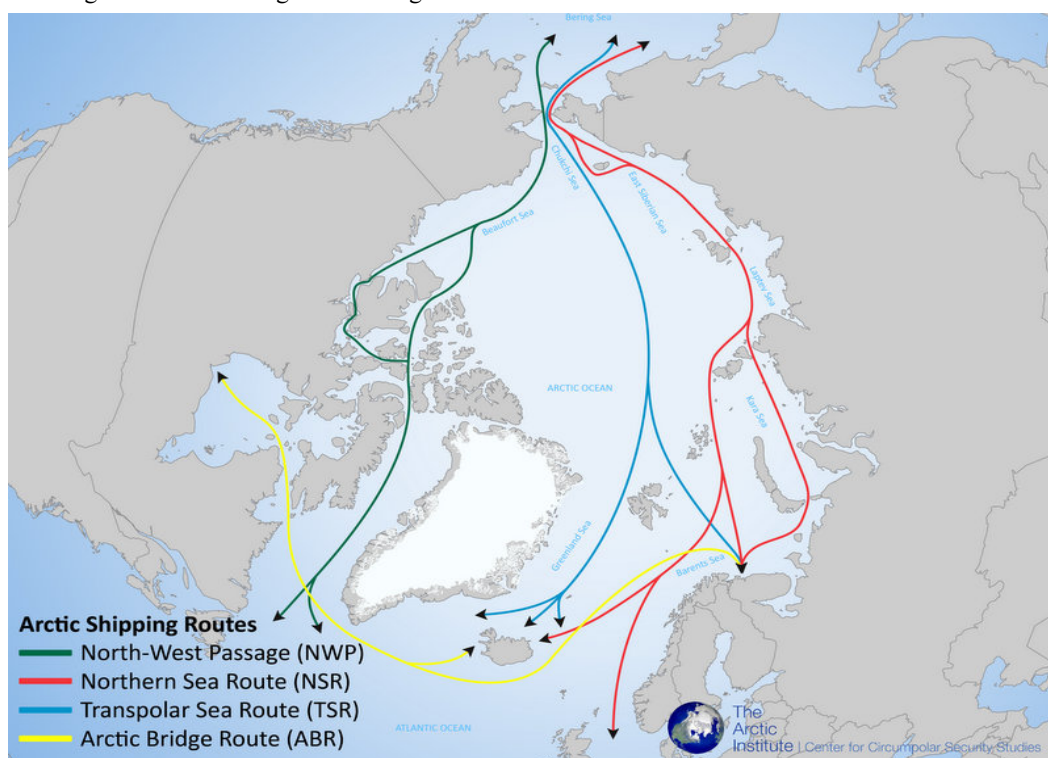


Fig. 1. Proposed viable trans-Arctic shipping routes. Retrieved from “The Arctic Institute, 2014,” <http://www.thearcticinstitute.org/2012/10/the-future-of-arctic-shipping>

## 2.2 Scope

In light of the findings and recommendations noted in the literature review, and more importantly the significant data limitations discovered during the secondary research, the following FSA is considered to be of realistic and manageable scope given the time and resources available. As discussed in the literature review, the FSA process involves five steps as outlined in Figure 2.

While much of the following FSA is based on research work dealing with vessels sailing in the waters off the coast of Greenland and the Baltic Sea, the hazards and challenges to shipping are similar throughout most of the Arctic. These consist of “navigation in ice and low temperatures, high latitude communications and navigation, remoteness from response resources, and limited hydrographic charting” [Janaro as cited in 96, **Enhancing Safety Through the Polar Code section, para. 4**].

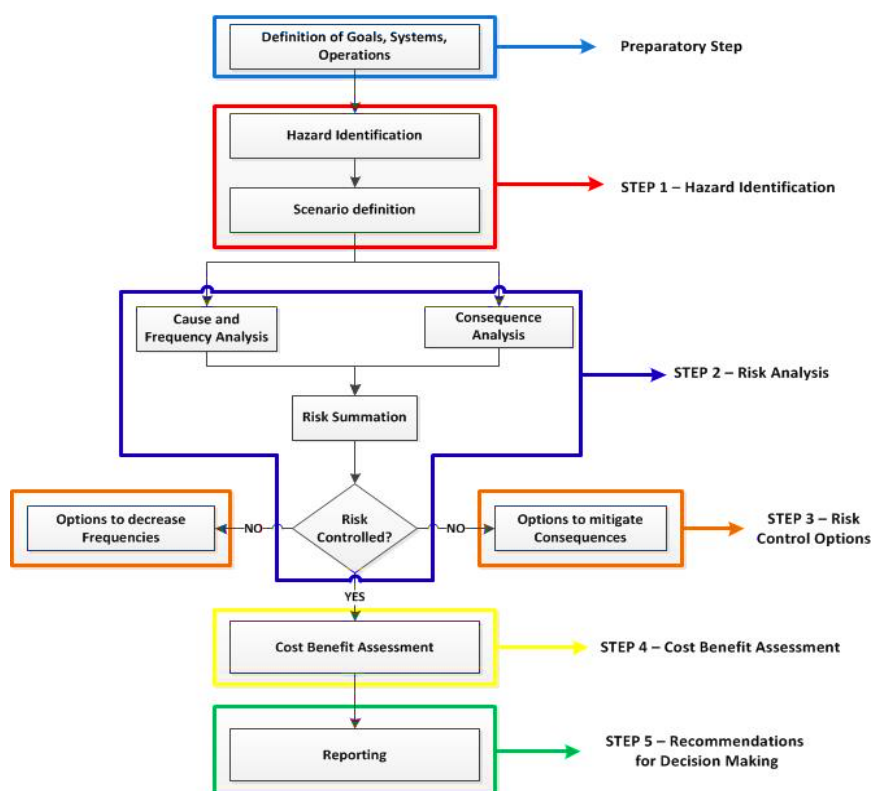


Fig. 2. The five steps of an FSA. *From “DNV Report No: 2005-1565, rev. 01-Formal Safety Assessment of Electronic Chart Display and Information System (ECDIS), 2005,”*  
[http://research.dnv.com/skj/FSA-ECDIS/FSA-ECDIS-CompleteReport\\_02-02-2006.pdf](http://research.dnv.com/skj/FSA-ECDIS/FSA-ECDIS-CompleteReport_02-02-2006.pdf)

## 2.3 FSA STEP 1: Hazard Identification

A Bayesian network is described as a probabilistic causal network enabling graphical representation of relations among random variables. The network consists of a set of nodes representing random variables and a set of links connecting these nodes, illustrated by arrows on a directed acyclic graph [20,97]. The basis for the conditional probabilities in a Bayesian network stems from well-founded theory and statistics appropriately balanced with subjective estimates and expert judgements. While

the following section is focused on hazards in Greenland waters, it is applicable as similar conditions exist in Canadian Arctic waters.

Gemynthe [98], in her master's thesis on the estimation of risk and hazards on maritime traffic, identified 28 potential hazards and 16 main hazards associated with shipping in Greenland waters. All direct and indirect connections among the 28 potential hazards are mapped out in the Bayesian network shown in Figure 3. The 16 main hazards are listed in Table 1 and are displayed as nodes. Generally, nodes having both many parents (depicted by arrows pointing to the node) and children (depicted by arrows pointing away from the node) are categorized as main hazards. Gemynthe conducted sensitivity analysis with respect to model inputs and outputs, and acknowledges there was a limited amount of statistical data available in the research; however, as a licensed mariner with experience gained from working on different ship types, estimations of the probabilities were gathered through empirical data and interviews with mariners who had experience sailing in the waters off Greenland.



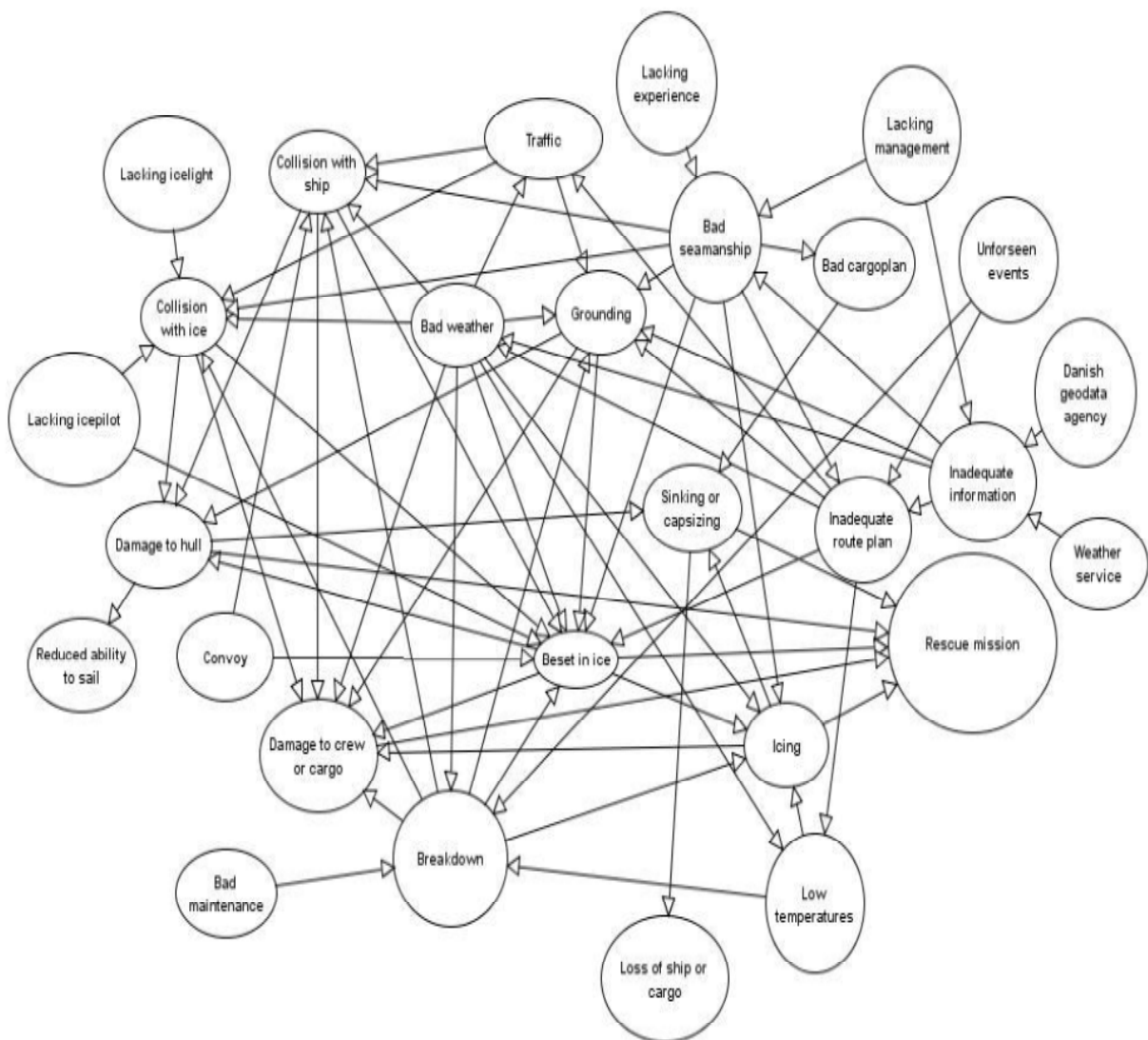


Fig. 3. Bayesian network of the 28 potential hazards and possible connections. *From “Estimate of Risk and Hazard on the Maritime Traffic in the Waters off Greenland,” by P. S. Gemynthe, 2015, Master’s thesis, DTU.*



**Table 1. Main hazards associated with shipping in Greenland waters**

- |                             |  |
|-----------------------------|--|
| • Damage to hull            | • Breakdown                            |
| • Collision with a ship     | • Traffic                              |
| • Collision with ice        | • Weather                              |
| • Beset in ice              | • Sinking or capsizing                 |
| • Bad seamanship            | • Damage to crew/cargo/general average |
| • Inadequate information    | • Low temperatures                     |
| • Inadequate route planning | • Icing                                |
| • Grounding                 | • Rescue mission                       |

---

*Note.* From “Estimate of Risk and Hazard on the Maritime Traffic in the Waters of Greenland,” by P. S. Gemynthe, 2015, Master’s thesis, DTU.

In helping to further distill the more dangerous hazards associated with Arctic shipping, Gemynthe [98] provides calculated estimates of the probability for a hazardous situation while sailing in Greenland waters. These probabilities are provided in Table 2.

**Table 2. Probability of a hazardous event occurring in the waters off Greenland**

- |                                 |                                 |
|---------------------------------|---------------------------------|
| • Damage to hull 5.199          | • Sinking or capsizing 1.761    |
| • Collision with ice 6.184      | • Icing 0.965                   |
| • Collision with ship 0.602     | • Bad seamanship 3.374          |
| • Damage to crew or cargo 2.303 | • Loss of ship or cargo 1.743   |
| • Reduce ability to sail 3.119  | • Low temperatures 4.906        |
| • Traffic 20.652                | • Inadequate information 11.370 |
| • Bad weather 10.634            | • Inadequate route plan 2.406   |
| • Grounding 2.519               | • Bad cargo plan 0.506          |
| • Beset in ice 6.669            | • Rescue mission 6.140          |
| • Breakdown 4.365               |                                 |

---

*Note.* From “Estimate of Risk and Hazard on the Maritime Traffic in the Waters off Greenland,” by P. S. Gemynthe, 2015, Master’s thesis, DTU.

It is important to note that while some events or situations may have a high probability of occurring, by themselves that may not pose a greater hazard to the vessel than an event or situation with a lower probability of occurrence. What is of greater importance for the FSA is the relationship among the various events or situational nodes. To that extent, Gemynthe [98] goes on to identify eight dangerous situations that should always be avoided as they pose a real threat to any ship sailing in the remote, environmentally harsh, and ice prone Greenland waters. These dangerous situations are noted in Table 3. The average calculated probability of these eight dangerous situations is 3.533%.

**Table 3. Dangerous situations posing a real threat to ships sailing in Greenland waters**

- Damage to hull = 5.199
- Collision with ice = 6.184
- Collision with ship = 0.602
- Grounding 2.519 =
- Beset in ice = 6.669
- Breakdown = 4.365
- Sinking or capsizing = 1.761
- Icing = 0.965

*Note.* From “Estimate of Risk and Hazard on the Maritime Traffic in the Waters off Greenland,” by P. S. Gemynthe, 2015, Master’s thesis, DTU.

Of particular interest for the scope of this FSA, which aligns itself with other findings made during this FSA research, are the probabilities for damage to hull, collision with ice, being beset in ice, and grounding. The average probability for these four dangerous situations is 5.142%.

In his risk management research on Arctic shipping, McNamara [99] identifies many of the same hazards identified by Gemynthe [98] in her estimation of risks and hazards off Greenland. Table 4 lists the hazards identified by McNamara [99] who identified grounding and vessel damage from contact with ice as the two most serious threats for vessels transiting the Northwest Passage (NWP).

**Table 4. Hazards to shipping in the Canadian Arctic**

<ul style="list-style-type: none"> <li>• Grounding</li> <li>• Structural damage due to ice contact</li> <li>• Fire/explosion</li> <li>• Machinery damage due to ice contact</li> <li>• Pollution release due to structural failure</li> <li>• Excessive hours of watch in ice conditions - fatigue</li> <li>• Storms</li> <li>• Propeller damage</li> <li>• Rudder damage</li> <li>• Ice ridges</li> <li>• Insufficient ice class for vessels</li> <li>• Poor performance of echo sounder due to ice</li> <li>• Vessels besetting</li> <li>• Freezing of pipes</li> <li>• Freezing of ballast systems</li> <li>• Hypothermia</li> <li>• Frostbite</li> <li>• Poor performance of position monitoring systems</li> <li>• Inaccuracies in chart horizontal datum</li> </ul>	<ul style="list-style-type: none"> <li>• Fatality due to animals (polar bears)</li> <li>• Extended daylight</li> <li>• Vessel collision</li> <li>• Striking of shoals/rocks</li> <li>• Uncharted/poorly charted waters</li> <li>• Strong currents</li> <li>• Fog/poor visibility</li> <li>• Excessive speed</li> <li>• Route deviations</li> <li>• Human factors/noise and vibration</li> <li>• Poor/missing landmarks for navigation</li> <li>• No marking/lack of identification of shoals/underwater hazard</li> <li>• Searchlights in operative or not equipped</li> <li>• Snow blindness</li> <li>• Freezing spray</li> <li>• Unreliable readings from compass while navigating</li> </ul>	<ul style="list-style-type: none"> <li>• Freezing of ship equipment</li> <li>• Narrow channels</li> <li>• Machinery breakdown</li> <li>• search and rescue response limited</li> <li>• Pressurized ice</li> <li>• Icebergs, growlers and bergy bits</li> <li>• Sinking/capsize</li> <li>• Navigator’s limited knowledge of ice conditions</li> <li>• Radar performance in ice infested waters</li> <li>• Channeling/funneling winds</li> <li>• Vessel and crew new to area</li> <li>• Freezing of cooling systems</li> <li>• Hydraulic systems for mooring equipment performing poorly</li> <li>• Navigation equipment failure</li> <li>• Limited ice information services</li> <li>• Dragging/loss of anchor</li> </ul>
---	---	--

*Note.* From “Formal Safety Assessment-Arctic Shipping,” by R. McNamara, 2014, MSTM 6049 Assignment, p. 24.

Adhering to the research principles of validity, reliability, and academic rigor in trying to create an exhaustive list of identified hazards to Arctic shipping, the research net was cast in the direction of the Baltic Sea and the Gulf of Finland. Finnish and Swedish mariners are well respected for their vast experience in operating vessels in ice covered waters. To that extent, the Finnish Maritime Administration (FMA) and the Swedish Maritime Administration (SMA) established a Winter Navigation Research Board and published a volume of research reports dealing with incidents and accidents in the Baltic Sea during winter months. Hanninen [100], in providing a general description of ice damages, identifies 14 hazards of winter navigation connected with vessel accidents, and by means of interviewing ship owners and operators, also outlines the reasons and consequences of the accidents. Table 5 identifies the reasons leading to accident damage and the possible consequences in the Baltic Sea.

**Table 5. Reasons for accidents and possible consequences in the Baltic Sea**

Reasons	Consequences
High speed in ice	This relates especially to ships of high propulsion power compared to their size. These ships may have open water speed over 20 knots. If the ship strikes an ice edge with full speed, damages may occur in the bow area. High speed in an ice channel may damage the ship’s side shell and plating above the water line on the bow area due to extended ice loading by the bow wave.
Collision with other ship in an ice channel	When ships are moving in an ice channel successively with short lead, the first ship may get stuck in ice and the next one may collide with the first one. This situation may occur especially if the first ship is small and has low propulsion power while the other ship is much bigger.
Damages during icebreaker assistance	A collision with an icebreaker may occur when in short lead assistance, when the icebreaker gets stuck in ice. Damage may also occur in a towing situation and in cutting situations, if the icebreaker cuts the ship too close and with high speed.
Damages in an ice channel	Mid and aft ship hull areas may be in contact with the channel edges when the ship is turning. Bilge and bilge keels may be damaged especially in old channels with thick edges.
Backing in ice	In heavy ice conditions ships get often stuck in ice. Then the ship has to back. Backing in ice may damage aft ship areas, especially the rudder and the propeller. Also, aft areas of the ship hulls may be damaged when backing in ice.
Compressive ice	The ice channel may get closed due to the moving ice field. In this situation the ship gets stuck in ice and damages occur, often in the mid ship area on the flat side region.
Ice ridges	Ice ridges may extend 3 m above and 20 m below the water level. Pieces of ice ridges may damage side, bilge and bottom areas, especially when a ship is towed through an ice ridge. Seawater wells in the bottom of the ship may get stuck due to small ice pieces from the ice ridge.
Manoeuvring in port	Ice rubble in port may become several meters thick. In addition, among the ice rubble there may be objects like rocks and wood. Manoeuvring in this ice rubble may damage several parts of the ship’s hull and the propulsion machinery.

Darkness and snowfall	During wintertime it is dark almost round the clock. This fact combined with snow, wind and freezing temperature naturally makes ice navigation more difficult than during the open water season.
Ships in bad repair or ships with insufficient ice strengthening	Ice damages on the ship's hull are often cumulative, i.e. dents develop throughout the winters. This means that ships may have relatively large deformations on the plating and on the frames. Due to corrosion and abrasion the thickness of the plating may have worn several millimeters. Ships without proper ice strengthening or ships in bad repair are likely to suffer more serious damage than other ships.
Inexperienced crew in ice navigation	During the last fifteen years ice conditions in the Baltic Sea have been quite easy for ice navigation. The average maximum ice extent during these years has been only half of the long-term average maximum value. Experience with winter navigation may have been forgotten or may not have been developed.
Icing effect	Ship's superstructure icing is caused by the lifting of spray into the relative wind by the ship's bow. The spray is then super-cooled and carried over the ship's superstructure to freeze on bulkheads, decks, and rigging. This especially concerns small ships such as fishing vessels and tugs.
Grounding events	A grounding event may occur due to drifting of the ship with a moving ice field. The other possibility is that the ship seeks an easier route in difficult ice conditions and then accidentally grounds.

*Note.* Adapted from “Incidents and Accidents in Winter Navigation in the Baltic Sea, Winter 2002-2003,” by S. Hanninen, 2003, Finnish-Swedish Winter Navigation Research Board.

In comparing the hazards to shipping identified by Gemynthe [98], McNamara [99], and Hanninen [100], it can be seen that the more common involve contact with ice, contact with another vessel in ice, vessel icing, the vessel becoming beset in ice or vessel grounding.

## **2.4 FSA STEP 2: Risk Analysis**

There were 157 reported marine occurrences in Canadian waters North of 60° between January 2000 and November 2014 [101]. Figure 4 shows the occurrences by year noting that numbers have been highest in recent years. Figure 5 shows the occurrence by month noting that numbers are highest in September. Figure 6 shows the occurrences by subtype noting that shipping accidents are the most prevalent. Figure 7 shows the occurrence by category noting that groundings are the most prevalent. Figure 8 shows the location of these reported accidents. The TSB [101] defines Class 3 and Class 5 occurrences as follows:

### *Class 3 occurrences (individual occurrence investigation)*

Individual occurrences that do not meet the criteria of Class 2 occurrences may be investigated when

1. there is significant public expectation that the TSB should independently make findings as to cause(s) and contributing factors; or

2. there is potential for better understanding the latent unsafe conditions contributing to a significant safety issue; or
3. a government representative so requests (pursuant to Section 14(2) of the *CTAISB Act*); or
4. the Board must do so to meet its obligations or commitments.

*Class 5 occurrences (data collection)*

Data pertaining to occurrences that do not meet the criteria of classes 1 through 4 will be recorded in suitable scope and detail for possible safety analysis, statistical reporting, or archival purposes. (Policy, Classes of Occurrences section)

Of the four Class 3 occurrences, three were listed as Shipping Accidents while one was listed as an Incident. As of February 2016, the marine investigation report for three of the four Class 3 occurrences had been completed and posted on the TSB website. The marine investigation report for the Class 3 incident that occurred on 14 October 2014 was incomplete at the time of writing.

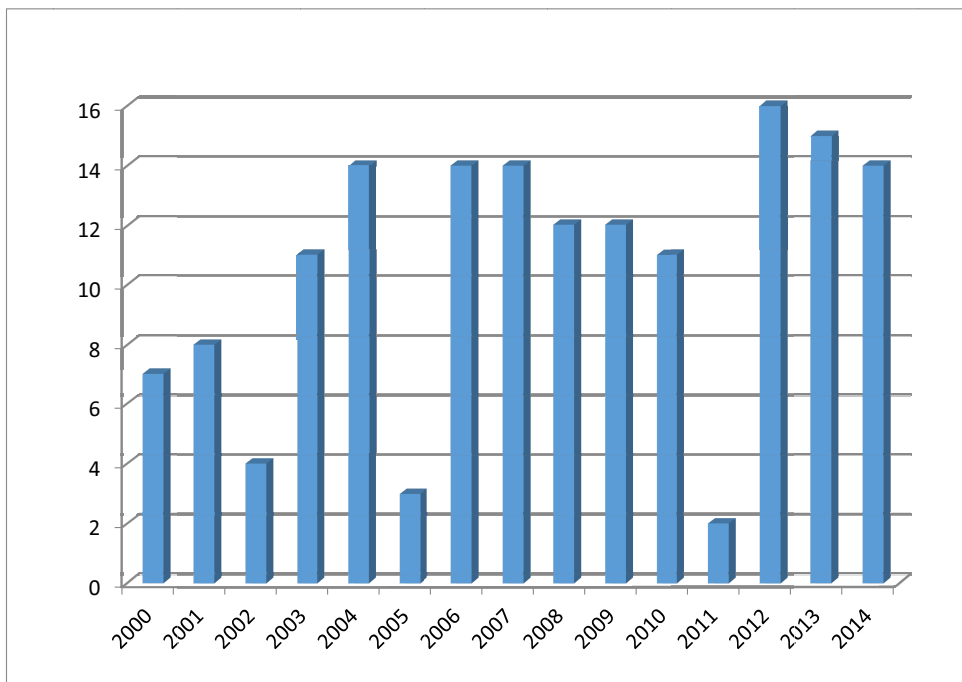


Fig. 4. Shipping occurrences by year from 2000 to 2014. *Numbers extracted from the TSB accident database, by Author.*

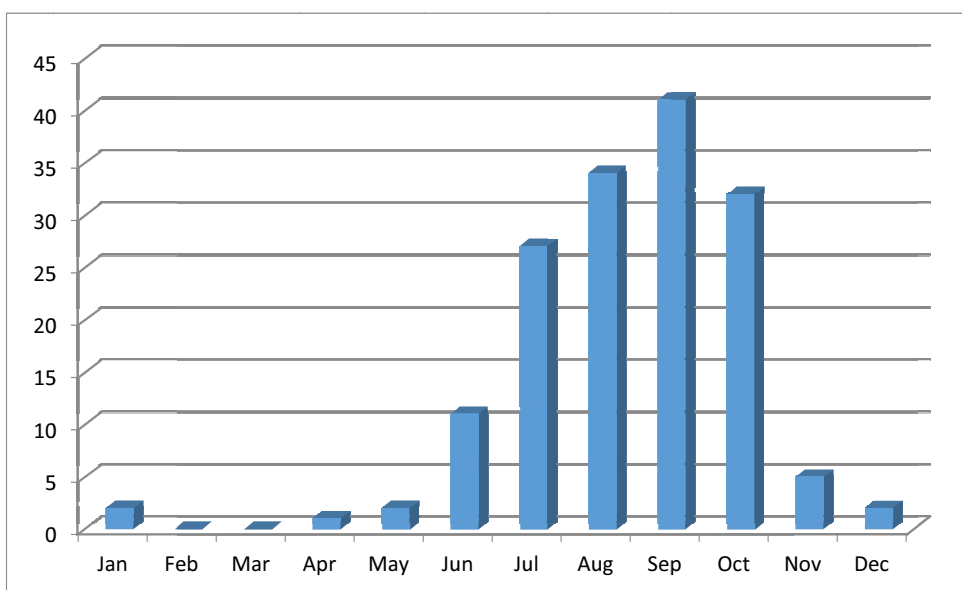


Fig. 5. Shipping occurrences by month from 2000 to 2014. *Numbers extracted from the TSB accident database, by Author.*

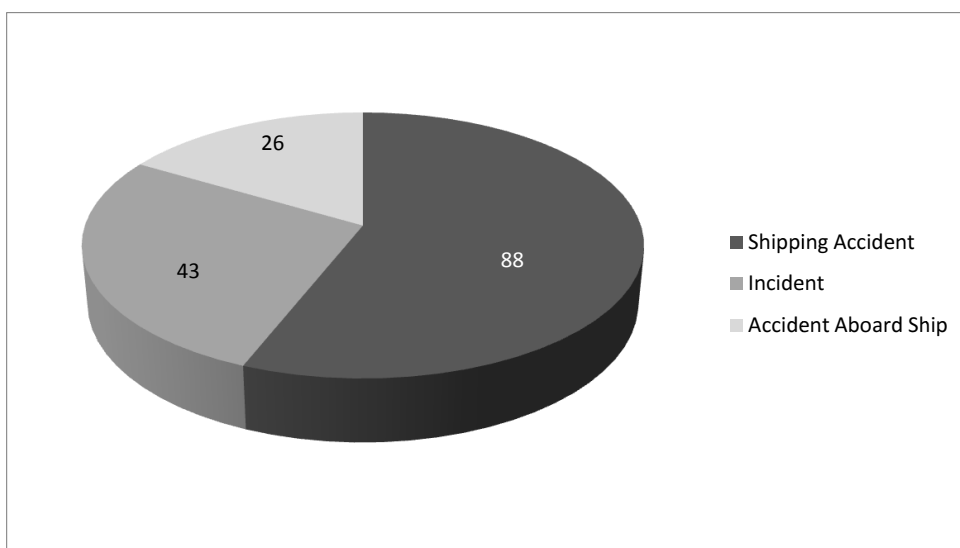


Fig. 6. Shipping occurrences by subtype from 2000 to 2014. *Numbers extracted from the TSB accident database, by Author.*

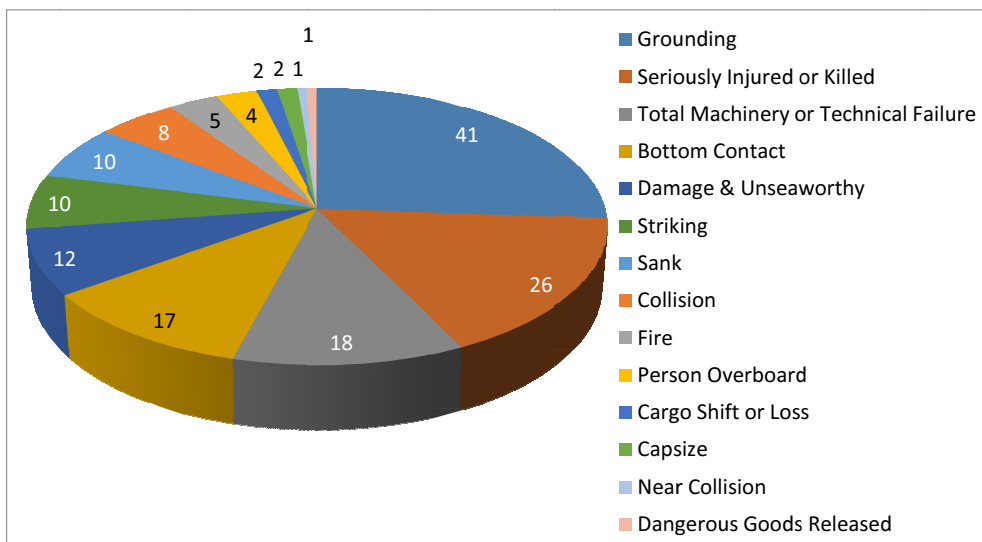


Fig. 7. Shipping occurrences by category from 2000 to 2014. *Numbers extracted from the TSB accident database, by Author.*



Fig. 8. Marine occurrences in Canadian waters north of 60° between January 2000 and November 2014, *by Author.*

As somewhat of a global comparison, although outside of the original scope of the project, the Lloyd's Maritime Intelligence Unit (LMIU) database shows that between 1995 and 2014 there were 450 shipping incidents reported globally between 66°N and 90°N [102]. See Appendix B for details of the 450 incidents. Figure 9 shows the shipping accidents north of 66° pan-Arctic by year from 1995 to 2014. Figure 10 shows the shipping accidents north of 66° pan-Arctic by month from 1995 to 2014. Figure 11 shows the shipping accidents north of 66° pan-Arctic by reason from 1995 to 2014. Figure 12 shows the locations of reported accidents North of 66° in pan-Arctic waters.

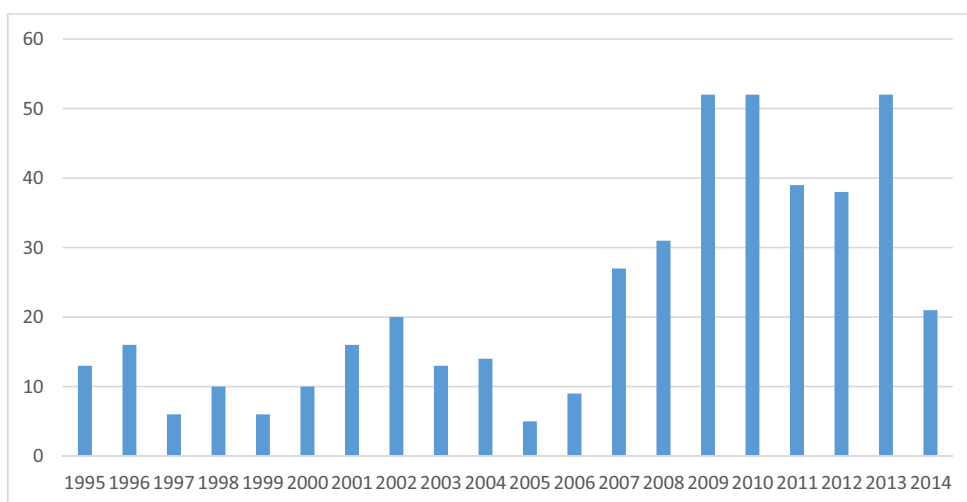


Fig. 9. Shipping accidents north of 66° pan-Arctic by year from 1995 to 2014. *Note, 2014 has only four months of data. Numbers extracted from the LMIU accident database as provided by J. V. N. M. Little, 2014, by Author.*

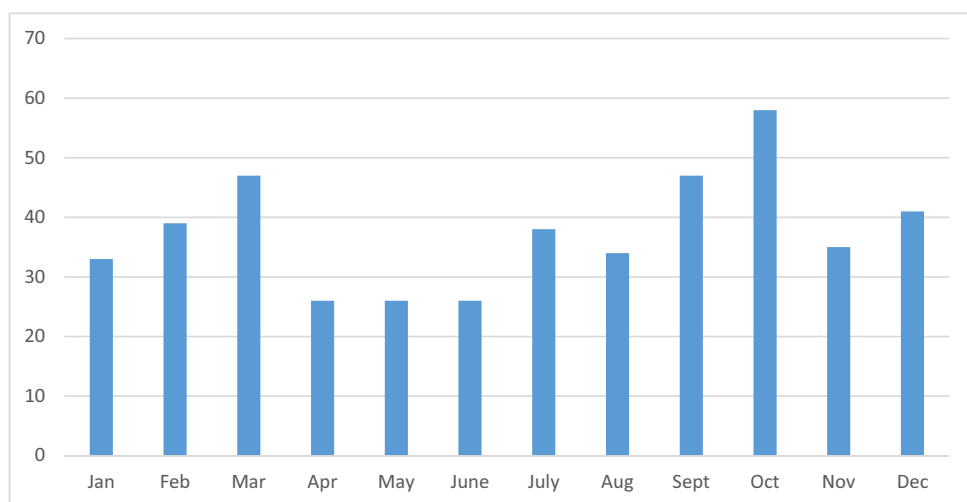


Fig. 10. Shipping accidents north of 66° pan-Arctic by month from 1995 to 2014. *Numbers extracted from the LMIU accident database as provided by J. V. N. M. Little, 2014, by Author.*



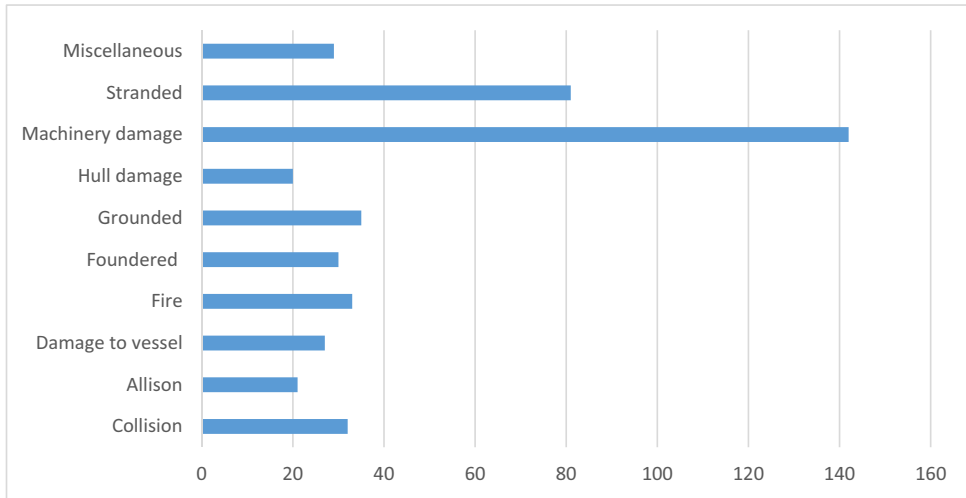


Fig. 11. Shipping accidents north of 66° pan-Arctic by reason from 1995 to 2014. **Numbers extracted from the LMIU accident database as provided by J. V. N. M. Little, 2014, by Author.**

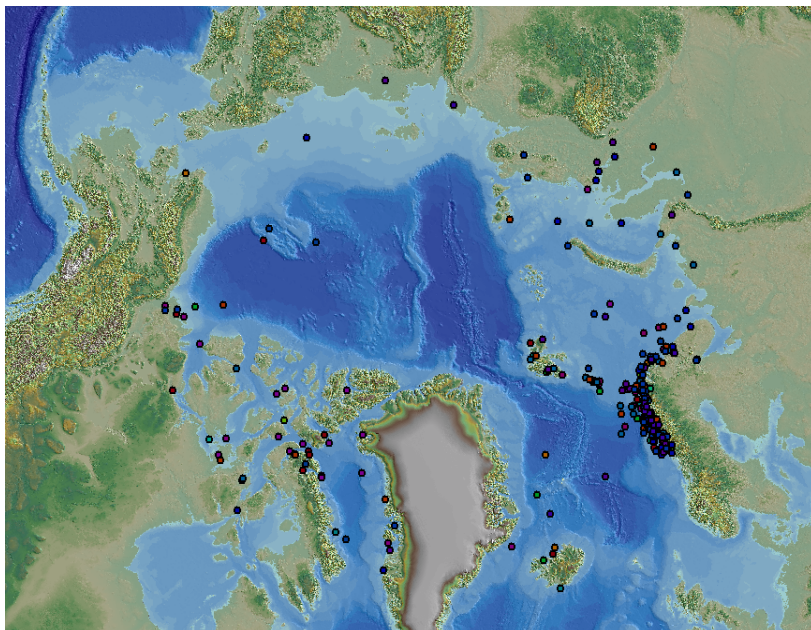


Fig. 12 – Raw plot on ArcMap™ of all 450 recorded major shipping incidents in the Arctic region sourced from LMIU.

Note: Different colours denote different years. Taken from: “An Investigation Into Patterns and Trends of Shipping Incidents Within the Arctic Circle With Specific References to Sea Ice Retreat,” by J. V. N. M. Little, 2014, Master’s thesis, UoP.

For the purposes of clarity with respect to the numerous terms and definitions used throughout various shipping occurrences, following are details from TSB [103] of the definitions marine occurrence, incident, shipping accident, and accident aboard ship:

Marine Occurrence:

- any accident or incident associated with the operation of a ship; and
- any situation or condition that the Board has reasonable grounds to believe could, if left unattended, induce an accident or incident as described above.

Incident:

- a person falls overboard from the ship;
- makes unforeseen contact with the bottom without going aground;
- fouls a utility cable or pipe, or an underwater pipeline;
- is involved in a risk of a collision;
- sustains a total failure of
  - the navigation equipment if the failure poses a threat to the safety of any person, property or the environment,
  - the main or auxiliary machinery, or
  - the propulsion, steering, or deck machinery if the failure poses a threat to the safety of any person, property or the environment;
- all or part of the ship's cargo shifts or falls overboard;
- is anchored, grounded or beached to avoid an occurrence;
- a crew member whose duties are directly related to the safe operation of the ship is unable to perform their duties as a result of a physical incapacitation which poses a threat to the safety of persons, property or the environment; and
- there is an accidental release on board or from the ship consisting of a quantity of dangerous goods or an emission of radiation that is greater than the quantity or emission levels specified in Part 8 of the Transportation of Dangerous Goods Regulations.

Shipping Accident: An accident resulting directly from the operation of a ship other than a pleasure craft, where the ship

- sinks, founders or capsizes;
- is involved in a collision (includes strikings and contacts);
- sustains a fire or an explosion;
- goes aground;
- sustains damage that affects its seaworthiness or renders it unfit for its purpose; and is missing or abandoned.

Accident Aboard Ship: An accident resulting directly from the operation of a ship other than a pleasure craft, where a person is killed or sustains a serious injury as a result of

- boarding, being on board or falling overboard from the ship; or
- coming into direct contact with any part of the ship or its contents. (Appendix B: Definitions based on TSB act and regulations section)

For comparison purposes, Mandryk [104] defines a serious incident as follows:

- serious structural or machinery damage likely to result in a vessel being declared a constructive total loss;

- structural or machinery damage rendering a vessel unseaworthy or requiring extensive repairs;
- disablement or break down resulting in a vessel requiring the assistance of salvors or the abandonment of a voyage or otherwise involving the vessel being removed from service for a reasonable period for repairs;
- any other incident resulting from damage considered to be serious enough to prevent a vessel from continuing in service; and
- any accident resulting in human fatality.

Following, in chronological order, are the summary details pertinent to this research project, of the three Class 3 occurrences, taken from the respective marine investigation reports [105].

**Marine Investigation Report M00H0008, Foundering, Fishing Vessel *AVATAQ*, Western Shore of Hudson Bay, 25 August 2000. [106]**

Findings as to Causes and Contributing Factors:

1. The heavy cargo load and the resulting low freeboard made the *Avataq* vulnerable to shipping water on deck as the weather deteriorated.
2. The free surface effect of water shipped on the afterdeck and retained by the stopped-up scuppers probably reduced the vessel's already marginal transverse stability, causing the *Avataq* to heel, downflood, and sink.
3. The involvement of RCC Trenton and the subsequent tasking of SAR resources were delayed while concerned local citizens conducted a land search and while NES Iqaluit assessed whether the *Avataq* had actually sunk.
4. The *Avataq* was not equipped with an appropriate MF radio or a 406-MHz EPIRB with which to send distress signals, nor was it required to be so equipped.
5. The *Avataq* was not equipped with an automatically releasing liferaft or immersion suits to increase the crew's probability of survival in cold water, nor was it required to be so equipped.

Findings as to Risk:

1. There was an awareness that the *Avataq* and other similar vessels were engaged in loading cargo at the Port of Churchill for delivery to communities on the western shore of Hudson Bay. Concerns for the safety of the vessels' practices had not been identified and passed on to the appropriate authorities. As a result, no assessment was made to determine whether the vessels were safely loaded or seaworthy for carrying cargo.
2. Without the knowledge acquired by formal training or experience in cargo loading, stability, or free surface effect, the crew of the *Avataq* did not recognize the risks associated with operating the vessel in the conditions encountered during the voyage.
3. Safety equipment carriage standards that are deemed to be appropriate for vessels operating in southern Canada are not adapted for the protection of crews of vessels operating in the isolated Arctic marine environment.
4. The NES does not have clear procedures in place to ensure that the appropriate RCC is notified promptly in situations when SAR resources may be needed.
5. Without the knowledge acquired by formal training in MED, northern operators of small commercial vessels may not have the ability to assess accurately their vessel's safety equipment carriage requirements or the skills necessary to safely abandon ship into cold water.

In review of this investigation report it is the opinion of the author that nothing was missing from an IMO perspective; however, the report does raise action items with respect to the need for crew certification on small fishing vessels. As this vessel was registered as a small fishing vessel it was not under the remit of the IMO in terms of International Conventions such as SOLAS STCW.

**Marine Investigation Report M10H0006, Grounding, Passenger Vessel CLIPPER ADVENTURER, Coronation Gulf, Nunavut, 27 August 2010. [107]**

**Findings as to Causes and Contributing Factors:**

1. The *Clipper Adventurer* ran aground on an uncharted shoal after the bridge team chose to navigate a route on an inadequately surveyed single line of soundings.
2. Despite having a non-functional forward looking sonar or using any other means to assess the water depths ahead of the vessel, the *Clipper Adventurer* was proceeding at full sea speed (13.9 knots).
3. The shoal had been previously identified and reported in a Notice to Shipping (NOTSHIP). However, the bridge team was unaware of and did not actively access local NOTSHIPS, nor did NORDREG specifically advise them of the NOTSHIPS applicable to the vessel's area of navigation.
4. Canadian Hydrographic Service (CHS) Central and Arctic did not issue a chart correction, depriving the bridge team of one source of critical information regarding the existence of a shoal on their planned route.
5. The voyage planning practice on board the *Clipper Adventurer* did not fully comply with the ship management company's Quality, Safety, and Environmental Protection (QSEP) program by not using the Bridge Procedures Guide for a passage plan appraisal, which resulted in local warnings (NOTSHIPS) not being obtained.
6. The ship management company's SMS did not provide the vessel's staff with safeguards to mitigate well-known risks, including revision of the voyage plan in conjunction with the management company; assurance that the forward looking sonar unit was operable; use of the zodiacs with portable echo-sounders when necessary; assurance that the vessel transited at lower speed when operating in poorly charted areas; and acquisition of NOTSHIPS local navigation warnings.

**Findings as to Risk:**

1. The practice of CHS Central and Arctic not to issue and apply chart corrections using Position Approximate and Position Doubtful symbols increases the risk that mariners will not be aware of known hazards when they do not obtain the applicable NOTSHIPS.
2. When NOTSHIPS are no longer broadcast, vessels operating in Canadian Arctic waters can only obtain the information on written NOTSHIPS by specific requests to MCTS or by accessing the CCG website, in areas with unreliable Internet connectivity, which may limit the mariners' awareness of known hazards.
3. When receiving sailing plan reports and providing routing advice to vessels, NORDREG does not proactively advise vessels about active NOTSHIPS for the areas that they will be transiting which may place vessels at increased risk if they have not obtained the information by other means.
4. Unless there is a complete assessment of the seaworthiness of a vessel prior to a refloating attempt, a vessel, its passengers and crew may be placed at risk.

5. When bridge recordings are not available to an investigation, this may preclude the identification and communication of safety deficiencies to advance transportation safety.

In review of this investigation report it is the opinion of the author that nothing was missing from an IMO perspective in terms of International Conventions such as SOLAS; STCW; however, the report does raise issues with respect to poor charting, deficiencies in the dissemination of NOTSHIPS, and weakness in the company's SMS protocol.

**Marine Investigation Report M12H0012, Grounding, Tanker *NANNY*, Chesterfield Narrows, Nunavut, 25 October 2012. [108]**

Findings as to Causes and Contributing Factors:

1. The vessel ran aground when it deviated from the charted route upon departure and did not return to it. This deviation was not discussed by the bridge team members, nor did they share navigational information throughout the voyage.
2. The deviation from the charted route continued as the vessel turned into Chesterfield Narrows. Prior to the grounding, after turning into the narrows, the master focused his attention on manoeuvring the main engine controls and thrusters, rather than monitoring the navigation of the vessel.
3. Due to insufficient monitoring of the vessel's navigation and ineffective bridge resource management, the bridge team was unaware of the extent to which the vessel was off the charted course as it entered the narrows.
4. Available navigation aids were not adequately cross-referenced, nor were they optimally set up to facilitate navigation.
5. The searchlights were not used to visually confirm that the vessel was lined up with the range beacons.

Finding as to Risk:

1. If navigational equipment and its associated features, such as alarms, are not optimally configured, potentially useful information to assist in the vessel's safe navigation may not be available to bridge teams.
2. Without formal training and continued proficiency in the principles of bridge resource management for all bridge officers, there is an increased risk that bridge team awareness and effectiveness will be impaired, thereby increasing the risk to the vessel, its crew, and the environment.
3. Without a complete and formal assessment of a vessel's seaworthiness prior to a refloating attempt, as well as readily-available search and rescue resources, there is a risk that such attempts may place a vessel, its crew and the environment at risk.
4. Not promptly reporting occurrences to appropriate authorities during an emergency may prevent a timely and coordinated response.
5. If data from the voyage data recorder/simplified voyage data recorder are not available to an investigation, this may preclude the identification and communication of safety deficiencies to advance transportation safety.

In review of this investigation report it is the opinion of the author that nothing was missing from an IMO perspective in terms of International Conventions such as SOLAS or STCW; however, the report

does raise issues with respect to poor bridge resource management (BRM) and voyage planning, poor charting, deficiencies in the dissemination of NOTSHIPS, and weakness in the company SMS protocol. In continuing with Step 2 of the FSA, Risk Analysis, it is necessary to introduce the IMO's Frequency Index, Severity Index and Risk Index as per Tables 6, 7 and 8 respectively. In Tables 6-8 the IMO provides an example dealing with a maritime safety issue. As shipping through Arctic waters is deemed a maritime safety issue, it was considered appropriate to use the information provided in Tables 6-8.

**Table 6. FSA frequency index**

Frequency Index (FI)			
FI	FREQUENCY	DEFINITION	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1000 ships, i.e. likely to occur in the total life of several similar ships	$10^{-3}$
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5,000 ships.	$10^{-5}$

Note. From "Revised Guidelines for the Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process," by International Maritime Organization, MSC-MEPC.2/Circ.12, p. 41, 2013b.

**Table 7. FSA severity index**

Severity Index (SI)				
SI	SEVERITY	EFFECTS ON HUMAN SAFETY	EFFECTS ON SHIP	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

Note. From "Revised Guidelines for the Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process," by International Maritime Organization, MSC-MEPC.2/Circ.12, p. 41, 2013b.

In general terms the Canadian Arctic is characterized as being unpopulated, remotely isolated, geographically vast, environmentally challenging, climatically harsh, poorly charted and serviced, ice covered and ice-infested.

**Table 8. FSA risk index**

Risk Index (RI)					
FI	FREQUENCY	SEVERITY (SI)			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
	Extremely remote	2	3	4	5

*Note.* From “Revised Guidelines for the Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process,” by International Maritime Organization, MSC-MEPC.2/Circ.12, p. 42, 2013b.

In light of the statistics provided by the TSB [105], Gemynthe [98], Little [102], McNamara [99], Hanninen [100], and the author’s knowledge and experience working in the Canadian Arctic, a RI of 7 as shown in Table 9 is deemed to be an accurate estimation for vessel damage from contact with ice or grounding in Arctic waters.

**Table 9. Risk Index for Vessel Damage in Arctic Waters**

Risk Index (RI)					
FI	FREQUENCY	SEVERTTY (SI)			
		1	2	3	4
		Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
<b>5</b>	<b>Reasonably probable</b>	6	<b>7</b>	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
	Extremely remote	2	3	4	5

*Note.* Adapted from IMO risk index, by Author.



### **2.5 FSA STEP 3: Risk Control Options**

According to IMO [20], “the purpose of step 3 is to first identify Risk Control Measures (RCMs) and then to group them into a limited number of Risk Control Options (RCOs) for use as regulatory options” (p. 9). Steps 1 and 2 of the FSA have identified that vessel damage from grounding or contact with ice poses the greatest risk to vessels operating in Arctic waters. It would therefore seem logical that in order to eliminate or mitigate this risk, knowledge of ice navigation and certainty with respect to accurate position fixing are critical. In order to investigate risk control options to eliminate or mitigate the risk of vessel damage it is necessary to ascertain what options are available to vessel owners and operators. In light of the professional nature of maritime navigation it was felt necessary to first examine the requirements expected of navigators in Arctic waters as per the IMO and, by association, Transport Canada (TC). Appendix A outlines a comprehensive list of IMO requirements through various international Codes and Conventions for vessels and the mariners that operate them in Arctic waters. Appendix B outlines an exhaustive list of publications required or recommended by TC for vessels sailing in Canadian Arctic waters.

With respect to the identification of potential RCMs and their grouping into a limited number of well thought out RCOs (IMO, 2013b), the provision of risk control with respect to controlling both the likelihood of initiation and escalation of accidents was taken into account. In deciding on RCOs available to vessel owners or operators, in light of the findings above, and supported by Smith [109], it would be expected that all vessels sailing in Arctic waters would be:

1. operated by officers and crew that had experience and knowledge of Arctic navigation;
2. fitted with ice detection radar; and
3. fitted with a powerful searchlight.

In consideration of the need of a qualitative evaluation of RCO interdependencies [20], the interdependencies of the three RCOs listed above are weak or non-existent. This is welcomed here as the cost-effectiveness of one option is not altered by the adoption of another option and consequently re-evaluation of the adopted options is deemed not necessary. While the importance of consideration for sensitivity analysis and uncertainty analysis is duly noted [20], in light of available time and resources for this research, it was not formally conducted.

In order to ensure that the Arctic navigation RCO is met, officers would need to be licensed as per IMO/STCW training requirements and complete an Arctic navigation training course. This happens to be one of the requirements of the PC. Likely acceptance of the new IMO ice navigation course is expected in 2017 for a subsequent 2018 adoption. Appendix C offers guidance on the standard of competence for ice navigation training. Notwithstanding IMO mandated content to come, the Fisheries and Marine Institute (MI) of Memorial University is one of several educational establishments in the Arctic countries currently providing ice navigation training. The MI offers a 30 hour Fundamentals of Ice Navigation course, in accordance with earlier IMO guidelines for ships operating in Arctic ice covered waters, the purpose of which is to introduce students to the essential information and tools required to conduct effective, safe and economic voyages through ice-infested waters [110]. Course topics include:

- Ice Regimes
- Regulations and Publications
- Vessel Characteristics



- Manoeuvring in Ice
- Navigation in Ice
- Icebreaker Operations in Canada and the Baltic
- Effects of Extreme Low Temperatures

The approximate cost of the course is CAD\$ 1900 (C. Hearn, personal communication, February 9, 2016). Provided that all bridge officers, normally four on board at a time, will be provided with ice navigation training, it can be roughly approximated that the total associated training cost, including paid leave, travel and accommodation, will be in the order of CAD \$25,000. For two rotating crews this cost will be doubled to CAD \$50,000 or approximately USD \$37,500.

Early in the research project, while looking for possible gaps or weaknesses in the current training of navigational officers, as per IMO requirements and guidelines, for Arctic shipping operations, the author conducted informal interviews with three vessel captains experienced in Arctic navigation and one senior manager from a reputable Arctic shipping company. There was unanimous consensus that at present no additional navigational training, outside of what is currently available as per IMO requirements and guidelines, was deemed necessary. It was deemed by the four interviewees that more on the job training and experience are critically important in order to safely navigate a ship in Arctic waters.

The approximate cost for installation of a complete ice radar, *sigma* S6 system from Rutter Technology is USD \$73,750 (B. Johnston, personal communication, February 10, 2016). The *sigma* S6 Ice Navigator™ Ice Detection and Navigation system enables ships operating in ice to differentiate between open water, ice pans, leads in ice fields, and the thicker ice ridges that impact operations in ice zones. Table 10 provides the specifications and cost in USD of the two part sigma S6 ice radar package.

**Table 10. Sigma S6 ice radar cost and specifications**

<b><i>sigma</i> S6 Ice Navigator™</b>	<b>USD \$43,350</b>
<ul style="list-style-type: none"> <li>• Marine certified (IEC 60945) <ul style="list-style-type: none"> <li>○ Rack Mountable/Desktop Radar Data Processor</li> <li>○ 19" marine certified Rack Mountable/Desktop monitor (alternate sizes available)</li> <li>○ Keyboard/Trackball Unit (Desktop style or Console Mount)</li> </ul> </li> <li>• Windows 7 operating system</li> <li>• SeaTrack tracker, optimized for ice tracking without constraints of navigational ARPA radar trackers</li> <li>• Fully motion compensated scan-to-scan integration of up to 128 radar sweeps, allowing the <i>sigma</i> S6 Ice Navigator™ to identify and detect the smaller bergy bits and growlers that pose a navigational threat to the vessels</li> <li>• Advanced sea, rain, interference &amp; clutter suppression</li> <li>• AIS Class-A and Class-B target overlay</li> <li>• Built-in interfaces for FLIR camera systems and TTM output to other camera systems for enhanced target verification and identification</li> <li>• Automatic Screen Recording in selectable time intervals for evidence documentation</li> <li>• Remote client capability</li> <li>• Computer-Based Training package</li> </ul>	

***sigma S6 100S6 X-band radar*** **USD \$30,400**

- Transceiver complete with 3kHz short pulse
- Rutter Radar 8' X-Band Antenna – Horizontally Polarized
- Cable Kit - 33M (Longer cable kits are available)

*Note.* Depending on the radar equipment fitted on board the vessel it may only be necessary to purchase the *sigma S6 Ice Navigator™*, by B. Johnston, 2016.

The approximate cost for installation of a very reliable, high powered, Seematz search light suitable for use during nighttime navigation in ice covered or ice prone water is CAD \$15,000 (R. Perron, personal communication, March 8, 2016). Table 11 provides specifications for the Seematz searchlight. As a redundancy measure, fitting two searchlights would cost approximately CAD \$30,000 or approximately USD \$22,500.

***Table 11. Seematz Searchlight Specifications***

- Seawater resistant aluminium case – powder coated
- Standard colour SEEMATZ–yellow or white
- All other RAL colours are possible
- All fittings made of stainless steel
- Front window made of SECURIT® glass – high-strength
- High performance reflector made of 99.9% anodic polished aluminium
- Combinable with electric motor remote controls for 24VDC or 230/380VAC
- or manual controls in different versions
- All searchlights are adjusted by hand by our specialists – therefore maximum range.

The following illuminants can be used:

Halogen ( HGS ) – the classic illuminant with an excellent cost/benefit factor. Available from 150 to 5000 Watt.

XENON ( XBO® ) – High performance illuminant with extremely far range. Light colour like daylight, good reflection through ice. Maximum luminous intensity immediately after power up, no cooling off period between power up and off necessary. Available from 450 to 7000 Watt.

Optional accessories are available for some of our searchlights. A selection is offered here:

- Glass mirrors
- Additional heating for use in polar regions
- UV-pane
- IR-pane
- Protective cover
- Morse flap
- Pressurized air equipment
- Electric motor focus adjustment
- Searchlights in stainless steel version
- Mounting for speakers and/or camera
- Further control installations by request (e.g. suspended)

*Note.* Seematz searchlights as fitted on board some vessels operating in Canadian Arctic waters. From *Seematz Searchlight*, 2016. Retrieved from [http://www.seematz.de/products.php?sprache=en&prod=s\\_search](http://www.seematz.de/products.php?sprache=en&prod=s_search)

## 2.6 FSA STEP 4: Cost Benefit Analysis

According to the IMO [20], the purpose of a cost benefit analysis (CBA) “is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3” (p. 12). Costs, expressed in terms of life cycle costs, may include all costs associated with the adoption of a RCO. The IMO [20] notes that “benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, indemnity of third party liabilities, etc., and an increase in the average life of ships” (p. 12). Attempting to quantify the benefit, and develop accurate cost-effectiveness indices of the three adopted RCOs for the prevention of accidents in Arctic water operations is very challenging as the body of empirical evidence and statistics associated with such operations is relatively small when compared to southern water operations. This aligns well with Kristiansen [91] who notes that estimating the benefits of safety measures is generally more complicated and difficult than determining the cost.

Regardless of the indices employed there are certain cost–effectiveness measures commonly used in CBA. Two of these are the gross cost of averting a fatality (GCAF) and the net cost of averting a fatality (NCAF). GCAF is the ratio of marginal cost of a risk control option to the reduction in risk to personnel in terms of the fatalities averted,  $GCAF = \Delta\text{Cost}/\Delta\text{Risk}$ . NCAF is the ratio of marginal cost, accounting for the economic benefits, of a risk control option to the reduction in risk to personnel in terms of the fatalities averted,  $NCAF = (\Delta\text{Cost} - \Delta\text{Economic Benefit})/\Delta\text{Risk}$ . As noted above, while the  $\Delta\text{Cost}$  may be relatively easy to calculate the  $\Delta\text{Economic Benefit}$  is not. Notwithstanding the above, an attempt was made to determine an approximate  $\Delta\text{Economic Benefit}$ .

It is widely known that, for numerous reasons, the cost of doing business in the Arctic is significantly greater than conducting the same business in the south. By some accounts, business in the Arctic can cost up to ten times more than in the south. With respect to oil spill cleanup costs, the average regional cleanup cost per tonne in North America in 2006 was USD \$24,000 [111]. IMO [20] provides a 2009 USD total spill cost (TSC) for all spills at \$67,275. Using a 5% interest rate for all net present values (NPV) [97] and assuming an hypothetical cleanup cost being tenfold in the Arctic, cleanup costs could be estimated approximately between USD \$400,000 and \$950,000 per tonne. Table 12 highlights the three RCOs adopted in step 3 plus their GCAF and NCAF values. For simplification of the GCAF calculations, only the reduction/prevention of an oil spill will be used. The reduction in risk with respect to the prevention in loss of life or a rescue mission are not accounted for; however, if included these benefits would only strengthen the case for adoption of the RCOs. With respect to calculating the NCAF, as is expected that the sum of all economic benefits including a reduction in sailing time, fuel and vessel damage [97] would be greater than the cost of the RCO, the number would be negative. In the event of a RCO reducing risk and resulting in a negative NCAF, the monetary benefits are greater than the costs associated with adopting the RCO [20].

**Table 12. GCAF and NCAF for all RCOs**

RCO	GCAF	NCAF
Ice Navigation Training	\$0.039	< 0
Sigma S6 Ice Radar	\$0.077	< 0
Seematz Searchlight	\$0.023	< 0

*Note.* The numbers are based on the economic benefits of oil spill prevention using the 2009 global cost modified to 2016 Arctic cost. The numbers are calculated by dividing the cost of the RCO by the 2009 modified global adjusted cleanup cost (e.g., \$37500/\$946,628), by Author.

In a different application of the RCOs affecting oil spills only, the RCO is considered cost effective if  $\Delta\text{Cost} < \Delta\text{SpillCost}$ , where  $\Delta\text{Cost}$  = expected cost of the RCO and  $\Delta\text{SpillCost}$  = (expected SpillCost without the RCO) – (expected SpillCost with the RCO) = expected benefit of the RCO. In the event of economic benefit ( $\Delta B$ ),  $\Delta\text{Cost}$  should be replaced by  $\Delta\text{Cost} - \Delta B$  [20]. For the purpose of this research it is assumed that the implementation of the three RCOs will prevent a spill from occurring and thus the expected SpillCost with the RCO will be zero. Therefore, using approximate values,  $\Delta\text{Cost} < \Delta\text{SC}$  as USD \$135K is less than USD \$945K. Adoption of all three of the RCOs is cost effective. Even with a largely conservative approach of costing Arctic oil spill cleanup at three times that of southern costs, the adoption of all three RCOs is still cost effective. The probability of an oil spill was not developed for use in the calculation above.

## **2.7 FSA STEP 5: Recommendations for Decision-Making**

Based on the FSA of Arctic shipping, noting that the probability of an oil spill was not calculated, the following observations are made:

- Ice Navigator Training is cost effective, easily accessible, has relatively low investment cost and no subsequent cost, and is transferable to all vessel types and sizes. The NCAF is calculated to be negative and the cost of implementation is likely to be less than the clean-up cost of a spill. It should be considered for implementation as a RCO.
- Sigma S6 Ice Radar is cost effective, easily accessible and has relatively low investment cost. It can be installed on all vessel types and sizes and can be transferred to other vessels. The NCAF is calculated to be negative and the cost of implementation is likely to be less than the clean-up cost of a spill. It should be considered for implementation as a RCO.
- Seematz Searchlight is cost effective, easily accessible, and has relatively low investment cost. It can be installed on all vessel types and sizes and can also be transferred to other vessels. The NCAF is calculated to be negative and the cost of implementation is likely to be less than the clean-up cost of a spill. It should be considered for implementation as a RCO.

### 3.0 Conclusions

The Canadian Arctic poses numerous hazards to shipping, especially to those mariners who have little or no knowledge as to its characteristics of being remote, vast, environmentally sensitive, frigid, often dark, poorly charted and serviced, ice covered and ice-infested. Research shows that the hazards of ice and bottom contact are the greatest risk drivers in Arctic shipping as they are frequently attributed to vessel damage events resulting in negative outcomes ranging from standing to sinking. While there are many approaches to risk management, the FSA approach proves to be a reliable method in the mitigation of risk in Arctic shipping. Overall, and not without its critics, the five step FSA approach is of no significant difference from many of the diligent and prudent ways used to successfully manage risk. Regardless, there appear to be few publicly available FSAs or other risk management assessments directed at Arctic shipping. On a comparative basis, the amount of statistical data available from Arctic shipping is significantly small when compared to global shipping. Limitations in statistical data impose challenges on risk management in Arctic shipping and in such cases the knowledge of experts is critical.

The FSA has been shown to have merit in determining maritime risk, and attempts to mitigate deficiencies in key areas such as HAZID, databank adequacy, transparency, risk assessment, and cost benefit analysis have been demonstrated. However, ongoing refinements are necessary, including continued improvement in the delineation of risk and environmental criteria, database breadth and availability, adoption and further development of BN and risk estimation modeling, continued proactive research and development as well as the fine-tuning of a system of checks and balances to ensure the guidelines of the FSA process are upheld so as to achieve its proactive and systematic objectives. Indeed, the FSA is necessarily a constantly evolving assessment tool that requires regular and continuous review so as not to stagnate and, indeed, to mirror the growth and change evident in the very industry it is designed to serve. Similarly, the FSA appears to be a viable tool for use in the development of the shipping industry in polar regions. As with the Polar Code, the FSA tool presents a starting point from which can grow a more standardized and informed Arctic-specific safety culture to facilitate a greater understanding of risks and in turn assume a greater responsibility for managing and reducing them. This opportunity to create the working culture and mindset of a region may, however, necessitate that existing FSA guidelines and approaches be appropriately tailored to reflect an increased regionalization of focus for optimal use in the challenging, fragile, and unique Arctic environment.

The FSA identified three cost-effective risk control options that were recommended for adoption in the mitigation of risk in Arctic shipping. These options consist of an ice navigation training course, ice navigation radar system, and high powered searchlights intended for use in harsh Arctic environments.

## 4.0 Recommendations for the Use of FSA in Arctic Shipping

While largely applicable to the broader FSA context, this review supports the following considerations for Arctic FSA development:

- Recognition that FSA development for winter navigation in general and Arctic applications in particular is a time-intensive venture, which, depending on the nature and extensiveness of the FSA, could take several years.
- Understanding that polar regions are remote and complex with sensitive and interconnected bio-diversity.
- Understanding that, as the Arctic is unique both culturally and in terms of the challenges that it presents, regional focus is critical.
- Recognition that consistency in FSA implementation is essential to the integrity of the entire FSA. Weight should be assigned to each of the assessment's stages to avoid skew or over-emphasis of some aspects.
- Realistic / Practical scope size to enable reasonable, manageable dissemination of results.
- Development and ongoing update of an Arctic-relevant, publicly available database(s).
  - Special consideration should be given to ensuring data collection is based on ongoing seasonal overviews of Arctic shipping transits, events, and associated best practices, necessary due to the never-uniform nature of the Arctic environment. Likewise, changes resulting from implementation of new design regulations, and so forth, should undergo regular, preferably seasonal, review for optimal data collection.
  - Recognition by administrations and governing bodies that international cooperation is vital to efficient assimilation and dissemination of data, especially given limited Arctic-specific databanks.
  - Recognition of the potential knowledge base of the seafaring community as well as local Arctic populations.
- Use of BN-type methods and modelling principles in event probability estimation to supplement the expert opinion required throughout the FSA process so as to avoid “thin-air” numbers as well as potential ensuing criticism and eventual undermining of the process.
  - Blending of objective and subjective aspects in probability concept in development of Arctic FSA in tandem with the potential development of a matrix which reflects this need, similar to the concordance coefficient.
  - Recognition of need for risk model development and justification as ways of accommodating new design and ensuing changes.
- Attention at HAZID stage to accurate identification of root cause with particular focus on human element.
- Recognition of the human element as an ongoing catalyst in all marine activities and associated risks and the value of using HRA-type models to help mitigate this.
- Recognition of the need in standardized training for navigation in polar waters, especially with regard to simulation training.
- Recognition of the need for development of accurate weather modeling and forecasting for transit and infrastructure planning.
- Recognition of the need for sound e-navigation interface in Arctic infrastructure development.
- Recognition of the need for training that (a) aligns with current technology and (b) keeps pace with often rapidly evolving technology and systems.

- Training in and recognition of the impact of what cost-cutting measures like reduction of crew size can mean to the human element role in root cause.
  - Inclusion of HE-related analysis and focus in MET curricula and syllabi.
- More research and development into cruise ship and fire, especially with regard to evacuation and rescue in remote environments.
- Use of exposure variables in closer alignment with airline industry vs an overall annual basis to determine ALARP.
- Recognition of potential for severe environmental consequences and resulting, likely higher, RCO costs and thereby a recognition of the heightened need for refinement of environmental criteria for this highly vulnerable region.
- Recognition of other determinants of oil spill accident severity and [adoption] cross-disciplinary approach (i.e. safety and environments)
- Recognition that the invariably difficult CBA stage is compounded in the Arctic due to its unpredictable characteristics. The Arctic presents a greater challenge in accurate operational and RCO cost prediction and is more expensive than similar operations in the south. As it is challenging and risky for stakeholders, the FSA process must be meticulous.

## References

- [1] Det Norske Veritas, *DNV report: Shipping 2020*, (2012), [http://www.lnqbunkering.org/lnq/sites/default/files/2012\\_DNV\\_Shipping%202020%20-%20final%20report.pdf](http://www.lnqbunkering.org/lnq/sites/default/files/2012_DNV_Shipping%202020%20-%20final%20report.pdf).
- [2] Rodrigue J., *The geography of transport systems*, 3rd edition, Routledge. (2013).
- [3] Akhtar M.J. and Utne, I.B., “Modelling the impact of human fatigue on the risk of shipping accidents”, *Transport Research Arena Conference*, Paris, France, (2014).
- [4] Knudson O.F. and Hassler B., “IMO legislation and its implementation, accident risk, vessel deficiencies, and administrative practices”, *Marine Policy*, Vol. 35, No. 2, (2011), pp 201-207.
- [5] Yang Z.L., Wang J. and Li K.X., “Maritime safety analysis in retrospect”, *Maritime Policy and Management: The Flagship Journal of International Shipping and Port Research*, Vol. 40, No. 3, (2013), pp 261-277. doi:10.1080/03088839.2013.782952
- [6] Ballesio J., “Risk-based approaches evolve at the IMO: Using risk assessment to develop rules and regulations”, *Marine Technology*, (2013, October), pp 16-18.
- [7] Hermanski G. and Daley C., “On formal safety assessment (FSA) procedure”, (2010), [https://www.researchgate.net/publication/44057113\\_On\\_formal\\_safety\\_assessment\\_FSA\\_procedure](https://www.researchgate.net/publication/44057113_On_formal_safety_assessment_FSA_procedure)
- [8] Haapasaaari P., Helle I., Lehtikoinen A., Lappalainen J. and Kuikka, S., “A proactive approach for maritime safety policy making for the Gulf of Finland: Seeking best practices”, *Marine Policy*, No. 60, (2015), pp 107-118.
- [9] Dawson, J., Porta, L., Okuribido-Malcolm, S., deHann, M. and Mussels, O., *Proceedings of the Northern Marine Transportation Corridors Workshop*, Vancouver, B.C.: University of Ottawa Research, (2016).
- [10] Hu S., Fang Q., Xia H. and Xi Y., “Formal safety assessment based on relative risks model in ship navigation. *Reliability Engineering and System Safety*, No. 92, (2007), pp 369-377.
- [11] Kontovas C.A. and Psaraftis H.N., “Formal safety assessment: A critical review”, *Marine Technology*, Vol. 46, No. 1, (2009), pp 45-59.
- [12] Eswara A.K., “*Formal safety assessment in maritime industry: Explanation to IMO guidelines*”, Visakhapatnam, India: Indian Maritime University, (2013).
- [13] International Maritime Organization, “Formal safety assessment”, (2016), <http://www.imo.org/en/OurWork/Safety/SafetyTopics/Pages/FormalSafetyAssessment.aspx>
- [14] United Kingdom Department of Transport, “*MV Herald of Free Enterprise*”, Report of Court Investigation No. 8074, London, England: Her Majesty's Stationery Office, (1987).
- [15] Keane K., “Piper alpha judge Lord Cullen says safety changes 'reduced risk'”, (2013), <http://www.bbc.com/news/uk-scotland-north-east-orkney-shetland-22863286>
- [16] Rosqvist T. and Tuominen R. “Qualification of formal safety assessment: An exploratory study”, *Safety Science*, Vol. 42, (2004), pp 99-120, doi:10.1016/S0925-7535(03)00005-5
- [17] Wang J., “The current status and future aspects in formal ship safety assessment”, *Safety Science*, Vol. 38, No. 1, (2001), pp 19-30.
- [18] Soares C. G. and Teixeira A.P., “Risk assessment in maritime transportation”, *Reliability Engineering System Safety*, Vol. 74, No. 3, (2001), pp 299-309.
- [19] International Maritime Organization, “*International goal-based ship construction standards for bulk carriers and oil tankers*”, (2015), <http://www.imo.org/en/OurWork/Safety/SafetyTopics/Documents/Focus%20paper%20on%20GBS.pdf>
- [20] International Maritime Organization, “*Revised guidelines for formal safety assessment (FSA) for use in the IMO rule-making process*”, MSC-MEPC.2/Circ.12, (2013), <https://imo.amsa.gov.au/secure/circulars/msc-mepc2/12.pdf>
- [21] International Maritime Organization, “*Formal safety assessment, including general cargo ship safety*”, MSC 94/13, (2014),



- [http://www.iacs.org.uk/document/public/Publications/Submissions\\_to\\_IMO/PDF/FORMAL\\_SA\\_FETY\\_ASSESSMENT\\_pdf2413.pdf](http://www.iacs.org.uk/document/public/Publications/Submissions_to_IMO/PDF/FORMAL_SA_FETY_ASSESSMENT_pdf2413.pdf)
- [22] International Maritime Organization, “*Single-hull oil tanker phase-out – FAQ*”, (2005), [http://www.imo.org/Safety/mainframe.asp?topic\\_id=1043](http://www.imo.org/Safety/mainframe.asp?topic_id=1043)
  - [23] International Maritime Organization, “*Report of the intersessional correspondence group on helicopter landing areas (HLAs)*”, MSC 70/14, (1998), <http://research.dnv.com/skj/Fsahla/MSC70-14.pdf>
  - [24] International Maritime Organization. “*Report of the joint working group*”, MSC 70/WP.12 as per MSC 69/22, paragraph 14.18, (1998), <http://research.dnv.com/skj/Fsahla/MSC70-23.pdf>
  - [25] International Maritime Organization, “*Bulletin 276 - 12/02 - Bulk carriers- New IMO requirements*”, MSC 76, (2002), [http://www.ukpandi.com/fileadmin/uploads/uk-pi/LP%20Documents/LP\\_Bulletins/Bulletin%20276.pdf](http://www.ukpandi.com/fileadmin/uploads/uk-pi/LP%20Documents/LP_Bulletins/Bulletin%20276.pdf)
  - [26] International Maritime Organization, “*Report of the Marine Environment Protection Committee*”, MEPC 62/24, (2012), <http://www.uscg.mil/imo/mepc/docs/MEPC%2062-24.pdf>
  - [27] International Maritime Organization, “*Formal safety assessment: Container vessels*”, MSC 83/INF. 8, (2007), [http://www.martrans.org/documents/2011/fsa/MSC\\_83-INF-8.pdf](http://www.martrans.org/documents/2011/fsa/MSC_83-INF-8.pdf)
  - [28] International Maritime Organization. “*FSA – Cruise ships: Details of the formal safety assessment*”, MSC 85/INF.2, (2008), [http://www.martrans.org/documents/2011/fsa/MSC\\_85-INF-2.pdf](http://www.martrans.org/documents/2011/fsa/MSC_85-INF-2.pdf)
  - [29] International Maritime Organization, “*FSA – RoPax ships: Details of the formal safety assessment*”, MSC 85/INF.3, (2008), [http://www.safedor.org/resources/MSC\\_85-INF-3.pdf](http://www.safedor.org/resources/MSC_85-INF-3.pdf)
  - [30] International Maritime Organization, “*Strategy for the development and implementation of e-navigation*”, MSC 85/Annex 20, (2008), <http://www.imo.org/en/OurWork/Safety/Navigation/Documents/enavigation/MSC%2085%20annex%2020for%20the%20development%20and%20implementation%20of%20e-nav.pdf>
  - [31] International Maritime Organization, “*Report of the formal safety assessment experts group*”, MSC 88, London, England, (2010).
  - [32] International Maritime Organization, “*Revised guidelines for formal safety assessment (FSA) for use in the IMO rule-making process*”, MSC-MEPC.2/Circ. 12/Rev. 1, (2015), <https://imo.amsa.gov.au/secure/circulars/msc-mepc2/12r1.pdf>
  - [33] UK P&I, “*What is formal safety assessment?*”, (2000), <http://www.ukpandi.com/knowledge/article/what-is-formal-safety-assessment-1913/>
  - [34] International Maritime Organization, “*Report of the Maritime Safety Committee*”, MSC 91/22, (2012), <http://www.uscg.mil/imo/msc/docs/msc-91-report.pdf>
  - [35] Kang H.J., Yang Y-S., Choi J., Lee J-K. and Lee D. “Time basis ship safety assessment model for a novel ship design”, *Ocean Engineering: An International Journal of Research and Development*, Vol. 59, (2013), pp 179-189, doi:10.1016/j.oceaneng.2012.12.007
  - [36] Rødseth Ø.J. and Burmeister H.C., “Risk assessment for an unmanned merchant ship”, *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 9, No. 3, (2015), pp 357-364, doi:10.12716/1001.09.03.08
  - [37] European Maritime Safety Agency [EMSA], “*A study assessing the acceptable and practicable risk level of passenger ships related to damage stability*”, No. OP/10/2013, (2016), <http://www.emsa.europa.eu/damage-stability-study.html>
  - [38] International Maritime Organization, “*Roueting measures and mandatory ship reporting systems*”, NCSR 3.INF.3, (2015), <https://edocs.imo.org/Final Documents?English/NCSP 3-INF.3>

- [39] International Maritime Organization, “Mandatory fire test procedures code”, MSC 88, (2010), <http://www.imo.org/en/MediaCentre/MeetingSummaries/MSC/Pages/MSC-88.aspx>
- [40] Smith M., “A joint industry programme”, *ShipArc 2015 Conference*, Malmo, Sweden, (2015).
- [41] International Maritime Organization, “Guidelines for the application of the human element analyzing process (HEAP) to the IMO rule-making process”, MSC-MEPC 2/Circ. 13, (2013), <https://imo.amsa.gov.au/secure/circulars/msc-mepc2/13.pdf>
- [42] Abramowicz-Gerigk T. and Hejmlich A., “Human factor modelling in the risk assessment of port manoeuvres”, *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 9, No. 3, (2015), pp 427-433, doi:10.12716/1001.09.03.16
- [43] Li K. X., Yin J., Yang Z. and Wang, J. “The effect of shipowners’ effort in vessels accident: A Bayesian Network approach”, (2014), [https://www.researchgate.net/publication/228963725\\_The\\_Effect\\_of\\_Shipowners%27\\_Effort\\_in\\_Vessels\\_Accident\\_A\\_Bayesian\\_Network\\_Approach](https://www.researchgate.net/publication/228963725_The_Effect_of_Shipowners%27_Effort_in_Vessels_Accident_A_Bayesian_Network_Approach)
- [44] Hetherington C., Flin R. and Mearns K. “Safety in shipping: The human element”, *Journal of Safety Research*, Vol. 37, (2006), pp 401-441.
- [45] Rothblum A., “Human error and marine safety”, Washington, D.C.: United States Coast Guard, (n.d.)
- [46] Montewka J., Goerlandt F. and Kujala P. “On a systematic perspective on risk for formal safety assessment (FSA)”, *Reliability Engineering and System Safety*, Vol. 127, (2014), pp 77-85.
- [47] Devanney J., “Formal safety assessment in wonderland”, (2008), [www.c4tx.org/pub/cas](http://www.c4tx.org/pub/cas)
- [48] International Maritime Organization, “Consolidated text of the guidelines for formal safety assessment (FSA) for use in the IMO rule-making process: MSC/Circ.1023–MEPC/Circ.392”, MSC 83/INF.2, (2007), <http://www.vtt.fi/files/projects/imofsaguidelines2007.pdf>
- [49] Mullai A., “Risk management system: Risk assessment frameworks and techniques in safe and reliable transport chains of dangerous goods in the Baltic Sea region project”, Project Series No. Serie 5:2006DaGoB, Turku, Finland: Turku School of Economics, (2006).
- [50] Jalonen R., Riska K. and Hanninen, S. “A preliminary risk analysis of winter navigation in the Baltic Sea”, No. 57, Norrköping, Sweden; Helsinki, Finland: Swedish-Finnish Board for Winter Navigation Research, (2005).
- [51] Psaraftis H. N. “Formal safety assessment: An updated review”, *Journal of Marine Science Technology*, Vol. 17, (2012), pp 390-402, doi:10.1007/s00773-012-0175-0
- [52] Yang Z.L. and Wang J., “Ship formal safety assessment”, In W. K. Talley (Ed.), *Maritime safety, security, and piracy*, London, England: Informa, (2008), pp. 31-53.
- [53] Dourmas, G.N., Nikitakos, N.V., & Lambrou, M.A. (2007). Hazards identification and prioritization in formal safety assessment using fuzzy logic theory. *International Symposium on Maritime Safety, Security, and Environmental Protection*. Athens, Greece.
- [54] International Maritime Organization, “Formal safety assessment: Report of the FSA experts group”, MSC 86/WP.9, (2009), <http://research.dnv.com/skj/FSA-SAFEDOR/MS86-WP9-FSA.pdf>
- [55] Devanney J. and Stewart P.J., “Bayesian analysis of oil spill statistics”, *Marine Technology*, Vol. 11, (1974), pp 365-382.
- [56] Redmill F. “The significance to risk analysis of risks posed by humans”, *Engineering Management Journal*, Vol. 12, No. 4, (2002).
- [57] Zec D., Zorovic D., and Vranic D. “Impact of the formal safety assessment on shipboard operations”, *Promet-Traffic and Transportation*, Vol. 10, No. 3, (1998), pp 127-130.
- [58] Wang J. and Foinikis P. “Formal safety assessment of container ships”, *Marine Policy*, Vol. 25, No. 2, (2001), pp 143-157.

- [59] Trbojevis V. M., “Risk-based methodology for safety improvement”, *Journal of Hazardous Materials*, Vol. 71, (2002), pp 467-480.
- [60] Koponen J., “Reducing risks of Arctic operations with ice simulator”, *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 9, No. 3, (2015), pp 385-390, doi:10.12716/1001.09.03.11
- [61] Dahlberg R., “Offshore is onshore”, *ShipArc Conference 2015*, Malmö, Sweden, (2015).
- [62] Henley E.J. and Kumamoto H., “*Probabilistic risk assessment*”, New York, NY: IEEE Press, (1992).
- [63] Montewka J., Ehlers S., Goerlandt F., Hinz T., Tabri K. and Kujala, P., “A framework for risk assessment for maritime transportation systems: A case study for open sea collisions involving ro-pax vessels”, *Reliability Engineering System Safety*, Vol. 124, (2014), pp 142-157.
- [64] Anand N., “A methodological approach to the management of risk and safety”, *International Human Element Bulletin*, Vol. 39, (2015, September), pp 3-7, <http://www.he-alert.org/>
- [65] Abramowicz-Gerigk T., Burciu, Z. and Kaminski P. “Practical aspects of risk acceptance criteria development in maritime shipping”, *Journal of Konbin*, Vol. 2, No. 26, (2013), doi:10.2478/jok-2013-0085
- [66] Moyseenko S.S., Meyler L.E. and Bondarev V.A., “Risk assessment for fishing vessels at fishing grounds”, *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 9, No. 3, (2015), pp 351-355, doi:10.12716/1001.09.03.07
- [67] Lappalainen J., “Incident reporting in Finnish shipping companies”, *WMU Journal of Maritime Affairs*, Vol. 10, No. 2, (2011), pp 167-181.
- [68] International Maritime Organization, “*Report of the intersessional meeting of the experts group on formal safety assessment (FSA)*”, SDC 3/3/4, (2015), <https://edocs.imo.org/Final Documents/English/SDC 3-3-4>
- [69] Mennis E., Platis A., Nikitakos N. and Fontaine J-G. “Enhancing safety in ship's critical systems using Markov modeling”, *International Journal of Reliability, Quality, and Safety Engineering*, Vol. 16, No. 1, (2009), pp 59-72.
- [70] Zhang D., Yan X.P. Yang Z.L., Wall A., and Wang J., “Incorporation of formal safety assessment and Bayesian network in navigational risk estimation of the Yangtze river”, *Reliability Engineering and System Safety*, Vol. 118, (2013), pp 93-105.
- [71] Zaman M.B., Santoso A., Kobayashi E., Wakabayashi N. and Maimun A., “Formal safety assessment for analysis of ship collision using AIS data”, *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 9, No. 1, (2015), pp 67-72, doi:10.12716/1001.09.01.08
- [72] Goerlandt F., Hänninen M., Ståhlberg K., Montewka J. and Kujala P. “Simplified risk analysis of tanker collisions in the Gulf of Finland”, *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 6, No. 3, (2012), pp 381-387.
- [73] LeFranc Y., “*IMO background related to the development of e-navigation*”, No. S100NW CG, (2014), <https://www.iho.int/>
- [74] Allianz Global Corporate and Specialty. (2015). Safety and shipping review 2015: An annual review of trends and development in shipping losses and safety. Munich, Germany: Author.
- [75] Ellis, J., Lundkvist, M., Westerlund, K., & Arola, T. (2012). *Methods to quantify maritime accidents for risk-based decision making* (No. W\_WP6\_4\_01). Retrieved from Efficient, Safe and Sustainable Traffic at Sea (EfficienSea) website: <http://efficiensea.org/>
- [76] IMO. (2007d). *Formal safety assessment: Liquefied Natural Gas (LNG) Carriers* (MSC 83/21/1; MSC 83/INF.3). Retrieved from <http://research.dnv.com/skj/FSA-SAFEDOR/LNG/MSC83-INF-3.pdf>

- [77] IMO. (2005a). *Amendments to the guidelines for formal safety assessment (FSA) for use in the IMO rule making process*: MSC/Circ.1023 - MEPC/Circ.392 (MSC/Circ.1180 MEPC/Circ.474). Retrieved from [www.imo.org/en/OurWork/Safety/SafetyTopics/Document](http://www.imo.org/en/OurWork/Safety/SafetyTopics/Document)
- [78] Aven, T. (2010). Risk management. *Risks in Technological Systems* (pp. 175-198). London: Springer-Verlag. doi:10.1007/978-1-84882-641-0\_12
- [79] Raiffa, H. (1968). *Decision analysis*. Reading, MA: Addison-Wesley.
- [80] Merrick, J. R. W., & van Dorp, R. (2006). Speaking the truth in maritime risk assessment. *Risk Analysis*, 26(1), 223-237. doi:10.1111/j.1539-6924.2006.00708.x
- [81] Barnett, A. (2006). Global passenger-mortality risk decreased substantially in accidents from 2000-2005. *Flight Safety Digest*, 25(1-2), 14-19.
- [82] Smith, A.P., Cooper, N., Hone, R., Whyte, P., Third, J., Wild, R., LeGoubin, A.L. (2015). *Navigation causes and their accidents*. London, England: Nautical Institute.
- [83] Mehta, D. (2012, April 9). Titanic tragedy led to changes at sea, but legacy of human error remains. The Canadian Press. Retrieved from [http://www.huffingtonpost.ca/2012/04/09/titanic-tragedy-led-to-ch\\_n\\_1411684.html](http://www.huffingtonpost.ca/2012/04/09/titanic-tragedy-led-to-ch_n_1411684.html)
- [84] Harati-Mokhtari, A., Wall, A., Brooks, P., & Wang, J. (2007). Automatic identification system: Data reliability and human error implications. *Journal of Navigation*, 60(3), 373-389.
- [85] Skjong, R. (2002). Risk acceptance criteria: Current proposal and IMO position. Surface Transport Technologies for Sustainable Development Conference, Valencia, Spain.
- [86] Swain, A. D., & Guttman, H. E. (1983). *Handbook of human reliability analysis with emphasis on nuclear power plant applications* (No. NUREG/CR-1278). Washington, D.C.: Nuclear Regulatory Research Commission.
- [87] El-Laden, S.B., & Turan, O. (2012). Human reliability analysis: Taxonomy and praxes of human entropy boundary conditions for marine and offshore applications. *Reliable Engineering System Safety*, 98, 43-54.
- [88] Akyuz, E., & Celik, M. (2015). Application of CREAM human reliability model to cargo loading process of LPG tankers. *Journal of Loss Prevention in the Process Industries*, 34, 39-48.
- [89] Devanney, J. (2008b). *Uses and abuses of ship casualty data*. Retrieved from Center for Tankship Excellence website: [www.c4tx.org/pub/cas](http://www.c4tx.org/pub/cas)
- [90] Qin, T., Chen, W., & Zeng, X. (2008). Risk management modelling and its application in marine safety. *Journal of Marine Science and Application*, 7, 286-291. doi:10.1007/s11804-008-7076-y
- [91] Kristiansen, S. (2005). *Marine transportation: Safety management and risk analysis*. Amsterdam, Netherlands: Elsevier, Butterworth, Heinemann.
- [92] Papanikolaou, A. D. (2009). *Risk-based ship design: Methods, tools, and applications*. Berlin, Germany: Springer.
- [93] GARD. (2015, August 31). New mandatory regulations for vessels operating in polar waters. *Hellenic Shipping News Worldwide*. Retrieved from <http://gard.no/ikbViewer/web/updates/content/20872272/new-mandatory-regulations-for-vessels-operating-in-polar-waters->
- [94] International Maritime Organization. (2011). *Report of the Maritime Safety Committee* (MSC 89). Retrieved from <http://www.imo.org/en/MediaCentre/MeetingSummaries/MSC/Pages/MSC-89th-session.aspx>
- [95] International Maritime Organization. (2010c). *International safety management code and guidelines on implementation of the ISM code*. London, England: Author.

- [96] Lauresen, W. (2016, March 6). Tabletop review for Crystal Serenity's Arctic voyage. *The Maritime Executive*. Retrieved from <http://www.maritime-executive.com/features/tabletop-review-of-crystal-serenitys-arctic-voyage>
- [97] Det Norske Veritas Research. (2005). *Formal safety assessment of electronic chart display and information system (ECDIS)* (No. 2005-1565-Revision 01). Retrieved from [http://research.dnv.com/skj/fsa-ecdis/fsa-ecdis-completereport\\_02-02-2006.pdf](http://research.dnv.com/skj/fsa-ecdis/fsa-ecdis-completereport_02-02-2006.pdf)
- [98] Gemynthe, P. S. (2015). *Estimate of risk and hazard on the maritime traffic in the waters of Greenland* (Master's thesis). Technical University of Denmark (DTU), Kongens Lyngby, Denmark.
- [99] McNamara, R. (2014). From "Formal Safety Assessment-Arctic Shipping," MSTM 6049 Assignment, Fisheries and Marine Institute, St. John's, Canada.
- [100] Hanninen, S. (2003). *Incidents and accidents in winter navigation in the Baltic Sea: Winter 2002-2003*. (No. 54). Norrkoping, Sweden; Helsinki, Finland: Swedish-Finnish **Board for Winter Navigation Research**.
- [101] Transportation Safety Board. (2014). *Occurrence classification policy*. Retrieved from <http://www.tsb.gc.ca/eng/lois-acts/evenements-occurrences.asp>
- [102] Little, J. (2014). An investigation into patterns and trends of shipping incidents within the Arctic Circle with specific reference to sea ice retreat (Doctoral thesis). Plymouth University, Plymouth, England.
- [103] Transportation Safety Board. (2015). *Statistical summary-Marine occurrences 2014*. Retrieved from <http://tsb.gc.ca/eng/stats/marine/2014/ssem-ssmo-2014.asp>
- [104] Mandryk, W. (2011). Marine Casualty Profiles. International Maritime Statistics Forum. Retrieved from Lloyds List Intelligence website: [www.lloydslistintelligence.com](http://www.lloydslistintelligence.com)
- [105] Transportation Safety Board. (2016). *Marine investigation reports*. Retrieved from <http://tsb.gc.ca/eng/rapports-reports/marine/index.asp>
- [106] Transportation Safety Board. (2000). *Marine investigation report: Foundering of fishing vessel Avataq* (No. M00H0008). Ottawa, ON: Author.
- [107] Transportation Safety Board. (2012a). *Marine investigation report: Grounding of passenger vessel Clipper Adventurer* (No. M10H0006). Ottawa, ON: Author.
- [108] Transportation Safety Board. (2012b). *Marine investigation report: Grounding of tanker Nanny* (No. M12H0012). Ottawa, ON: Author.
- [109] Smith, M-D. (2016, March 3). First major cruise ship sails icy Northwest Passage this summer. *Embassy News*. Retrieved from [http://www.embassynews.ca/news/2016/03/02/First-major-cruise-ship-sails-icy-Northwest-Passage-this-summer/48306#.VtcyWY\\_wkSw.linkedin](http://www.embassynews.ca/news/2016/03/02/First-major-cruise-ship-sails-icy-Northwest-Passage-this-summer/48306#.VtcyWY_wkSw.linkedin)
- [110] Center for Marine Simulation. (2016). Fundamentals of ice navigation. Retrieved from Marine Institute website: <https://www.mi.mun.ca/programsandcourses/shortcourses/fundamentalsoficenavigation/>
- [111] Skjong, R., Vanem, E., & Endresen, O. (2007). *Risk evaluation criteria*. (No. SAFEDOR-D-4.5.2-2007-10-24-DNV-RiskEvaluationCriteria-rev-3.0). Retrieved from <http://www.safedor.org/resources/SAFEDOR-D-04.05.02-2005-10-21-DNV-RiskEvaluationCriteria-rev-3.pdf>



# appendix





## Appendix A: Requirements for Vessels and Arctic Navigators as per IMO

### Requirements

<p>RESOLUTION A.1024(26) GUIDELINES FOR SHIPS OPERATING IN POLAR WATERS</p>	<p>1.2 Ice Navigator</p> <p>1.2.1 All ships operating in polar ice covered waters should carry at least one Ice Navigator qualified in accordance with chapter 14. Consideration should also be given to carrying an Ice Navigator when planning voyages into polar waters.</p> <p>1.2.2 Continuous monitoring of ice conditions by an Ice Navigator should be available at all times while the ship is underway and making way in the presence of ice.</p> <p>14.2 Ice Navigator qualifications and training. The Ice Navigator should have documentary evidence of having satisfactorily completed an approved training programme in ice navigation</p> <p>15. Such a training programme should provide knowledge, understanding and proficiency required for operating a ship in polar icecovered waters, including recognition of ice formation and characteristics; ice indications; ice manoeuvring; use of ice forecasts, atlases and codes; hull stress caused by ice; ice escort operations; icebreaking operations and effect of ice accretion on vessel stability. Qualifications of an Ice Navigator should include documentary evidence of having completed on the job training, as appropriate, and may include simulation training</p> <p>13.3 Operating and training manuals Operating manual</p> <p>13.3.1 The operating manual, or supplementary manual in the case of ships not normally operating in polar waters, should contain at least the following information on issues directly related to operations in such waters. With respect to contingency planning in the event that the ship suffers ice damage, the manual should conform to guidelines developed by the Organization:13</p> <p>13 Refer to the Guidelines for the structure of an integrated system of contingency planning for shipboard emergencies, as adopted by resolution A.852(20).</p> <p>Normal operation</p> <p>.1 principal particulars of the ship;</p> <p>.2 loading procedures and limitations including any applicable recommendations against carrying pollutants in tanks and compartments against the hull envelope, maximum operational weight, position of centre of gravity and distribution of load necessary for operation in polar waters;</p> <p>.3 acknowledgment of changes in standard operating procedures for radio equipment and navigational aids applicable to Arctic and Antarctic operations;</p> <p>.4 operating limitations for the ship and essential systems in anticipated ice conditions and temperatures;</p> <p>.5 passage planning procedures accounting for anticipated ice conditions;</p> <p>.6 deviations in standard operating procedures associated with operation of propulsion and auxiliary machinery systems, remote control and warning systems and electronic and electrical systems made necessary by operations in polar waters;</p> <p>.7 deviations in standard damage control procedures made necessary by operations in polar ice covered waters;</p>
---	--

	<p>.8 evacuation procedures into water, onto ice, or into a combination of the two, with due regard to chapter 11 of these Guidelines;</p> <p>.9 information regarding the handling of the ship as determined in accordance with chapter 16 of these Guidelines (environmental protection and damage control);</p> <p>.10 maximum towing speeds and towing loads where applicable;</p> <p>.11 procedures for checking the integrity of hull structure;</p> <p>.12 description and operation of fire detection and fire extinguishing equipment in a polar environment;</p> <p>.13 details arising from the standards of chapter 3 of the Guidelines (subdivision and stability) likely to be of direct practical use to the crew in an emergency; and</p> <p>.14 guidance taking into account the results of any risk or failure analysis reports developed during the ship's operational history and its design limits and redundancy features.</p>																
RESOLUTION MSC.385(94) INTERNATIONAL CODE FOR SHIPS OPERATING IN POLAR WATERS (POLAR CODE)	<table><tr><th>Ice conditions</th><th>Tankers</th><th>Passenger ships</th><th>Other</th></tr><tr><td>Ice Free</td><td>Not applicable</td><td>Not applicable</td><td>Not applicable</td></tr><tr><td>Open waters</td><td>Basic training for master, chief mate and officers in charge of a navigational watch</td><td>Basic training for master, chief mate and officers in charge of a navigational watch</td><td>Not applicable</td></tr><tr><td>Other waters</td><td>Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch</td><td>Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch</td><td>Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch.</td></tr></table> <p>Guidance: The polar waters operational manual (PWOM) should establish the means by which decisions as to whether ice conditions exceed the ship's design limits should be made, taking into account the operational limitations on the Polar Ship Certificate. An appropriate decision support system, such as the Canada's Arctic Ice Regime Shipping System, and/or the Russian Ice Certificate as described in the Rules of Navigation on the water area of the Northern Sea Route, can be used. Bridge personnel should be trained in the proper use of the system to be utilized. For ships that will operate only in ice-free waters, procedures to ensure the ship will keep from encountering ice should be established.</p>	Ice conditions	Tankers	Passenger ships	Other	Ice Free	Not applicable	Not applicable	Not applicable	Open waters	Basic training for master, chief mate and officers in charge of a navigational watch	Basic training for master, chief mate and officers in charge of a navigational watch	Not applicable	Other waters	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch.
Ice conditions	Tankers	Passenger ships	Other														
Ice Free	Not applicable	Not applicable	Not applicable														
Open waters	Basic training for master, chief mate and officers in charge of a navigational watch	Basic training for master, chief mate and officers in charge of a navigational watch	Not applicable														
Other waters	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch.														
MSC/Circ.1056 MEPC/Circ.399	<p>1.2 Ice Navigator</p> <p>1.2.1 All ships operating in Arctic ice covered waters should carry at least one Ice Navigator qualified in accordance with chapter 14.</p> <p>2 loading procedures and limitations including any applicable recommendations against carrying pollutants in tanks and compartments against the hull envelope, maximum operational weight, position of centre of gravity and distribution of load necessary for operation in Arctic ice covered waters;</p> <p>.3 acknowledgment of changes in standard operating procedures for radio equipment and navigational aids applicable to Arctic operations;</p> <p>.4 information regarding the handling of the ship as determined in accordance with chapter 16 of these Guidelines (Environmental protection and damage control);</p> <p>.5 maximum towing speeds and towing loads where applicable; Risk management</p> <p>.6 procedures for checking the integrity of hull structure;</p> <p>.7 description and operation of fire detection and fire extinguishing equipment in</p>																

	<p>an Arctic environment; And for Polar Class ships, the operating manual should include the following supplementary information, in clearly defined chapters specified by the Administration:</p> <ul style="list-style-type: none"> <li>.8 operating limitations for the ship and essential systems in anticipated ice conditions and temperatures;</li> <li>.9 details arising from the standards of chapter 3 of these Guidelines (Subdivision and stability) likely to be of direct practical use to the crew in an emergency;</li> <li>.10 passage planning procedures accounting for anticipated ice conditions;</li> <li>.11 deviations in standard operating procedures associated with operation of propulsion and auxiliary machinery systems, remote control and warning systems and electronic and electrical systems made necessary by operations in Arctic ice covered waters;</li> <li>.12 deviations in standard damage control procedures made necessary by operations in Arctic ice covered waters; and</li> <li>.13 evacuation procedures into water, onto ice, or into a combination of the two, with due regard to chapter 11 of these Guidelines.</li> </ul> <p>14.1.3 All of the ship's officers and crew should be made familiar with cold weather survival by training or self-study of course material or publications addressing the measures set forth in section 13.4.</p> <p>14.1.4 As many as possible of the ship's deck and engine officers should be trained in ship operations in ice covered waters.</p> <p>14.2 Ice Navigator qualifications and training</p> <p>The Ice Navigator should have documentary evidence of having satisfactorily completed an approved training program in ice navigation. Such a training program should provide knowledge, understanding and proficiency required for operating a ship in Arctic ice covered waters, including recognition of ice formation and characteristics; ice indications; ice manoeuvring; use of ice forecasts, atlases and codes; hull stress caused by ice; ice escort operations; icebreaking operations and effect of ice accretion on vessel stability.</p> <p>14.3.1 Where firearms are carried in accordance with paragraph 11.4.2, a minimum of two crew members should be cognizant of current firearm regulations and guidelines and be trained in the use of shotguns or hunting rifles.</p> <p>14.3.2 A minimum of two crew members should be trained in the use of low frequency radio equipment where fitted.</p>
STCW	<p>1 Masters, chief mates and officers in charge of a navigational watch on board ships operating in polar waters, as required by the Polar Code, shall hold a certificate in basic training in polar waters, as required by the Polar Code.</p> <p>Every candidate for a certificate in advanced training for ships operating in ice covered waters shall:</p> <ul style="list-style-type: none"> <li>.1 meet the requirements for certification in basic training in polar waters;</li> <li>.2 have, while performing watchkeeping duties, at least two (2) months of approved seagoing service while serving in an operational or management level deck position within Polar waters on board ships operating in [polar waters][ice-covered waters[ice-coverage above 10%]; and</li> <li>.3 have completed approved advanced training for ships operating in ice covered waters and meet the standard of competence specified in section A-V/3., paragraph 2 of the STCW Code.</li> </ul> <p>Basic knowledge of ice characteristics and areas where different type of ice can be expected in the area of operation:</p> <ul style="list-style-type: none"> <li>1. Ice physics, terms, formation, growth, aging and stage of melt;</li> <li>2. Ice types and concentrations;</li> </ul>

	<p>3. Ice pressure and distribution;  4. Friction from snow covered ice.  5. Implications of spray-icing; danger of icing up, precautions to avoid icing up and options during icing up;  6. Ice regimes in different regions. Significant differences between the Arctic and the Antarctic, first year and multiyear ice, sea ice and land ice;  7. Use of ice imagery to recognize consequences of rapid change in ice and weather conditions;  8. Knowledge of ice sky and water blink;  9. Knowledge of differential movement of icebergs and pack ice;  10. Knowledge of tides and currents in ice-covered waters;  11. Knowledge of effect of wind and current on ice.</p> <p>Basic knowledge and ability to operate and manoeuvre a ship in ice:  1. Safe speed in the presence of ice and icebergs;  2. Ballast tank monitoring;  3. Cargo operation in Ice condition for liquid cargoes;  4. Cargo operation at anchor, in ice infested waters;  5. Awareness of engine loads and cooling problems;  6. Safety procedures during ice transit.</p> <p>Basic knowledge of commercial and regulatory considerations:  1. Local regulations for entering different regions;  2. International regulations including the Antarctic treaty and the Code for ships operating in polar waters;  3. Knowledge of accident reports concerning vessels in polar waters;  4. Knowledge of IMO standards for operation in remote areas;  5. Knowledge of IMO standards for operations of ship's boats and tenders.</p> <p>Basic knowledge of crew preparation, working conditions and safety:  1. Recognize limitations of search and rescue readiness and responsibility, including radio area A4 and its SAR communication facility limitation;  2. Awareness of Contingency planning;  3. How to establish safe working procedures specific to Polar environments such as extreme low temps, ice covered surfaces , PPE, use of buddy system, and working time limitations;  4. Recognize dangers when crews are exposed to low temperatures;  5. Crew preparation including personal protective gear and safe working practices;  6. Human factors including cold fatigue, medical-first aid aspects, crew welfare;  7. Survival requirements including the use of PSK and GSK;  8. Awareness of the most common hull and equipment damages and how to avoid these;  9. Superstructure-deck icing, including effect on stability and trim;  10. Prevention and removal of ice including the factors of accretion;  11. Recognize fatigue problems due to noise and vibrations;  12. Identify need for extra resources, such as bunker, food and extra clothing.</p> <p>Basic knowledge of environmental factors and regulations:  1. Identify particular sensitive sea areas regarding discharge;  2. Identify areas where shipping is prohibited or should be avoided;  3. Special areas in MARPOL;  4. Recognize limitations oil-spill equipment;  5. Plan for coping with increased volumes of garbage, bilge water, sewage, etc.;  6. Lack of infrastructure.  7. Oil spill and Pollution in Ice, including with consequences;  8. Awareness that all the usual things that could go wrong would have more</p>
--	--

	<p>serious consequences in ice-covered waters;</p> <p>Knowledge of voyage planning and reporting:</p> <ol style="list-style-type: none"> <li>1. Information sources;</li> <li>2. Reporting regimes in polar waters, including: NORDREG, GOFREP, AUSREP;</li> <li>3. Development of safe routing and passage planning to avoid ice where possible;</li> <li>4. Passage planning;</li> <li>4. Noting the extensive poorly surveyed or un-surveyed areas in polar regions has the expertise to determine Ability to recognize the limitations of hydrographic information and charts in polar regions and whether the information is suitable for safe navigation;</li> <li>5. Passage planning deviation and modification for dynamic ice conditions.</li> </ol> <p>Knowledge of equipment limitations:</p> <ol style="list-style-type: none"> <li>1. Understand and identify hazards associated with limited terrestrial navigational aids in Arctic and Antarctic polar regions;</li> <li>2. Understand and recognize high latitude errors on compasses;</li> <li>3. Understand and identify limitations in discrimination of radar targets and ice-features in ice-clutter;</li> <li>4. Understand and recognize limitations of electronic positioning systems at high latitude;</li> <li>5. Understand and recognize limitations in nautical charts and pilot descriptions;</li> <li>6. Understand and recognize limitations in communication systems.</li> </ol> <p>Knowledge and ability to operate and manoeuvre a ship in ice:</p> <ol style="list-style-type: none"> <li>1. Preparation and risk assessment before approaching ice-infested waters, including presence of icebergs, and taking into account wind, darkness, swell, fog and pressure ice;</li> <li>2. Conduct communications with an icebreaker and other vessels and maintain contact with any other vessel in the area and the local SAR Organization;</li> <li>3. Understand and describe the conditions for the safe entry and exit to and from ice or open water, such as leads or cracks, avoiding icebergs and dangerous ice conditions and maintaining safe distance to icebergs Conditions were it is not safe to enter areas containing ice or icebergs because of wind, darkness, swell fog and pressure ice;</li> <li>5. Understand and describe ice ramming procedures – including double and single ramming passage;</li> <li>6. Recognize and determine the need for bridge watch team augmentation based upon environmental conditions, vessel equipment and vessel ice class Bridge operation including watches, use of searchlights;</li> <li>7. Recognize the presentations of the various types of ice as they appear on radar;</li> <li>8. Understand icebreaker convoy terminology and communications. Take icebreaker direction and move in convoy;</li> <li>9. Understand methods to avoiding avoid besetment and to freeing free beset vessel, and consequences of besetment;</li> <li>12. Understand towing and salvage in ice, including risks associated with operation;</li> <li>13. Handling ship in various ice concentration and coverage, including risks associated with navigation in ice, and turning-backing; avoidance; etc.;</li> <li>14. Use of different type of propulsion and rudder systems, including limitations to avoid damage when operating in ice;</li> <li>15. Use of heeling and trim-systems. Explain the hazards in connection with ballast and trim in relation with ice;</li> <li>16. Docking and undocking in ice covered waters, including hazards associated with operation and the various techniques to safely dock and undock in ice covered waters;</li> </ol>
--	--

	<p>Knowledge of safety:</p> <ol style="list-style-type: none"> <li>1. Understand the procedures and techniques for abandoning the ship and survival on the ice and in ice-covered waters;</li> <li>2. Recognize limitations on fire-fighting systems and Life Saving systems due to low temperatures;</li> <li>3. Understand unique concerns in conducting emergency drills in ice and low temperatures;</li> <li>4. Understand unique concerns in conducting emergency response in ice and low air and water temperatures.</li> </ol>
--	--

*Note. Adapted from International Maritime Organization, Resolution A.1024(26) Guidelines For Ships Operating in Polar Waters, Resolution MSC.385(94) International Code for Ships Operating in Polar Waters (Polar Code), MSC/Circ.1056, MEPC/Circ.399, and STCW, by Author.*

## **Appendix B: Publications Required or Recommended by Transport**

### **Canada to be Carried on Vessels Sailing in the Canadian Arctic**

#### **Required:**

- Arctic Waters Pollution Prevention Act
- Arctic Waters Pollution Prevention Regulations
- Arctic Shipping Pollution Prevention Regulations
- Vessel Pollution and Dangerous Chemicals Regulations
- Navigation Safety Regulations
- Marine Personnel Regulations
- Ship Station (Radio) Technical Regulations
- Ship Station Radio Regulations
- Shipping Safety Control Zones Order
- Northern Canada Vessel Traffic Services Zone Regulations
- Steering Appliances & Equipment Regulations
- Charts and Publications Regulations
- Notice to Industry
- Coasting Trade Act
- Arctic Waters Oil Transfer Guidelines - TP 10783
- Marine Liability Act
- Ice Navigation in Canadian Waters (Canadian Coast Guard [CCG])
- Arctic Ice Regime Shipping System (AIRSS) Standards – TP 12259
- Arctic Ice Regime Shipping System (AIRSS) – TP 14044E (Pictorial Guide)
- Annual Notice to Mariners
- Radio Aids to Marine Navigation
- Arctic Sailing Directions (Canadian Hydrographic Service [CHS])
- Tide Tables (CHS)
- Life Saving Equipment Regulations
- Survival in Cold Waters -TP 13822

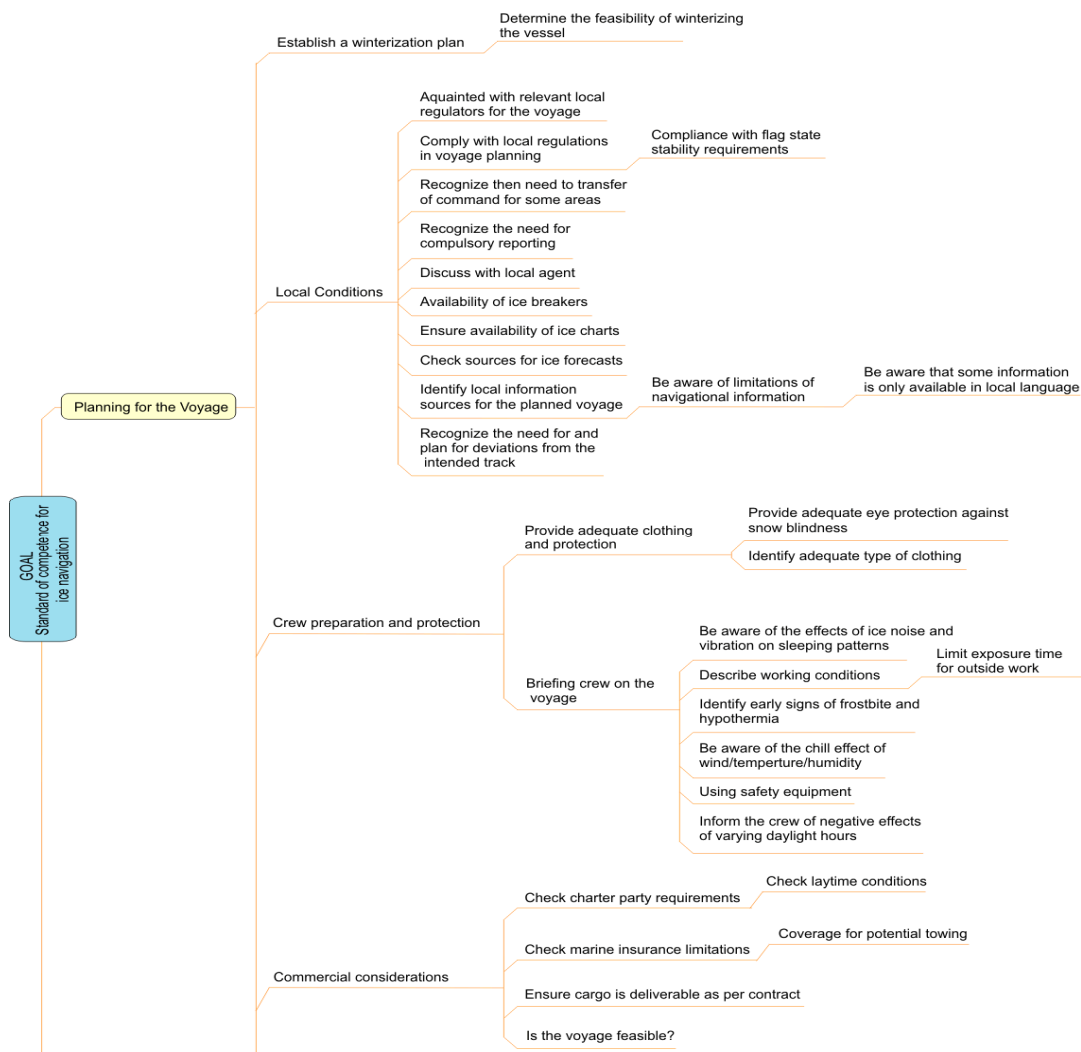
#### **Recommended:**

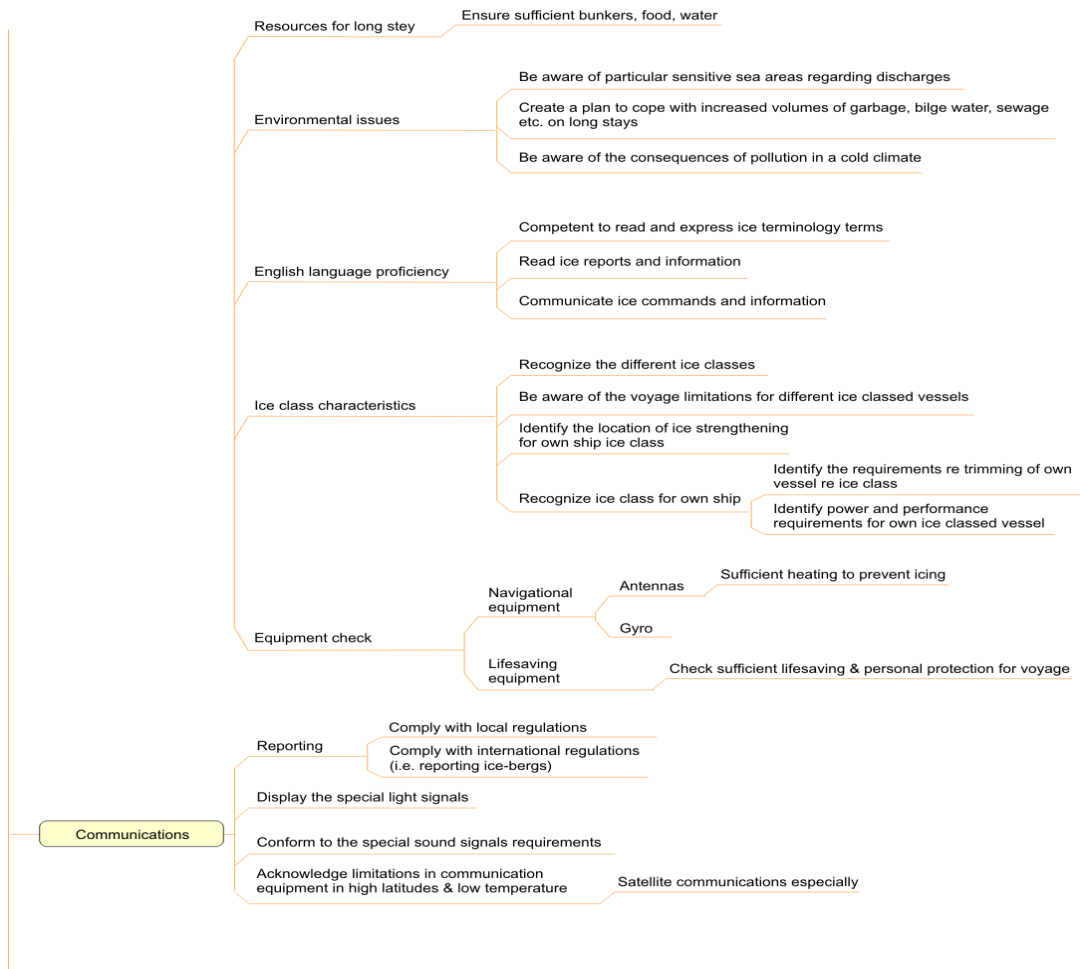
- Transport Canada DVD on AIRSS (April 1996)
- Understanding and Identifying Old Ice in Summer (G.W. Timco, Dec 2008)
- Arctic Chart Catalogue (CHS)
- Ship to Ship Transfer Guide (CDI, ICS, OCIMF, SIGTTO)
- The Ice Navigation Manual (Toomey and Dickens, 2010)
- NORDREG Reporting & Routing Regulations (See # 10 above)
- CIS Seasonal Outlook (Environment Canada [EC])
- Manual of Standard Procedures for Observing and Reporting Ice Conditions-MANICE (EC)
- Polar Ship Operations-A Practical Guide (D. Snider, Nautical Institute)
- Note. Adapted from TC, 2016, by Author

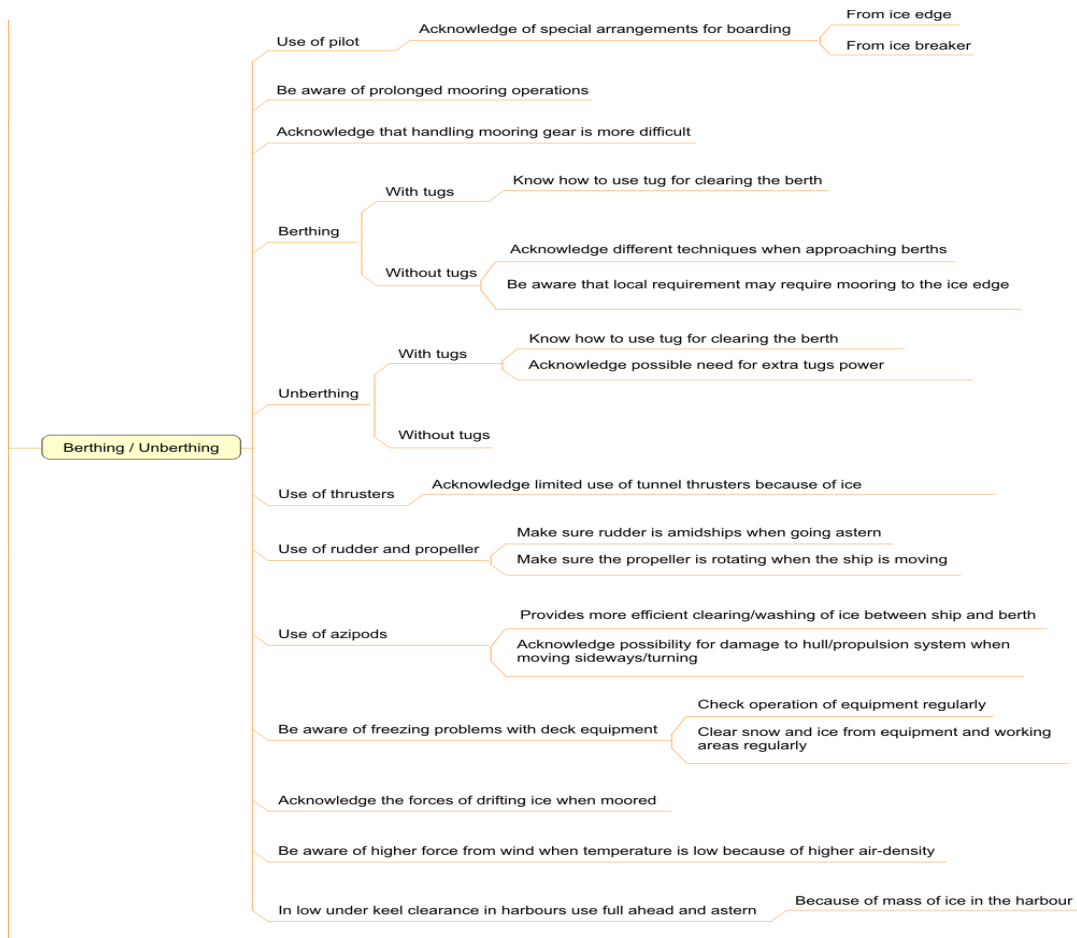


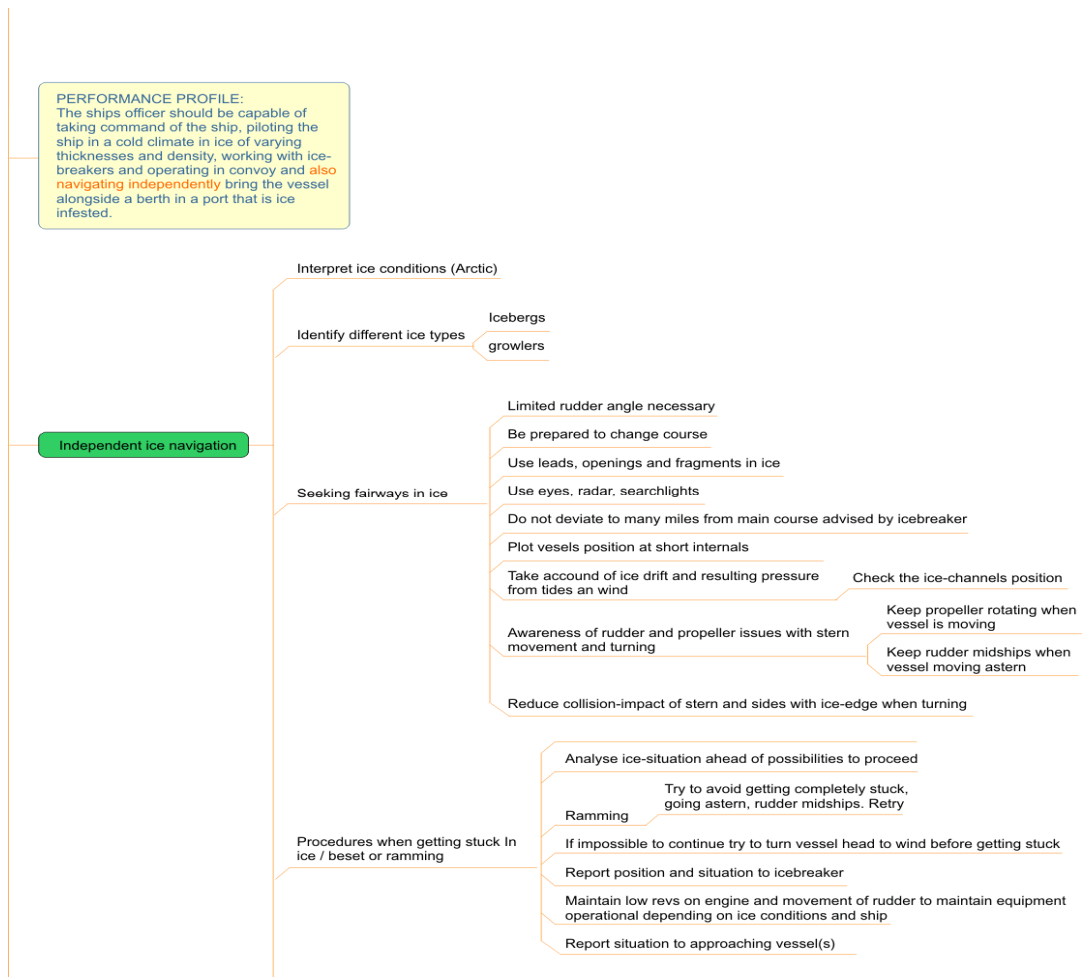


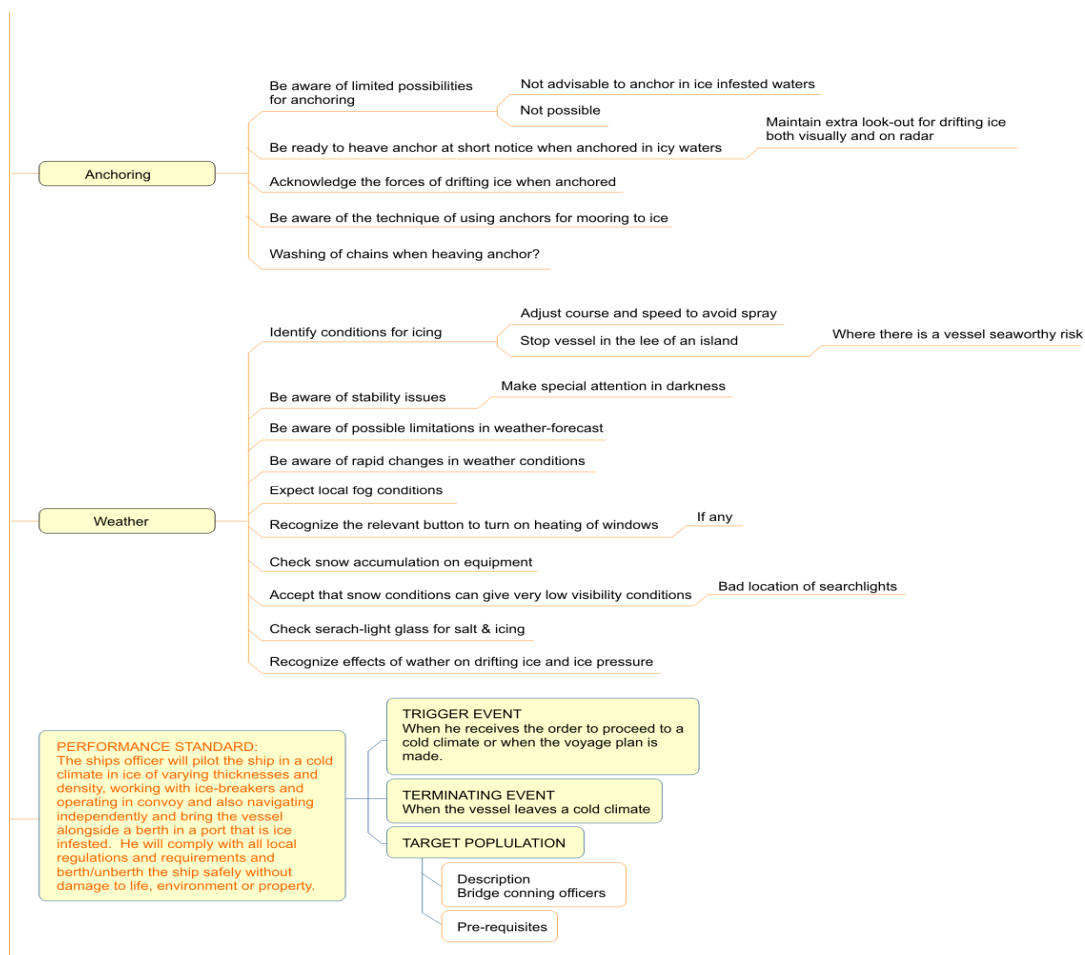
## Appendix C: Standard of Competence for Ice Navigation

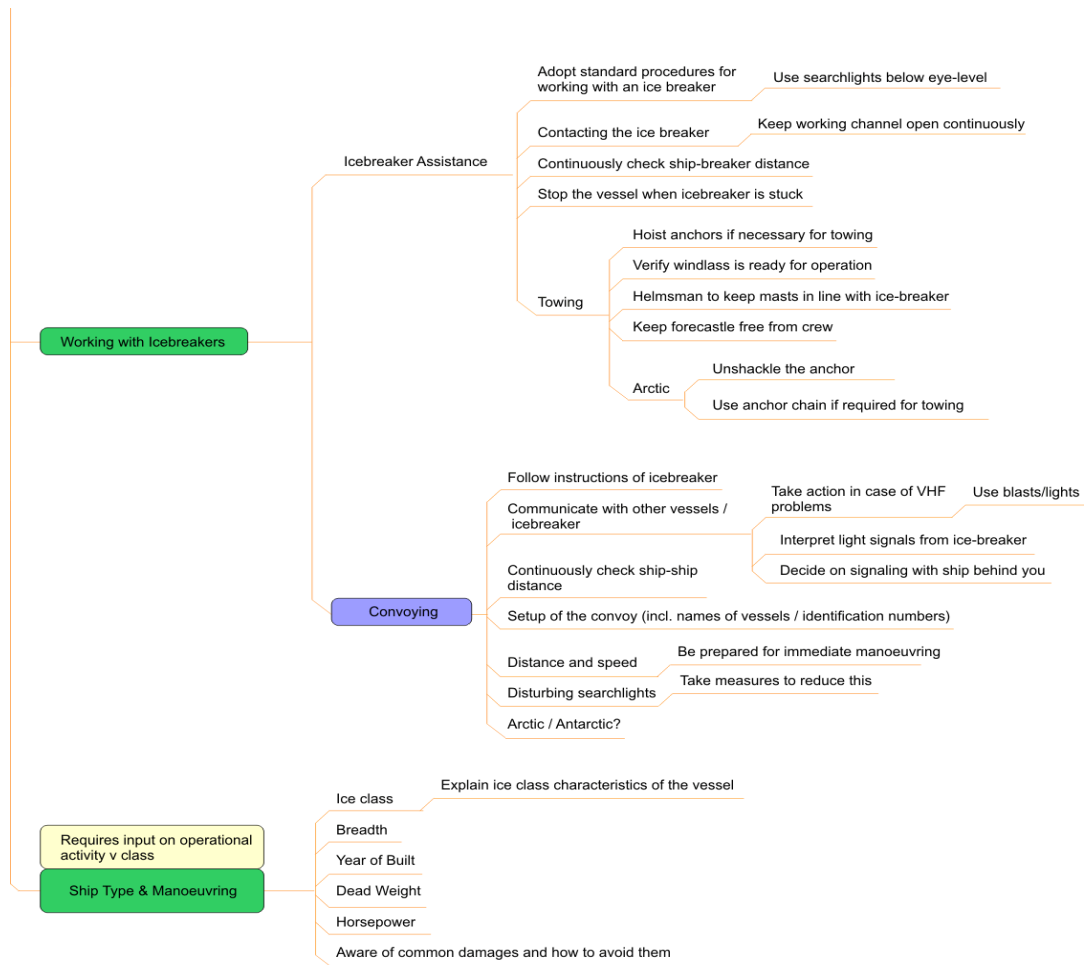












## Appendix D: Project Correspondence

-----Original Message-----

>> From: Jim Parsons  
 >> Sent: Tuesday, December 29, 2015 2:04 PM  
 >> To: [vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)  
 >> Subject: IAMU  
 >> Season's Greetings, Vladimir  
 >> Checking now to ask how the document mapping for the Arctic training requirements (IMO, STCW, etc.) is progressing?  
 >> ATB  
 >> Jim

Original Message-----

From: Jim Parsons [<mailto:Jim.Parsons@mi.mun.ca>]  
 Sent: Tuesday, January 05, 2016 2:53 PM  
 To: Vladimir.E. Kuzmin  
 Cc: Catherine Dutton  
 Subject: Re: IAMU  
 Thank you, Vladimir  
 Also, did you manage to find any Arctic shipping accident reports for your general region?  
 ATB  
 Jim

> On Jan 5, 2016, at 06:28, Vladimir.E.Kuzmin wrote:  
 > <[vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)>  
 > Happy New Year and Merry Christmas Jim, <Merry Christmas.JPG>  
 > My best wishes to you and your family. In Russia we celebrate  
 > Christmas on the 7th of January because of the Orthodox Church difference in calendar. So we are  
 > on holidays till 11th of January. I've made moderate progress, revert with more info after holidays.  
 > With best Wishes,  
 > Vladimir  
 > Отправлено с iPhone  
 >> 5 янв. 2016 г., в 2:06, Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)> написал(а):  
 >> Happy New Year, Vladimir  
 >> Have you made any progress with the document mapping since our  
 >> conversation at the Sheraton Hotel in St. John's?  
 >> I await your reply. >> All the best,>> Jim

-----Original Message-----

From: Vladimir E. Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]  
 Sent: Monday, January 11, 2016 4:40 PM  
 To: Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)>  
 Cc: Catherine Dutton <[Catherine.Dutton@mi.mun.ca](mailto:Catherine.Dutton@mi.mun.ca)>  
 Subject: RE: IAMU

Hello Jim,

This document was not extracted from IMO documents, it is based on experience. We can use it to identify gaps between practice and IMO documents. I searched Rulecheck database for ice navigation results are attached herewith

<https://onedrive.live.com/redir?resid=772860BD32DF50A3!2305&authkey=!AIpgkYO>

pG-rvJes&ithint=file%2cdocx. I found cadet who could make more detailed search but basically IMO documents lack practical details, these details could be taken from mindmap I provided to you.

I will try to call you tomorrow, there's 6.30 hours difference between us, when are you available tomorrow?

Kind regards,

Vladimir

Original Message-----

From: Vladimir.E.Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]

Sent: Sunday, January 10, 2016 5:51 PM

To: Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)>

Cc: Catherine Dutton <[Catherine.Dutton@mi.mun.ca](mailto:Catherine.Dutton@mi.mun.ca)>

Subject: RE: IAMU

Hello Jim,

Here's mindmap regarding ice specific competencies which might be usable for IAMU work. I attach both in mindjet form as well as pdf file.

As to statistics as I already mentioned I have mostly for the Baltic sea but for training purposes this should be well enough. Also Finnish colleagues provides some data for their waters (also attached).

Kind regards,

Vladimir

-----Original Message-----

From: Jim Parsons [<mailto:Jim.Parsons@mi.mun.ca>]

Sent: Monday, January 11, 2016 6:48 PM

To: Vladimir.E.Kuzmin <[vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)>

Cc: Catherine Dutton <[Catherine.Dutton@mi.mun.ca](mailto:Catherine.Dutton@mi.mun.ca)>

Subject: RE: IAMU

Hi Vladimir

I have looked at the mapping doc but fail to see where this shows that it has been extracted from STCW, SOLAS, MARPOL or other IMO docs. I am available to Skype if you like.

ATB,

Jim

From: Vladimir Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]

Sent: Monday, February 15, 2016 1:36 PM

To: Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)>

Subject: Re: IAMU project

Hello Jim,

Yes, it should be from 2010 but I check once more and ask student to add more accurately there it was taken from (part, section, etc.)



As to the date and place - in my data I do not always have an accurate position, but if we indicate it then it would be clearly seen that it is not from the polar area though as I mentioned previously for our purpose - identifying gaps - any ice covered waters would be OK.

Kind regards,

Vladimir

On Mon, Feb 15, 2016 at 5:56 PM, Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)> wrote:

Thank you, Vladimir

No news from IMO on ice navigation at the moment.

Please confirm if the STCW requirements in the table are from the 2010 Manila Amendments?

Maybe we should put Date and Lat/Long columns in the table?

All the best,

Jim

From: Vladimir Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]

Sent: Monday, February 15, 2016 9:56 AM

To: Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)>

Subject: IAMU project

Hello Jim,

Any news from IMO on ice navigation?

In attachment one table devoted to IMO training requirements and template related to incident/accident data. If the first table is OK, pls provide data on Canadian waters and I proceed with the 2nd table with the assistance of my student

Kind regards,

Vladimir

From: Vladimir Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]

Sent: Tuesday, February 16, 2016 7:11 AM

To: Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)>

Subject: Re: IAMU project

Nothing new, only polar code. Anything else?

Kind regards,

Vladimir

On Tue, Feb 16, 2016 at 1:27 PM, Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)> wrote:

How about bergy waters.

ATB, Jim

On Feb 16, 2016, at 06:34, Vladimir Kuzmin

<[vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)<<mailto:vladimir.e.kuzmin@gmail.com>>> wrote:

Hello Jim,

Searched for polar waters, Arctic waters, and high latitudes. Only Arctic waters produced some additional files which I forward to my student. Any other suggestions to search?

As soon as he updates the table I'll resend it to you.

Regards,

Vladimir

On Tue, Feb 16, 2016 at 12:22 PM, Jim Parsons

<[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)<<mailto:Jim.Parsons@mi.mun.ca>>> wrote:

Thank you, Vladimir. How about searching for polar waters, Arctic waters, and high latitudes. ATB  
Jim

On Feb 16, 2016, at 04:55, Vladimir Kuzmin

<[vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)<<mailto:vladimir.e.kuzmin@gmail.com>>

<<mailto:vladimir.e.kuzmin@gmail.com><<mailto:vladimir.e.kuzmin@gmail.com>>>> wrote:

Hello Jim,

As I mentioned I have access to the EMSA RuleCheck system - screenshot 1. There is a search facility  
- screenshot 2.

So I have searched for word ice, ice navigation, polar navigation and saved results as pdf for student to  
search within documents. Results were sent to you yesterday.

If you have suggestion on other words for search - let me know and I do the search for them also.

Regards,

Vladimir

On Tue, Feb 16, 2016 at 3:47 AM, Jim Parsons

<[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)<<mailto:Jim.Parsons@mi.mun.ca>><<mailto:Jim.Parsons@mi.mun.ca><<mailto:Jim.Parsons@mi.mun.ca>>>> wrote:

Hi Vladimir

Did the student also check SOLAS and MARPOL to see if there were any requirements in these  
conventions?

ATB

Jim

On Feb 15, 2016, at 13:35, Vladimir Kuzmin

<[vladimir.e.kuzmin@gmail.com](mailto:vladimir.e.kuzmin@gmail.com)<<mailto:vladimir.e.kuzmin@gmail.com>><<mailto:vladimir.e.kuzmin@gmail.com><<mailto:vladimir.e.kuzmin@gmail.com>>><<mailto:vladimir.e.kuzmin@gmail.com><<mailto:vladimir.e.kuzmin@gmail.com>><<mailto:vladimir.e.kuzmin@gmail.com>>>>> wrote:

Hello Jim,

Yes, it should be from 2010 but I check once more and ask student to add more accurately there it was  
taken from (part, section, etc.)

As to the date and place - in my data I do not always have an accurate position, but if we indicate it  
then it would be clearly seen that it is not from the polar area though as I mentioned previously for our  
purpose - identifying gaps - any ice covered waters would be OK.

Kind regards, Vladimir

On Mon, Feb 15, 2016 at 5:56 PM, Jim Parsons

<[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)<<mailto:Jim.Parsons@mi.mun.ca>><<mailto:Jim.Parsons@mi.mun.ca><<mailto:Jim.Parsons@mi.mun.ca>>><<mailto:Jim.Parsons@mi.mun.ca><<mailto:Jim.Parsons@mi.mun.ca>>>>> wrote:

Thank you, Vladimir

No news from IMO on ice navigation at the moment.

Please confirm if the STCW requirements in the table are from the 2010 Manila Amendments?

Maybe we should put Date and Lat/Long columns in the table?

All the best, Jim

From: Vladimir Kuzmin

[<mailto:vladimir.e.kuzmin@gmail.com><<mailto:vladimir.e.kuzmin@gmail.com>><<mailto:vladimir.e.kuzmin@gmail.com><<mailto:vladimir.e.kuzmin@gmail.com>>><<mailto:vladimir.e.kuzmin@gmail.com><<mailto:vladimir.e.kuzmin@gmail.com>>>>>

[<mailto:vladimir.e.kuzmin@gmail.com>](mailto:vladimir.e.kuzmin@gmail.com)[<mailto:vladimir.e.kuzmin@gmail.com>](mailto:vladimir.e.kuzmin@gmail.com)[<mailto:vladimir.e.kuzmin@gmail.com>](mailto:vladimir.e.kuzmin@gmail.com)>>>]

Sent: Monday, February 15, 2016 9:56 AM

To: Jim Parsons

[<Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)[<mailto:Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)[<mailto:Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)[<mailto:Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)>>>[<mailto:Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)[<mailto:Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)[<mailto:Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)>>>>

Subject: IAMU project

Hello Jim,

Any news from IMO on ice navigation?

In attachment one table devoted to IMO training requirements and template related to incident/accident data. If the first table is OK, pls provide data on Canadian waters and I proceed with the 2nd table with the assistance of my student

Kind regards, Vladimir

From: Vladimir.E.Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]

Sent: Friday, April 08, 2016 7:09 PM

To: Jim Parsons [<Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)

Subject: RE: Draft of FSA Final Report

Hello Jim,

Sorry for being late with reply, I was at Nizhny Novgorod at Inland Shipping University there, that was a part of cross-check program between marine-related Universities in Russia.

I will look through your article and revert with comments. And to your previous questions:

1) How did the student identify the gaps in IMO training for the Canadian accidents? I did not think there was enough information provided by the Canadian TSB to identify these gaps.

I agree with you, it was just a mentioning of what happened without any details, my report are local, but they are much more detailed.

2) Maybe you can provide diagrams for your/Baltic stats? I wonder if they are already included in the LMIU stats that I have shown??? Maybe your student can cross-check this for us?? He is checking, but I think it is already in.

3) How are you thinking to show gaps in stats and Polar Code? – The basic idea is that Polar code is too general, probably the PWOM will help with hands-on recommendation but it is should be also reflected in training. For example, one of the most often problems in GOF is blocking of seachests by ice, that could be easily avoided by switching to bottom seachests or to internal tank if available but the engineers simply not aware of such problems as they do not have any formal ice navigation training...

Kind regards, Vladimir

From: Jim Parsons [<mailto:Jim.Parsons@mi.mun.ca>]

Sent: Friday, April 08, 2016 11:03 PM

To: Vladimir E. Kuzmin

Subject: Draft of FSA Final Report

Hi Vladimir

PSA for your review and comments.

Happy Friday, Jim

From: Vladimir Kuzmin [<mailto:vladimir.e.kuzmin@gmail.com>]

Sent: Monday, May 02, 2016 12:58 PM

To: Jim Parsons [<Jim.Parsons@mi.mun.ca>](mailto:Jim.Parsons@mi.mun.ca)

Subject: Re: IAMU report

Hello Jim,

You did a great job, no doubts. There is actually almost nothing left to add. So the only thing I add shown in red and they are in the executive summary - just a few lines. By the way, what do you mean saying that "It is expected that the IMO will approve a Polar Code ice navigation course in May 2016"? - highlighted by yellow, near my additions in red.

Just as a small remark, quite often you refers to Canadian Arctic, though sometimes it is really different but we have much more in common regarding ice navigation, especially training, so most of the paper you could mention just Arctic, but that is not a big deal, I guess you were going to reflect Canadian experience in the paper.

Regards, Vladimir

On Fri, Apr 29, 2016 at 2:02 PM, Jim Parsons <[Jim.Parsons@mi.mun.ca](mailto:Jim.Parsons@mi.mun.ca)> wrote:

Thank you, Vladimir

Is there anything you would like to add to the paper?

I shall be around during early June.

Happy Friday. ATB, Jim





## **International Association of Maritime Universities**

Meiwa Building 8F, 1-15-10 Toranomon, Minato-ku, Tokyo 105-0001, Japan

Tel : 81-3-6257-1812   E-mail : [info@iamu-edu.org](mailto:info@iamu-edu.org)   URL : <http://www.iamu-edu.org>

ISBN No. 978-4-907408-15-2