

# Identifying and Assessing Emerging Risks in Marine Transportation

Completed in partial fulfillment of a Master of Marine Affairs, School of Marine and Environmental Affairs, University of Washington

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Sponsor: International Tanker Owners Pollution Federation, David Campion and Mark Whittington

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### **NOTICE**

This report has been reviewed by ITOPF and the NOAA Office of Response and Restoration. Such review does not signify that the contents of this report necessarily represent the official positions of ITOPF, NOAA, or the government of the United States, nor does mention of trade names or commercial products constitute endorsement or recommendation for their use.

## ACRONYMS

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DPSIR – A framework with components including: Driving Forces, pressures, States, Impacts, and Responses

DWT – Deadweight Tons/Tonnage

EIA – U.S. Energy Information Agency

FPSO – Floating Production Storage and Offloading Vessel

GHG – Greenhouse Gas

HFO – Heavy Fuel Oil

IMO – International Maritime Organization

LNG – Liquefied Natural Gas

LSHFO – Low Sulphur Heavy Fuel Oil

MDO/MGO – Marine Diesel Oil/Marine Gas Oil

NEP – Northeast Passage

NSR – Northern Sea Route

NWP – Northwest Passage

RCP – Representative Concentration Pathways

RWS – Rijkswaterstaat Noordzee

SLR – Sea Level Rise

SSR – Southern Sea Route

TEU – Twenty-Foot Equivalent Unit

USGS – United States Coast Guard

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## FOREWORD

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International Tanker Owners Pollution Federation (ITOPF) provides critical services to tanker owners during emergency response situations, such as spill response, claims analysis and damage assessment, information services, contingency planning and advice, and training and education. ITOPF responds to spills involving oil, chemicals, and other substances including vegetable oils, cereals, coal, and containerized cargoes. Over the course of 45 years, ITOPF has attended over 750 incidents in 100 countries, including revolutionary cases such as the *Amoco Cadiz*, *Exxon Valdez*, *Braer*, *Sea Empress*, *Erika*, *Prestige* and *Hebei Spirit*. Our project team is proud to be the beneficiary of the 4<sup>th</sup> annual ITOPF R&D Award. With this honor the ITOPF R&D Award Committee recognizes that the nature of shipping is changing across many fronts, transforming the character, and geography of risks that need to be accounted for. ITOPF's Managing Director, Dr. Karen Purnell, said “As shipping routes and products change, new risks are emerging. The challenge facing spill preparedness and response organizations is to understand how best to prepare for efficient and effective response to these emerging risks. This project will add to our understanding and aid informed decision-making.”

Additional assistance was provided by the Office of Response and Restoration, which is part of National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service. This office provides expertise in preparing for, evaluating, and responding to threats in U.S. coastal environments caused by oil, chemicals, and marine debris.

# 1. INTRODUCTION

## 1.1. Purpose and Scope of the Study

---

This report examines potential future challenges to safely shipping commodities around the world. The marine transportation system is constantly influenced by a range of environmental, economic, and technological factors. These present new opportunities while at the same time potentially posing risks for which the system as a whole must be prepared. This report seeks to identify and assess emerging risks in marine transportation. These risks, while not fully understood now, have the potential to alter the nature and location vessel casualties in the future. While it is beyond the scope of this study to recommend specific risk avoidance or mitigation strategies, the report's broader purpose is to aid in risk mitigation and response preparation.

## 1.2. Driving Forces of Risk

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The driving force, pressure, state, impact, and responses (DPSIR<sup>1</sup>) causal framework is useful for characterizing causal linkages between societal forces or “pressures” and the resulting environmental change (aka impact) (Kristensen 2004). The framework emphasizes how societal response can be directed at any or all of the preceding variables guided by considerations of practicality or expected benefits in relation to the costs of response. DPSIR is often applied to problems of pollution management or the management of technological risks, making it well suited to the present study.

In consultation with our ITOPF sponsors, the following three driving forces (“drivers”) were judged particularly important areas of focus for this report:

1. *The Changing Environment* – Risks associated with the increased frequency of extreme weather events, sea level rise, changes in Arctic sea ice, and thawing permafrost.
2. *Changing Patterns of Trade* – While change is constant in world trade, our principal focus was with the expansion of the Panama and Suez Canals, development of Arctic marine trade routes, and changes in North American oil trade patterns.

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<sup>1</sup> For more information of the DPSIR Framework, please see Kristensen (2004).

3. *Developing Technologies* – Pressures associated with increasing vessel sizes, the reliance on vessel automation coupled with crew fatigue, the use of LNG and/or other alternative fuels as a method of propulsion, and gaps in salvage efforts related to these areas.

These driving forces can result in a variety of “pressures” that can express themselves as the emerging risks that are the focus of this study. For example, melting Arctic sea ice is a “driver” that leads to the “pressure” of more vessels in Arctic waters with the attendant risk of oil spills. Following Kristensen (2004), how industry and others within the Arctic marine transportation system respond now and in the future influences the severity of this emerging risk.

This report makes use of multiple methods to identify and evaluate possible future conditions affecting each of the three drivers under consideration. Generally, we followed the policy research process described by Majchrzak and Markus (2014), although we deemphasized the latter three of the seven steps these authors outline, as the purpose of our study was not to develop policy recommendations. We primarily employ literature reviews aided by interviews with industry and other experts to help us better understand current and future trends in shipping and their associated risks. We developed a list of potential interviewees together with questions that we would pose to them in consultation with our ITOPF sponsors.

We did not do formal risk analysis, as this was beyond the scope of the study. Our review prioritized literature studies in which others had estimated risks or employed techniques that help frame the contexts in which future risks might emerge, or which lead to qualitative estimation of risk. Such methods include scenarios, models, Delphi techniques, and horizon scanning. Given the nature of the problems studied, the second part of our method was to highlight the extent to which there was agreement across studies we reviewed.

We consider three general time frames over which risks might emerge:

1. *Approximately 0 – 5 years*: Current risks
2. *Approximately 5 – 10 years*: Potential risks whose occurrence depends on the outcomes of ongoing events
3. *Approximately 10 – 20+ years*: Potential risks whose occurrence depends on the outcome of events in the previous time periods, including any mitigating actions

Finally, we independently assessed uncertainty in outcomes for the three time periods over which risks might emerge.

### 1.3. Concepts of Risk and Cause

---

Risk is the product of the likelihood of an event (its probability) and its consequences (Bernstein 1997). This report seeks to identify factors that could affect the future probability of occurrence and/or consequences of events should they occur within the global marine transportation network. Such factors can be both exogenous and endogenous to the global shipping system. Examples of exogenous influences include the risk drivers associated with weather and climate, such factors as rising sea levels, reduction in Arctic sea ice, or increased storminess. The forces driving globalization are also endogenous to the shipping system. Examples of endogenous influences include changing trade routes or products in trade, or changes in vessel technologies. These influences could increase risk in some instances even as they offer new commercial opportunities.

Technological advances will generally reduce current risks. At the same time, they could inadvertently introduce new failure modes that are poorly understood—if understood at all—at the time of their introduction. Perversely, some changes that reduce known risks may introduce other latent risks. Examples can be found in the 2010 Deepwater Horizon accident in the Gulf of Mexico, where great leaps in technological sophistication were accompanied by changes in industry management that rendered the technologies in use less under control than had been assumed (National Commission on the BP Deepwater Horizon Oil Spill 2011).

The notion of “emerging risk” is appropriate to the examination of marine transportation system risk from this perspective. Lloyd’s of London defines emerging risk as, “an issue that is perceived to be potentially significant but which may not be fully understood” (Beecroft n.d.). The uncertainty about the true character of emerging risks stems from many factors, including the difficulty of understanding the complex interactions associated with the adoption of new technologies or with operating in unfamiliar environments (International Risk Governance Council 2010).

Emerging risks can be new risks that grow from more familiar risks that evolve in unexpected ways in response to system changes, with unanticipated consequences (Woerner 2011).<sup>2</sup> Risks can emerge as a result of the environmental, economic, and technological pressures considered in this report, including difficult-to-anticipate interactions among these factors or with other factors directly or indirectly linked. Examples in the latter category include human interactions with new technologies or human responses to operating in unfamiliar environments. The implications of such potential future risks are contingent on the actions taken to mitigate them. Tools like scenario analysis are useful for identifying and analyzing emerging risks. They provide ways for plausible futures to be systematically defined and examined for their consequences in terms of potential future risks (Leschine et al. 2015). Because they are anticipatory in nature, scenario analysis and other future-oriented analytical approaches can point toward effective risk mitigation strategies.

Borrowing from Mitchell (2010), this report examines risk in terms of both "permissive" and "triggering" causes. A permissive cause is a contextual element that creates the conditions for incidents to occur, whereas a triggering cause is a specific event leading to an incident, also known as a proximate cause (Mitchell 2010). An example of a permissive cause was seen off the coast of Houston, Texas in 2015, when the lack of oil buyers led to major vessel congestion with more than 50 commercial vessels, carrying over 20 million barrels of oil, anchored outside the port (Associated Press 2015). The permissive cause in this event was the congestion that increased the probability of an accident occurring.<sup>3</sup> An example of a triggering cause is the collision of the *RMS Titanic* with the iceberg that led to sinking. These two types of cause differ in how they contribute to an incident. A permissive cause is the background or context that increases the probability that an incident will occur, whereas a triggering cause leads directly to an incident at a specific point in time. Many triggering causes can be associated with a particular permissive cause, and more than one permissive cause may underlie a particular incident. This differentiation is useful in providing a holistic picture of impending risk in the marine transportation sector.

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<sup>2</sup> This type of risk is often referred to as a "changing risk." The two terms are interchangeable in this report.

<sup>3</sup> Studies have shown that the majority of vessel related spills occur within ports, and that there exists a strong correlation between the length of time a vessel spends in a port traffic system and the probability of an accident occurring (De and Ghosh 2003, Alderton 2004, as reported by Talley 2013).

The International Risk Governance Council (2010) further elaborates on the nature of emerging risk, highlighting the importance of uncertainty, complexity, and context:

- *High uncertainty risks* – Risks for which there is little understanding about either the potential consequences that may result or their probabilities of resulting in incidents.
- *Impacts of increasing complexity on risk* – As the 2010 Deepwater Horizon accident illustrated, increasing complexity can result in the gradual loss of safety margins. Charles Perrow (1984) observed that complex systems typically feature high levels of interconnectedness and interdependency with non-linear feedbacks between crucial subsystems.
- *Impacts of changes in context on risk* – Altering familiar operating environments may also alter the nature, probability, and consequences of the associated risks. Modern “megaships” may be inherently safer due to the advanced technologies they incorporate, but the incidents that do occur may be of greater consequence due to the amount of cargo and fuel they carry.

From a management perspective, uncertainty, complexity, and context provide a useful approach for considering risk due to the interactions of risk and cause. Section 8 considers the interactions of risks and cause that the preceding sections of this report identify.

## 1.4. Current State of Maritime Shipping

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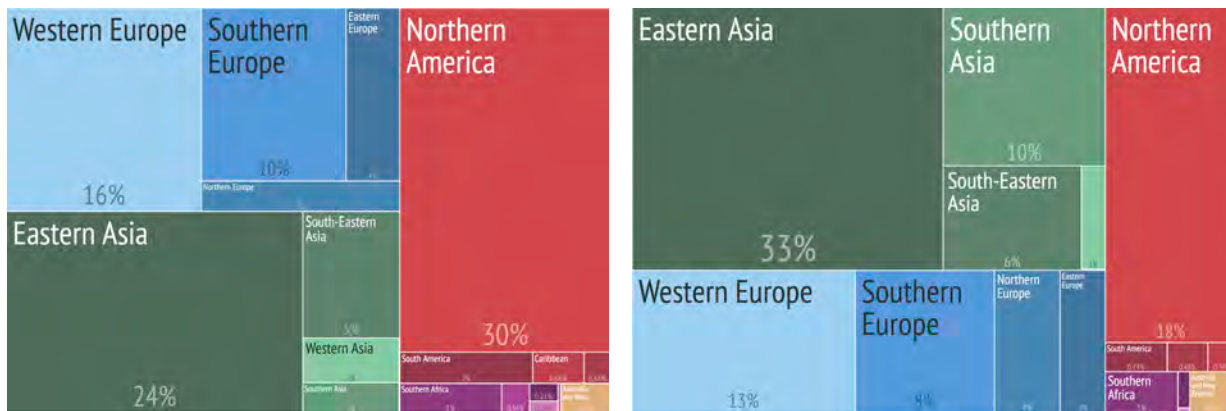
This section will examine the routes vessels are taking, the cargos they are carrying, and the vessels themselves. We analyze the routes of vessels of greatest tonnage, the containerized cargo and bulk cargo that is most shipped, and the ages of vessels in use. By looking at the current state of shipping, we establish a baseline for comparing risks that might emerge as a result of the three driving forces of risk we identify in Section 1.2

### 1.4.1. Routes of Vessels of the Greatest Tonnage

As of 2014, there were over 85,000 vessels traversing the seas, excluding fishing vessels and commercial vessels less than 100 gross tons (Mandryk 2011, Equasis Statistics 2014). The

majority of these vessels are general cargo vessels<sup>4</sup>, although bulk carriers, oil and chemical tankers, and containerships account for most of the gross tonnage of the world’s shipping fleet (Equasis Statistics 2014). The enrolled membership of ITOPF as of 2016 represented approximately 97% of the world tanker fleet, including 11,700 vessels representing 357 million gross tons. The ITOPF registered non-tanker fleet representing about 90% of the international fleet comprised 717 million gross tons (ITOPF 2016). The trade patterns of oil tankers and containerships have a high likelihood of changing in the future.

Oil tankers are an important consideration in pollution risks associated with maritime trade. About 63% of all crude oil production is transported in oil tankers (U.S. Energy Information agency 2014). Crude oil imports to the United States have been decreasing since 2011 due to the ample supply of shale oil, prompting an overall downward trend in global oil shipments (UNCTAD 2014). The change in global oil import trends can be seen in Figure 1.



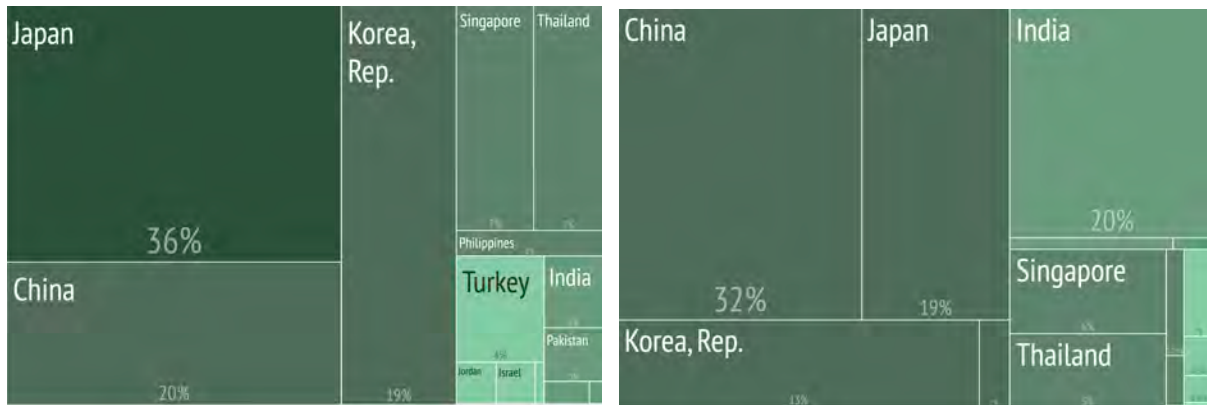
**Figure 1: Net imported crude oils by region in 2004 (left) and 2014 (right)**

The amount of crude oil imported by major import regions as a percentage of the total global trade in 2004 (left) and 2014 (right). Notice the increase in total oil imports by Eastern Asia and the decrease in North America. Experts believe the North American downward trend is likely due to the United States’ development of shale oil.

(Generated using the Atlas of Economic Complexity 2016)

Crude oil demand in many Asian countries, particularly China, has been increasing. Figure 2 shows the change in crude oil imports in 2004 and 2014 in Asia. China and India top the importers in 2014 contrasting with Japan as the region’s dominant importer in 2004.

<sup>4</sup> General cargo vessels are considered ships that do not carry containerized cargo or cargo that is usually carried by bulk such as iron ore, grain, etc. Instead, these vessels carry cargo such as furniture, building materials, etc. (Allianz 2015).

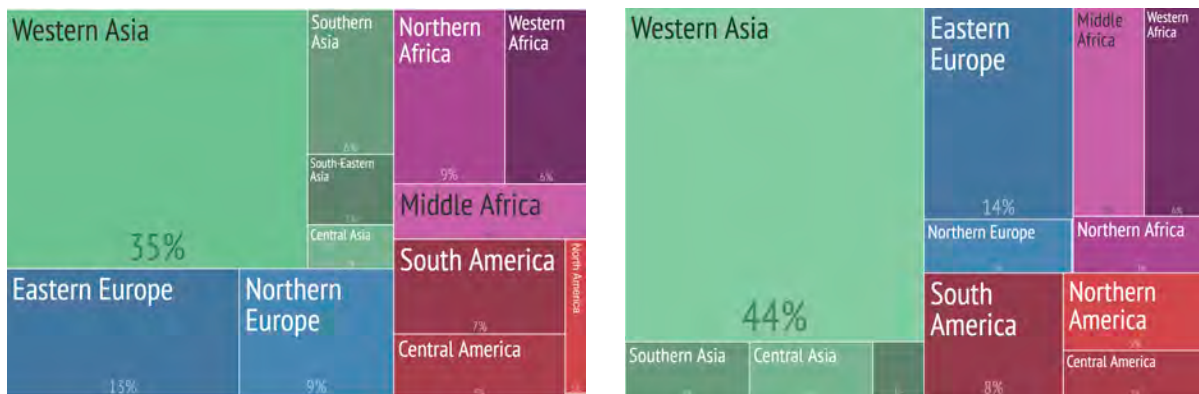


**Figure 2: Net imported crude oils as a percentage of total, by country in Asia in 2004 (left) and 2014 (right)**

The amount of crude oil imported by major Asian nations in 2004 (left) and 2014 (right). China and India show increasing oil imports, while Japan’s imports decrease.

(Generated using the Atlas of Economic Complexity 2016)

Figure 3 shows the top net exporters of crude oil in 2004 and 2014. While Western Asia (the Middle East) continues to dominate exports in 2014, North America significantly increased its share. The recent lifting of the United States’ oil export ban could have major effects on oil trading and could even cause a shift in the top exporters of crude oil, although the effects have yet to be fully realized (BP 2016).



**Figure 3: Net Crude Oil Exported by Major Regions by share of total in 2004 (left) and 2014 (right)**

This figure shows the amount of crude oil exported by major oil export regions as a percentage of the total world exports from 2004 (left) to 2014 (right). Western Asia dominates as an exporter, but the recent lifting of the United States crude oil export ban could cause significant regional changes.

(Generated using the Atlas of Economic Complexity 2016)

In 2013, dry cargo (which includes commodities carried in bulk, general cargo, break-bulk and containerized trade) accounted for the largest volume, 70%, of shipped cargoes globally (UNCTAD 2014). In 2014, containerized trade increased by approximately 5.3% or 171 million



TEUs (UNCTAD 2015). Of the 2013 dry cargo, 44% of the total volume of dry cargo bulk commodities shipped were iron ore, coal, grain, bauxite and alumina, and phosphate rock (UNCTAD 2014). In 2014 Indonesia placed an export restriction on bauxite trade which then reduced global bauxite and alumina trade by approximately 25% (UNCTAD 2015). Conversely, shipments of phosphate rock increased by 7% (UNCTAD 2015). As for other bulk cargoes, steel and forest products made up 42% of the total volume (UNCTAD 2015).

In 2013, containerized trade grew by 4.6%, largely driven by import demand from Europe and the United States (UNCTAD 2014). As shown in Table 1, containership markets are largely focused on servicing routes between East Asia and the West Coast of the United States, and between East Asia and Europe (Montes et al. 2012, World Shipping Council<sup>b</sup> 2016). It is expected that with the arrival of the new mega-containerships, the vessels servicing the latter trade will remain mostly on Asia-Europe routes (UNCTAD 2014).

**Table 1: Top Trade Routes in 2013 (Million TEUs Shipped)**

The top containerized trade routes as of 2013. This figure shows how routes are mostly focused on servicing East Asia and the West Coast, as well as East Asia and Europe.

<i>Routes</i>	<i>West Bound</i>	<i>East Bound</i>	<i>Total</i>
<b>Asia-North America</b>	7.7	15.4	<b>23.1</b>
<b>Asia-Northern Europe</b>	9.2	4.5	<b>13.7</b>
<b>Asia-Mediterranean</b>	4.7	2.1	<b>6.7</b>
<b>Asia-Middle East</b>	3.7	1.3	<b>5.0</b>
<b>Northern Europe-North America</b>	2.6	2.1	<b>4.7</b>

(Table Adapted from World Shipping Council<sup>b</sup> 2016)

Table 2 shows the top containership ports in 2011 and 2013 in regards to their throughput capacity. Each port grew from 2011 to 2013 except for Hong Kong, which fell 2.03 million TEU or about 1%. Understanding which ports in the world are most important for the containership sector helps in decisions about where to prioritize adaptations and improvements.

**Table 2: Top Containership Ports 2011 and 2013 (Million TEUs)**

The top containership ports in 2011 and 2013. Every port except Hong Kong grew in volume processed between 2011 and 2013. Knowing these top ports will help focus priorities of port adaptations and improvements for future climate impacts, shifting trade routes, and new types of vessels/cargo.

<i>Port</i>	<i>Volume 2011 (Million TEU)</i>	<i>Volume 2013 (Million TEU)</i>
<b>Shanghai</b>	31.7	33.6
<b>Singapore</b>	29.9	32.6
<b>Shenzhen</b>	22.6	23.3
<b>Hong Kong</b>	24.4	22.4
<b>Busan, S. Korea</b>	16.2	17.7

(Table Adapted from World Shipping Council 2016)

### 1.4.2. The Age of Vessels

Multiple factors including design, age, and maintenance standards can affect the structural integrity of vessels. This section examines the influence of vessel age which has found to be correlated to accident risk due to both structural concerns and operational conditions (Butt et al. 2012, Zayed et al. 2013, Ship Recycling 2011). Diminishing structural integrity in aging vessels can affect the probability of an incident. More than 32% of all vessels are over 25 years old (Table 3). On average, the youngest vessels are containerships and oil tankers, while the oldest are general cargo vessels (UNCTAD 2014). The five largest vessel-owning countries—China, Germany, Greece, Japan, and the Republic of Korea—have the youngest fleets (UNCTAD 2014).

**Table 3: Percentage of the Total Number of Vessels, in the World Fleet by Age and Gross Tonnage Category**

<i>Vessel Age Category</i>	<i>Small<sup>(1)</sup></i>	<i>Medium<sup>(2)</sup></i>	<i>Large<sup>(3)</sup></i>	<i>Very Large<sup>(4)</sup></i>	<i>Total</i>
<b>0-4 yrs. old</b>	13.1	15.6	30.3	33.9	<b>17.7</b>
<b>5-14 yrs. old</b>	22.9	31.2	48.8	50.3	<b>31.6</b>
<b>15-24 yrs. old</b>	18.3	19.2	16.5	13.7	<b>18.2</b>
<b>25+ yrs. old</b>	45.7	34.0	4.4	2.1	<b>32.5</b>

<sup>(1)</sup> Gross Tonnage (GT)<500, <sup>(2)</sup> GT<25,000, <sup>(3)</sup> GT<60,000, <sup>(4)</sup> GT>60,000

(Table Adapted from Equasis Statistics 2014)

## 1.5. Future State of Maritime Shipping

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The marine transportation system is highly dynamic, with complex interactions among economic, political, legal, technological, and human factors at local, regional, and global scales. Accurately predicting the future state of maritime shipping is complex, often resulting in predictions with a high degree of uncertainty. Changes in specific trade routes and technology adoption can be especially difficult to forecast. Different methods can be applied to predict how the future might take shape, including scenario development, Delphi method forecasting, horizon scanning, and others. Each of these methods has strengths and limitations. Rather than considering the most likely future state of maritime shipping, it can be more useful to explore the range of futures that might occur. Table 4 gives an overview of multiple perspectives on the future state of shipping derived from five recent, comprehensive reports. The different possible futures these reports identify depend on how they treat potential global changes in environment, trade patterns, and vessel technologies.

“DNV Shipping 2020” looks at four different scenarios for the changing environment and developing technologies, and how these factors will shape the future of shipping in 2020 and beyond (DNV 2012). An overarching finding of this report is that future vessel technologies and designs will be directly influenced by the marine transportation system’s response to the climate change. For example, they predict that more than one in ten newly-built vessels will have gas-fueled (LNG) engines installed, that newly-built vessels will emit up to 35% less CO<sub>2</sub> than current ones, and that the use of scrubbers will become a viable option for vessels in response to enforcement of a global sulfur limit. The report also acknowledges the uncertainty associated with predicting the future state of shipping, which depends heavily on the global response to the climate change (DNV 2012).

Two reports by Lloyd’s Register discuss possible changes to shipping by the year 2030. The first report, “Global Marine Trends 2030,” takes a broad view of the marine transportation system, laying out three scenarios for the evolution of trade for specific vessel types including containerships, bulk carriers, and LNG vessels. It predicts that China will remain the leader in containership trade with both Chinese trade routes and bulk carrier tonnage continuing to increase. Lloyd’s (2013) also expects LNG trade to increase, resulting in the continuing

expansion of LNG trade routes. The authors caution that the uncertainty surrounding the future usage of oil and LNG contributes to resulting uncertainty in their predictions about trade and trade routes for both commodities (Lloyd's Global Marine Trends 2013).

Lloyd's also produced a similar report to "DNV Shipping 2020," entitled "Global Marine Technology Trends 2030." This report employed the horizon scanning approach, focusing on technologies that may emerge in the marine transportation system. The authors expect that hybrid propulsion systems and greater degrees of vessel automation will be more widely adopted, and that technology will play a major role in the evolution of the future state of shipping. Like the DNV report, these findings emphasize the uncertainty that surrounds the future state of shipping, and how the future that emerges will depend on future global policies, specifically carbon policies (Lloyd's Global Marine Technology Trends 2015).

Dinwoodie et al. (2013) and Dinwoodie et al. (2014) used the Delphi Method to promote scenario development, enrich multidisciplinary efforts, and create a consensus among experts' predictions for future shipping trends until 2050. Overall, the conclusion of "Maritime Oil Freight Flows to 2050" (Dinwoodie et al. 2013) is that oil tanker demand will not rise drastically. However, several demand offsets were expected by 2050, including shorter sea routes via the Arctic, upgraded canals, reduced haul lengths, and more efficient vessel operating plans to reduce carbon emissions, oil intensity, and modal shifts to pipelines. In "Dry Bulk Shipping Flows to 2050," (Dinwoodie et al. 2014) the authors conclude that global dry bulk shipping demand will double by 2050 to Western economies and quadruple elsewhere, although with significant uncertainty about when and how this demand will transpire. Similar to the findings of Dinwoodie et al. (2013), these estimates depend on demand for shorter average haul lengths after 2030, as routes shift to account for Arctic sea ice melt and canal upgrades.

All five reports address the three drivers of the changing marine transportation environment that are the focus of this report. Each of the five reports describe unique potential outcomes using differing methodologies, while recognizing the complex interplay in the shipping industry among altering environments, patterns of trade, and development of new technologies.

**Table 4: Summary of Major Reports Addressing the Future of Maritime Shipping<sup>5</sup>**

<i>Report</i>	<i>Methodology</i>	<i>Trends</i>	<i>Results</i>	<i>Discussion of Uncertainty</i>
Det Norske Veritas (DNV). (2012). DNV Shipping 2020.	Scenarios	More than 1 in 10 new vessels in the 5-10 year time frame will have gas fueled engines	“Full effect of the regulatory requirements on technology uptake will come after 2020”	Climate change in terms of emissions
Lloyd’s Register. (2013). Global Marine Trends 2030.	Scenarios	In 2030: Greater LNG trade; China will remain leader in container trade; increases in bulker carrier tonnage	LNG trade routes will expand and increase. Australia to China/Japan will be the main LNG route	Oil and LNG trade and trade routes largely depend on future economic growth
Lloyd’s Register. (2015). Global Marine Technology Trends 2030.	Horizon Scanning	Greater usage of vessel automation and diesel-electric and hybrid propulsion	Technology will play a major role in what the future of shipping looks like and in many cases the tools for a “smart ship” are already here	Cybersecurity and piracy threats
Dinwoodie et al. (2013). Maritime oil freight flows to 2050: Delphi perceptions of maritime specialists.	Delphi	Maritime oil freight flows to 2050 demand not expected to rise	Global tanker demand will rise moderately by 2050	Economic shifts in oil tankers, in 10–20+ year time frame, may depend on unpredictable factors
Dinwoodie et al. (2014). Dry bulk shipping flows to 2050: Delphi perceptions of early career specialists.	Delphi	In 2050: Shorter hauls are expected; dry bulk tonnage expected to increase moderately	Expected doubling of raw material shipping to the West; Ice melt in Arctic and canal upgrades bring shorter hauls	Uncertainty about when and how dry bulk demand shipping will change due to economic patterns, regulatory changes, and technology development

<sup>5</sup> For Arctic specific scenarios, please see Hansen (2016), Keupp (2015), and Arctic Council (2009).

## 1.6. Current State of Vessel Casualties

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A vessel casualty is generally defined as any incident on a vessel that results in financial loss in the form of property damage or loss of life, or environmental damage. Property damage could be to the structure or equipment, or any other part of a vessel that would prevent it from continuing service (Mandryk 2011, Ugurlu et al. 2013). We follow the approach used in the Marine Casualty Profiles report conducted for Lloyd's List Intelligence in excluding incidents that result from piracy, war, or deliberate attempts to damage. Instead, incidents that result from accidental causes are considered. An exception comes in the discussion of compromised cybersecurity, in which the risk is principally the result of an intentional effort executed by a third party entity (Mandryk 2011, Lloyd's Technology 2015).

The types of incidents considered as vessel casualties differ with each source analyzing the data. These are triggering causes that might result in a pollution event. Some of these reports are broad, such as "Marine Accident Analysis with GIS," which classifies incident types as collisions, groundings, damage to vessel or equipment, occupational accidents, fire/explosion, flooding/sinking, and other (Ugurlu et al. 2013). Different categorizations, such as foundering, missing, hull/machinery damage, contact, collisions, fire/explosion, wreck/stranded, and piracy are found in other reports (Allianz 2015, Butt et al. 2012). Table 5 is a selected list of potential incident types compiled from multiple reports.

**Table 5: Incident Types**

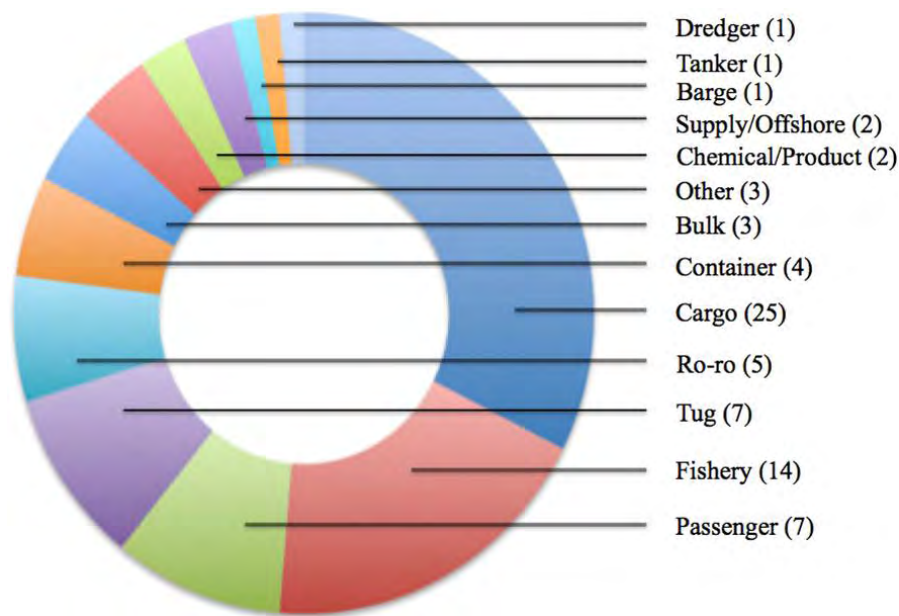
Definitions for incident types that this report considers in detail. This list was compiled from multiple reports.

<i>Incident Type</i>	<i>Definition</i>
Allision	Vessel “allides” or strikes a fixed object, such as stationary vessel or a bridge, (Konrad 2007)
Collision	Two moving vessels strike each other (Konrad 2007)
Grounding	“Vessel strikes the sea bottom, shore or underwater wrecks,” (Arendt et al. 2010, Butt et al. 2012)
Foundering	“Sinking due to rough weather, leaks, break in two, etc.,” (Arendt et al. 2010, Butt et al. 2012)
Hull Damage/Failure	Any structural damage to the hull (Allianz 2015)
Equipment Damage/Failure	Any damage or failure of equipment or machinery onboard
Fire/Explosion	Any uncontained fire onboard or explosion
Instability/Sinking	Loss of vessel stability resulting in sinking
Cargo Loss	Loss of cargo overboard, either in an isolated event or in addition to a spill (Allianz 2015)

Although human error is often involved in the cause of a vessel casualty, most reports do not actually consider it a defined incident type (Butt et al. 2012, Corovic and Djurovic 2013, Ugurlu et al. 2013). While human factors can be both permissive and triggering causes of vessel casualties, this report focuses on a subset of human factors that are triggering events. In this report, we consider human factors as triggering events causing one or more types of incidents, each of which could then lead to a vessel casualty.

The most common incident type remains foundering, defined as, “Sinking due to rough weather, leaks, breaking in two, etc., but not due to other categories such as collision [and so on]” (Arendt et al. 2010, Butt et al. 2012, Allianz 2015). Weather is an important permissive cause. Changes in climate and rising sea levels potentially increase the probability of some of these incident types. These changing and emerging risks will be further discussed throughout Section 3.

Figure 4 shows the total losses<sup>6</sup> by vessel type in 2014. Thirteen different vessel types are considered, with cargo vessels<sup>7</sup> by far having the highest total losses (Allianz 2015). Some emerging risks such as storminess and sea level rise could affect all vessel types (Section 3.2.1, 3.2.2), while others only affect certain vessel types. For example, containerships, bulk carriers, and LNG carriers are specifically affected by risks associated with developing technologies, increasing the potential losses for these types of vessel<sup>8</sup> (Allianz 2015, Butt et al. 2012, UNCTAD 2014).



**Figure 4: Total Losses by Type of Vessel**

The number of total losses by vessel type for 2014. Cargo vessels have by far the most total losses, followed by fishery vessels. Barges, Dredgers, and Tankers are among the vessels that had the least number of total losses.

(Adapted from Allianz 2015, data sourced from Lloyd’s List Intelligence Casualty Statistics)

Turning back to overall casualties and not just total losses, various reports disagree about the geographic location where most casualties occur. For example, the authors of “Marine Accident Analysis with GIS” find that the Far East and Northern Europe have the highest rate of vessel

<sup>6</sup> A total loss is defined as when a vessel of 100 gross tons or more is completely destroyed, damaged beyond the point of being insured, or when the vessel is not practicable to be repaired, as the cost to restore the vessel is more than the vessel is worth (Allianz 2015).

<sup>7</sup> Cargo vessels are considered vessels that do not carry containerized cargo or cargo that is usually carried by bulk carriers such as iron ore, grain, etc. Instead these vessels carry cargo such as furniture, building materials, etc. (Allianz 2015).

<sup>8</sup> These vessel types are discussed throughout Section 5



casualties, whereas the report “Marine Casualty Profiles” finds that the Eastern Mediterranean/Black Sea had the highest overall annual rate of vessel casualties despite lesser shipping volumes (Ugurlu et al. 2013, Mandryk 2011). Both reports calculated annual casualty rates using the number of vessels. More recently, “Allianz Global Shipping and Safety Review 2015” found the region with the highest number of casualties to be the British Isles, North English Channel, and the Bay of Biscay. However, the authors of this report took a different approach and analyzed the total losses, a subset of casualties, from 2013 and 2014 to identify trends. Overall, Allianz found that total loss casualties in the top 10 regions decreased during this period, except for the British Isles which experienced three total losses in 2013 and six total losses in 2014 (Allianz 2015). Some of the differences in the overall reported rates are due to some reports considering total casualty rates versus total losses. It is important to note, however, that there is often some discrepancy resulting from the underreporting of as many as 50% of all casualties (Hassel et al. 2011). In Section 3.4 as well as throughout Section 4, the changing and emerging geographic locations of vessel incidents, such as the Panama Canal and the Arctic, will be further discussed.

**Table 6: Top 10 Regions for Casualties Including Total Losses: 2005 to 2014**

Top regions for vessel casualties as well as total losses over the last nine years. Of the regions listed, the British Isles, North English Channel, and Bay of Biscay is the only region that has had an increased number of total losses between the years 2013 and 2014, all other regions decreased by as much as 11 total losses.

Specified Region	Number of Casualties Including Total Losses	Number of Total Losses
British Isles, North English Channel, Bay of Biscay	4,381	96
East Mediterranean and Black Sea	3,754	163
South China, Indo China, Indonesia, and Philippines	1,932	253
Japan, Korea, and North China	1,723	158
Baltic	1,579	31
Great Lakes	1,349	7
West Mediterranean	888	56

Specified Region	Number of Casualties Including Total Losses	Number of Total Losses
Iceland and Northern Norway	855	25
Gulf of Mexico	806	24
North American West Coast	783	17
Others	6,495	293
<b>Total</b>	<b>24,545</b>	<b>1,123</b>

(Adapted from Allianz 2015)

Many reports agree that despite the increase in vessel traffic, the overall rate of vessel casualties has decreased. The decrease in the incidence of vessel casualties is largely due to improved safety standards and the use of younger vessels (Butt et al. 2012). However, various factors have contributed to more severe consequences and financial costs of a vessel casualty in certain situations (Allianz 2015, Butt et al. 2012).

## 2. METHODOLOGY

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This report seeks to identify and assess emerging risks in marine transportation that have the potential to lead to vessel casualties in order to help response organizations prepare for these emerging challenges. The methodology for this report was adapted from the process described by Majchrzak and Markus (2014). Several factors from Majchrzak and Markus (2014) were considered with when refining this report's scope, including the research problem itself, aspects not included in the research, causal models of the pressures within the identified drivers, the context and stakeholders affected, and the potential outcomes of risk.

### 2.1. Iterative Steps

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The project generally follows an iterative policy research method. First, the research question was framed and examined in a social, technological, and economic context, while considering the sponsor's requirements. Next, the existing information was gathered and evaluated via an extensive literature review surrounding the concepts of drivers and pressures from the DPSIR framework. The third step was to determine which reports provided either evidence fragments or

complete syntheses. The fourth step was to determine remaining knowledge gaps through the construction of emerging risk drivers' causal chain models. Once gaps were identified from the models, new evidence was gathered through structured interviews with subject matter experts across a wide range of fields.

Throughout the process of developing causal chain models, the interactions between pressures that make up a driver were identified and examined. After the pressures had been identified, they were then broken down into a narrower grouping of emerging risk consequences:

- Increased frequency of incidents
- Shifting routes
- New cargoes and fuels
- Larger amounts
- New incident triggers
- Increased difficulty of salvage

Emerging risk consequences were further classified with respect to incident types and permissive or triggering causes of risk. The final step was to assemble the evidence into findings that consider the number of permissive and triggering causes across the pressures, the time frame of pressure evolution, the materiality of risk, and pressure interactions across ports and the Arctic. Definitions of emerging risk (Section 1.3) and uncertainty (Section 7.2) were jointly developed and then applied throughout the report. The definition developed for emerging risk served as the foundation for the “Implications” element of Sections 3, 4, and 5 and the definition for uncertainty served as the foundation for Section 7.2, “Materiality of Risk.”

The materiality of risk was then assessed based on the strength of literature evidence and uncertainty surrounding the pressures. The assessments of strength of evidence and uncertainty were then compared by the authors of this report through inter-judge calibration. Finally, the conclusion discusses the mitigations strategies response organizations can take to manage risk.

## 2.2. Role of Scenarios

The use of scenarios enables a more complete discussion of the future climatic changes, trade patterns, and developing technologies. The scenarios used in this report include global perspectives such as the climate change scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), shipping perspectives developed by Lloyd’s Register, and specific reports on regional shipping in the NSR. The main scenarios used in the report are summarized in Table 7.

**Table 7: Scenarios Referenced**

Possible scenarios for future shipping states, climatic changes both globally and in an Arctic context.

<i>Scenarios Referenced in Report</i>
<p><b>Lloyd’s Register Marine Fuel Trends 2030</b></p> <p><i>Status Quo:</i> “Business as usual, economic growth at the current rate, short-term solutions, rapid regulatory change. In this scenario, shipping will develop but in a controlled rate.”</p> <p><i>Global Commons:</i> “More economic growth, more international cooperation, regulation harmonization, international trade agreements, emphasis on environmental protection and climate change, expansion of globalization. Shipping will be favored in this scenario.”</p> <p><i>Competing Nations:</i> “Dogmatic approaches and regulatory fragmentation, protectionism, local production and consumption, trade blocks, brake in globalization. Shipping will be negatively impacted in this scenario.”</p>
<p><b>Intergovernmental Panel on Climate Change (IPCC) AR5</b></p> <p><i>High Representative Concentration Pathways (RCP):</i> “Scenarios without additional efforts to constrain emissions (‘baseline scenarios’) lead to pathways ranging between RCP6.0 and RCP8.5.” RCP8.5 is the RCP with high radiative forcing.</p> <p><i>Low RCP:</i> “RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures.” RCP2.6 is the RCP with low radiative forcing.</p>
<p><b>Hansen et al. Arctic Shipping – Commercial Opportunities and Challenges</b></p> <p><i>Northern Sea Route:</i></p>

### Scenarios Referenced in Report

The results of this study indicate that “Arctic liner shipping may become economically feasible around 2040, if the ice cover continues to diminish at the present rate.”

#### **Keupp – The Northern Sea Route: A Comprehensive Analysis**

Examining only freight transport volume between Europe and Asia/Australia

##### *Capacity Potential for Northern Sea Route (NSR) by 2030:*

NSR likely becomes more “attractive” to ship owners as current operational issues (such as conditions of navigation) change and transportation volume becomes more “relevant.” Russia must invest in development to minimize shipping risks to “level of ship owners’ desire” with competitive fees for icebreakers support in order for this to occur.

##### *Capacity Potential for Northern Sea Route (NSR) by 2050:*

307 million tons of cargo moving east to west and 134 million tons moving west to east (these boundaries are high end estimates).

(Lloyd’s Register Global Marine Fuel Trends 2030, IPCC AR5 2013, Hansen et al. 2016, and Keupp et al. 2015)

## 3. THE CHANGING ENVIRONMENT

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This section explores the emerging risks associated with climate change and the primary ways in which these risk could affect shipping within the global maritime transportation network.

Climate change can amplify existing environmental risks by impacting both the probabilities and consequences of incidents. In order to effectively evaluate causes of risk from Storminess,<sup>9</sup> Sea Level Rise (SLR), Sea Ice, and Permafrost, we consider them separately in a Global context and in an Arctic context.

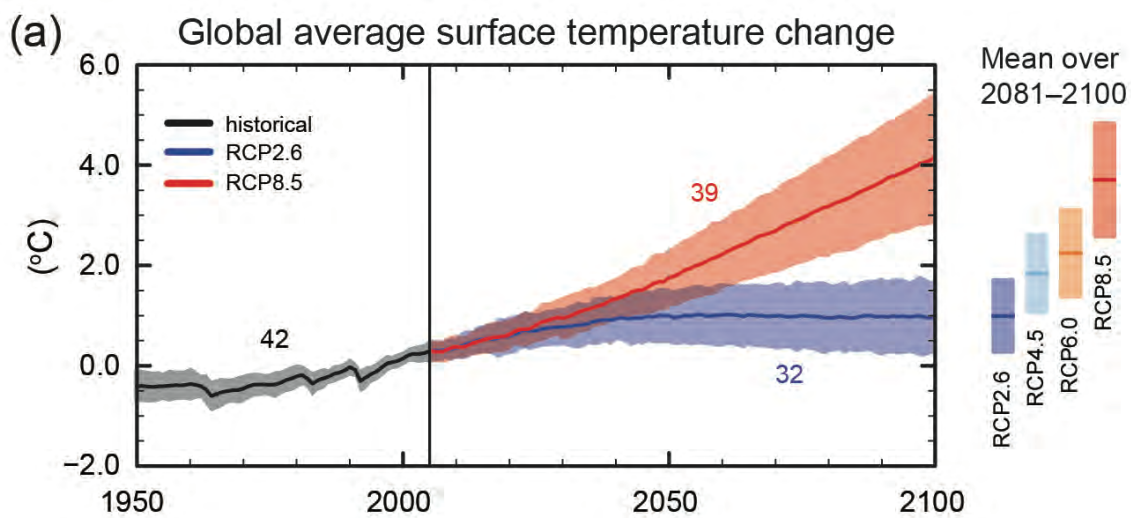
Uncertainties exist in the expected state of Earth’s future climate system. These uncertainties have four primary root causes: natural variability inherent in the earth’s climate system, limitations in climate system data and models, future greenhouse gas emission levels due to emissions control and mitigation strategies, and the extent and effectiveness of adaption at local and global scales. This report considers IPCC AR5 (2013) to be a primary authority for identifying the likely state of future climates and scenarios that represent them. Additional sources are included when they advance the state of knowledge provided by IPCC AR5. These

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<sup>9</sup> In this report, storminess is considered in a global context as well as in an Arctic context.

sources include Hansen et al. (2016), Østregren et al. (2013), Chatham House-Lloyd's (2012), Arctic Council (2009), among others.

This section will consider scenarios that are within the bounds of the IPCC AR5 (2013) high and low Representative Concentration Pathways (RCPs) as a way to bound the range of possible future climate states (Figure 5). Global climate change scenarios from IPCC AR5 (2013) demonstrate the complex interplay of factors affecting climate change and its potential impact of the marine transportation system.



**Figure 5: Projected Global Annual Average Surface Temperature Changes**

The projected annual average surface temperatures are based on IPCC AR5 high RCPs (in red) and low RCPs (in blue) and the region of overlap between the scenarios (in purple). Note that the shading in each scenario denotes a measure of uncertainty. Forecasted temperature changes do not begin to diverge until about 2025.

(IPCC AR5 2013)

### 3.1. Changing Environment Common Terms and Definitions

Arctic – The area fully within the Arctic Circle and all Northern Hemisphere borderless regions considered to be ‘cold climates’ or temperate/sub-Arctic areas, such as the Aleutian Islands. The physical processes that are characteristic of the Arctic also occur south of the Arctic Circle in other ‘cold climate’ regions (IPCC AR5 2013, Østregren et al. 2013, Jensen 2010, Arctic Council 2009).

Fetch – The area over water where the wind blows in a constant direction, thereby transferring energy to a water surface and generating waves (Thomson and Rogers 2014).

Ice-Albedo Feedback – A positive feedback loop or process where a change in the area of sea ice and snow alters the reflectivity (albedo) of solar energy. Less ice allows for more solar radiation to be absorbed by the water, rather than reflected, and heat up the ocean (IPCC AR5 2013).

Landfall – The intersection of a tropical cyclone with a coastline (National Hurricane Center n.d.).

Northeast Passage (NEP) – The NEP is defined as the navigational beginning and end of the shipping route from Rotterdam in the North Sea, to Yokohama in the Pacific Ocean (Østreng et al. 2013, Arctic Council 2009).

Northern Sea Route (NSR) – The NSR is defined as the navigational beginning and end of the shipping route from the Kara Gate or Cape Zhelaniya to the Bering Strait. The NSR is the main section of the NEP located in Russian waters (Østreng et al. 2013, Arctic Council 2009).

Northwest Passage (NWP) – The NWP is defined as the navigational beginning and end of the shipping route from the Bering Strait to the Labrador Sea mostly in Canadian waters (Østreng et al. 2013, Arctic Council 2009).

Permafrost – Frozen ground that remains at or below 0°C for at least two years (IPCC AR5 2013). Permafrost is defined solely by temperature (National Snow & Ice Data Center n.d.).

Polar Lows – Arctic small-scale cyclones that can develop as cold air interacts with comparatively warmer oceans (Østreng et al. 2013).

Polar Vortex – Systems of winds that circle the poles at high altitudes (Cornell Climate Change n.d.).

Representative Concentration Pathways (RCP) – Aggregated measures of all anthropogenic greenhouse gas emissions. RCPs are expressed in watts per square meter (IPCC AR5 2013).

Salvage – Any effort to avoid the loss of a vessel or its cargo in order to limit financial loss and/or navigation hazards (Hess 2013).

Sea Level Rise (SLR) – The rise of global sea levels due to ocean thermal expansion and glacier melting. This causes shoreline retreat and an increased flooding risk (Church et al. 2013).

Storm Surge – Unusually high water levels produced by extreme storms, such as cyclones. Storm surges result in extreme coastal and inland flooding (U.S. Climate Resilience Toolkit n.d.).

Thermokarsk – Lakes and ponds that result from the uneven settling of the ground as permafrost thaws (Yoshikawa and Hinzman 2003).

Trans-Polar Passage (TPP) - The TPP is defined as the navigational beginning and end of the shipping route from the Fram Corridor, between Greenland and Svalbard, to the Davis Corridor (Østreng et al. 2013).

## 3.2. Global Pressures

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### 3.2.1. Storminess

Climate shifts can lead to changes in components of extreme weather events including their intensity, frequency, spatial extent, duration, and timing (IPCC 2012, National Academies of Sciences, Engineering, and Medicine 2016). This section examines the elements of intensity, frequency, and spatial extent regarding storm and precipitation events as they relate to the marine transportation system. In order to distinguish between storms and precipitation events, storms will be considered all extreme weather events that combine precipitation with strong winds. Weather and storms in particular are contributing factors in many maritime incidents. It is important for response planning and operations to consider how shifts in extreme weather events could affect land and coastal infrastructure in addition to vessels.



Warmer surface ocean waters lead to shifts in storm intensity and contribute a greater energy supply to cyclone<sup>10</sup> formation (Elsner et al. 2008, Trenberth 2007). IPCC AR5 (2013) states that there has been a global increase in the average cyclone maximum wind speed and rate of precipitation. Additionally, further changes in some regions are likely in the late 21<sup>st</sup> century regarding storm and precipitation events (IPCC AR5 2013).

The 21<sup>st</sup> century projections of storm events indicate that the global net frequency of cyclones will remain constant or decrease (IPCC AR5 2013, Australian Government Bureau of Meteorology n.d.). However, regional storm frequency is increasing in some areas, such as in the North Atlantic (IPCC AR5 2013). Precipitation events are projected to significantly increase in polar and tropical regions, while the subtropics will experience minor decreases in the 2080–2099 timeframe (IPCC AR5 2013). Overall, IPCC AR5 (2013) concludes that the global average annual precipitation (both in intensity and frequency) through the year 2100 is expected to increase.

Storm tracks are expected to shift poleward in the northern and southern hemispheres (IPCC AR5 201, Kossin et al. 2014). Poleward shifts are occurring at an average rate of approximately 58 km per decade or an average repositioning of cyclones poleward at a rate of about one degree of latitude per decade (Kossin et al. 2014). Examples of these shifts include destructive storm events like Hurricane Sandy (2012) reaching the eastern coast of the United States and Typhoon Haiyan (2013) making landfall in the Philippines. Regional variations in storm and precipitation events are cataloged in Figure 8.

**Table 8: Projected Regional Changes in Major Marine-Related Weather Events by 2080–2099**

Overview of projected regional changes in major marine-related weather events by 2080–2099. Based on IPCC AR5 (2013), RCPs with radiative forcing higher than the lowest RCP.

<i>Region</i>	<i>Projected Major Marine-Related Weather Event Changes by 2080–2099</i>
<b>East Africa</b>	Increased precipitation extremes due to landfall cyclones.
<b>Antarctica</b>	Increased precipitation along coasts.
<b>Arctic</b>	Increased precipitation by mid-[21 <sup>st</sup> ] century due to extratropical cyclones.

<sup>10</sup> Throughout this report, cyclones, extratropical cyclones, hurricanes, polar lows, tropical cyclones, and typhoons will all be considered equivalent. While the formation of these events differ in temperature gradients, frontal features, etc., their impacts to vessels, ports, and intermodal systems can be similar (Guerrero 2016).

<i>Region</i>	<i>Projected Major Marine-Related Weather Event Changes by 2080–2099</i>
<b>Asia</b>	<p><i>East Asia:</i> Increased monsoon precipitation and typhoon landfall.</p> <p><i>Southern Asia:</i> Increased precipitation due to landfall cyclones.</p>
<b>Southern Australia &amp; New Zealand</b>	Increased precipitation due to tropical and extratropical storms.
<b>Europe &amp; Mediterranean</b>	Increased precipitation due to enhanced extremes of storms and decreased precipitation in the east.
<b>North America</b>	<p><i>Canada, Mexico, &amp; the USA:</i> Increased precipitation due to tropical cyclones along the west coast of the USA and Mexico, the Gulf of Mexico, and the eastern coast of the USA and Canada.</p> <p><i>Central America &amp; Caribbean:</i> Increased precipitation due to tropical cyclones making landfall on both coasts.</p>
<b>Pacific Islands</b>	Increased precipitation due to tropical cyclones.
<b>Southern South America</b>	Increased precipitation.

(Adapted from IPCC AR5 2013)

### 3.2.2. Sea Level Rise

Global sea levels are affected by ocean warming, the loss of land-based ice (in glaciers and ice sheets), and the reduction of land-based water storage (in lakes, reservoirs, and groundwater storage) (Gregory 2013, Mimura 2013). Melting sea ice does not contribute to sea level rise (SLR) because it is already floating, thereby displacing its own mass (Østrem et al. 2013). Global sea levels have risen since the early 20<sup>th</sup> century (Mengel et al. 2016, Hay et al. 2015, Gregory 2013, IPCC AR5 2013) and this trend is likely to continue in more than approximately 95% of the ocean area well beyond the year 2100, even if the global mean temperature stabilizes (IPCC AR5 2013, Horton et al. 2014). The future rise of sea levels is depicted in Table 9, which provides high and low scenarios for sea level rise in four time frames. The IPCC AR5 (2013) data shown in Table 9 and Figure 6 does not consider the abrupt SLR that could occur with the

collapse of marine sectors of the Antarctic ice sheet. While the probability of a rapid collapse of the West Antarctic Ice Sheet in the 21<sup>st</sup> century is unknown, some sources have indicated early collapse of a keystone glacier is underway (Sumner 2014, Schroeder et al. 2013). IPCC AR5 (2013) did determine that a collapse, if it occurred, would contribute several tenths of a meter to SLR in the 21<sup>st</sup> century.

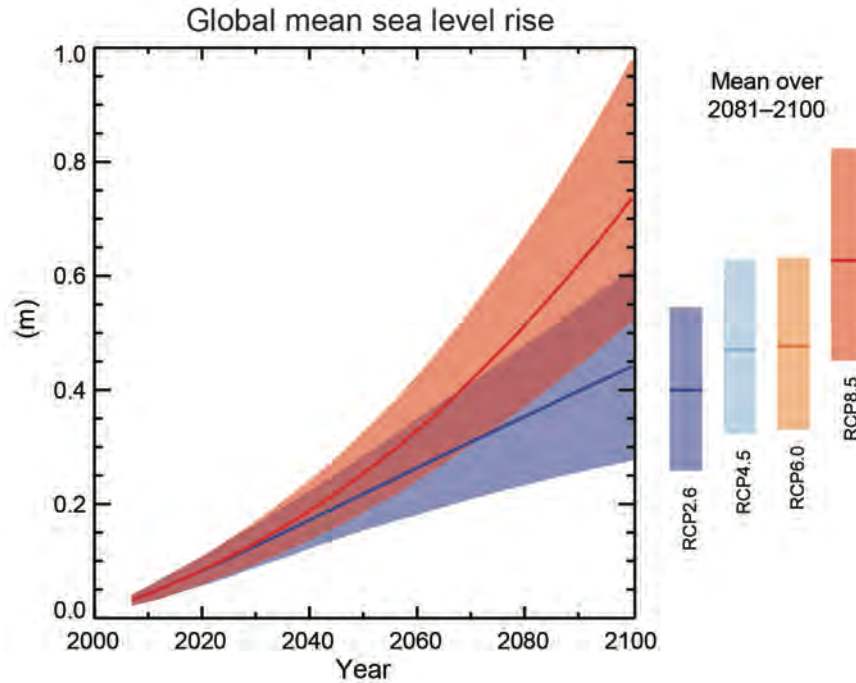
Differences between global and regional sea levels are important to note because some regions are experiencing SLR increases faster than the global average (e.g., Norfolk, Virginia and Grand Isle, Louisiana), while some locations are experiencing sea level decreases compared to the global average (e.g., Neah Bay, Washington, and Kodiak Island, Alaska) (U.S. Climate Resilience Toolkit n.d.). Regional changes do alter erosion and deposition patterns in and around ports and such alterations can cause port channels and basins to change in shape and possibly destabilize (Becker et al. 2012, UNCTAD 2011). Shifts in sedimentation patterns could lead to increases in dredging and/or cause vessels to face weight restrictions (UNCTAD 2011) when entering port systems.

**Table 9: Projected Global Mean Sea Level Rise**

Projected Global Mean Sea Level Rise (in meters), under IPCC AR5 (2013), Horton et al. (2014), and Mengel et al. (2016) RCPs. IPCC AR5 (2013) incorporated all RCPs except 2.6 (low RCP), Horton et al. (2014) incorporated RCP 3 and 8.5 (high RCP), and Mengel et al. (2016) incorporated RCP 2.6, 4.5, and 8.5.

Year(s)	2046–2065	2081–2100	2100		2300	
<b>Source</b>	IPCC AR5 (2013)	IPCC AR5 (2013)	Mengel et al. (2016)	Horton et al. (2014)	Mengel et al. (2016)	Horton et al. (2014)
<b>Likely sea level rise under high RCP scenario</b>	0.22-0.38	0.45-0.82	0.60-1.0	0.5-1.5	2.0-3.0	1.3-4.0
<b>Likely sea level rise under low RCP scenario</b>	0.17-0.32	0.26-0.55	0.40-0.60	0.25-0.7	0.60-1.0	0.5-1.2

(Adapted from Mengel et al. 2016, Horton et al. 2014, IPCC AR5 2013)



**Figure 6: Global Mean Sea Level Rise Mean Over Four RPC Scenarios**

Future projected SLR based on relative 1986–2005 measurements. The projected sea levels are based on IPCC AR5 (2013) high RCP (in red) a low RCP (in blue) and the significant divergence region shown between them (in purple). Note that the shading in each scenario denotes a measure of uncertainty.

(IPCC AR5 2013)

### 3.2.3. Implications

The frequency and location of storm events could impact the timing and location of ship incidents as temporal and spatial distribution of intense storm change due to climate impacts. Future patterns of coastal development and adaption to climate change will be significant factors in location, nature, and extent of marine transportation risks. The severity of destruction to coastal infrastructure from storm events can also significantly affect incident preparedness and response capabilities. In the present time frame, global ports and intermodal systems are likely to experience intense storm events and increased precipitation.

When storms combine with SLR, the consequences can be compounded (Table 10). For example, critical facilities and services could be left vulnerable for extended periods of time, i.e., the duration of the event or longer, damaging infrastructure, equipment, and cargo, causing drainage systems to be obstructed, and causing significant traffic disruptions. Figure 7 shows how storms and SLR will place many of the world critical port facilities at risk in the 21<sup>st</sup>

century. In the 10–20+ year time frame, storm events and increased precipitation will likely combine with SLR to increase the susceptibility of ports and port systems flooding (Transportation Research Board 2016, UNCTAD 2011), Table 11.

Given the resources and services that ports provide, these two pressures will have serious and broad repercussions for the efficiency of the greater maritime transportation network (UNCTAD 2011). While infrastructure risks can be mitigated, ports must integrate mitigation into both infrastructure and emergency response plans for mitigation to be effective. How risks are mitigated depends on the state of Earth’s future climate, which cannot be precisely forecast. Ports can integrate the use of scenarios in planning to address uncertainty associated with potential future climate states.

**Table 10: Global Pressures Across Examined Time Frames**

Summary of the global implications of the Storminess and SLR pressures across the 0–5 and 10–20+ year time frames.

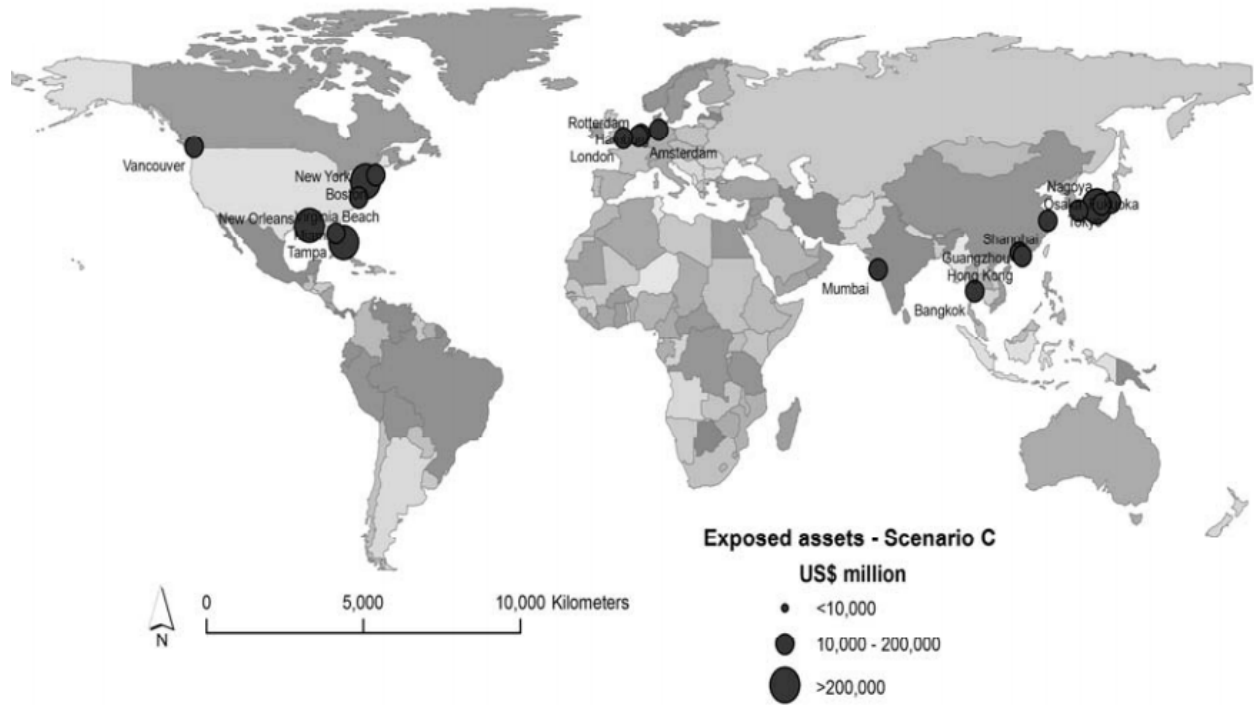
<i>Pressure</i>	<i>0–5 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<b>Storminess</b>	Vessels and ports in certain regions are likely to encounter storms of increasing intensities that are also shifting poleward. The frequency of storm events in the northern Atlantic Ocean is increasing and some regions will experience increases in precipitation.	Vessels and ports in certain regions will encounter storms of further increasing intensities and further poleward shifts. The frequency of northern Atlantic Ocean storm events will increase and some regions will experience additional increases in precipitation.
<b>Sea level rise (SLR)</b>	Sea levels will continue to rise, as will the rate of rise. SLR is not likely to significantly impact most port systems.	SLR will continue to increase with the rate of rise increasing. The severity and geographic extent of impact to port systems will depend on how rapidly sea level rises and the compounding effects of storminess.

**Table 11: Changing Global Environment Implications**

The primary pressures associated with the Global Changing Environment driver with a breakdown of the Causes (Permissive/Triggering) and Changes in Probability/Consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage (IDS). Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL), Loss of Infrastructure (LI). Note that an additional incident type is shown here (Loss of Infrastructure (LI)) as it is relevant to the Changing Environment driver.

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>Storminess</b>	X		X	X	IFI, IDS	F, ED/F, I/S, CL, LI	Changes in Consequence develop when the pressures of Storminess and SLR combine.
<b>SLR</b>	X		X	X	IFI, IDS	G, LI	Changes in Consequence develop when the pressures of Storminess and SLR combine.

Storminess and SLR each represent a permissive cause with the potential to create changes in the probability and consequence of risks. Each pressure potentially increases the frequency of incidents and the difficulty of salvage. When storminess and SLR intersect during events, storm surge and waves can impact rescue support and port facilities increasing difficulty of salvage.



**Figure 7: Top 20 Cities for Exposed Port Assets in 2070**

Exposure of the world’s 20 largest port cities to coastal flooding from storms and storm surges by 2070. It is important to note that the top 20 port cities include both river and marine ports.

(Nicholls et al. 2008)

### 3.3. Arctic Pressures

This section will explore the emerging risks in the Arctic that are produced by climate change impacts to sea ice, storminess, and permafrost. The effects of rising seas in the Arctic have yet to be fully assessed (Østreng et al. 2013) or be fully confronted in the literature. Due to this, SLR is not examined in an Arctic context in this report.

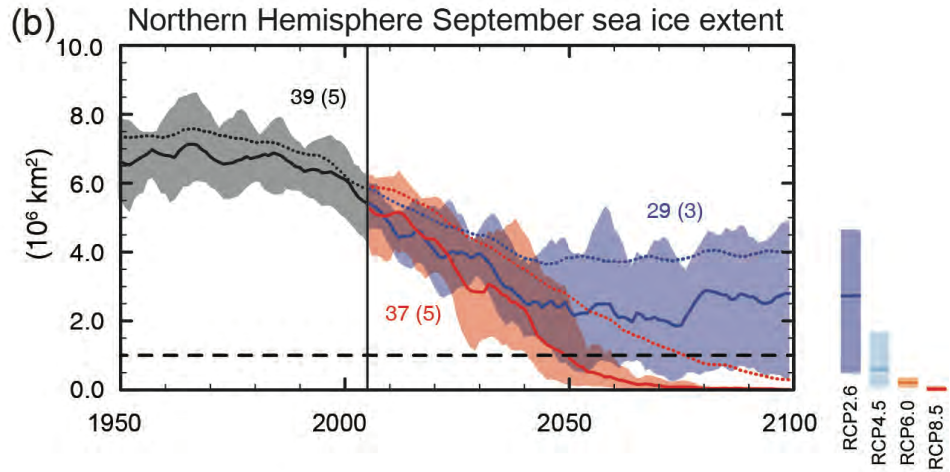


### 3.3.1. Sea Ice

Sea ice covers much of the Arctic Ocean and its vicinity, but the ice varies in shape, age, thickness, and hardness (Vihma 2014). Arctic sea ice undergoes seasonal cycles with retreat occurring during the summer months and growth in winter months. Summer sea ice retreat does not always occur earlier in the southern Arctic and later in the north, but rather a much more complex process is at work (Thomson 2015). Over recent decades, Arctic sea ice has been thinning, while age and spatial extent have been decreasing every season (IPCC AR5 2013, Østreng et al. 2013).

A decrease in ice extent creates an increase in fetch and affects the water surface available to absorb solar radiation. Fetch affects sea state by increasing wave energy and creating nearshore storms surge and waves, (Thomson and Rogers 2014, Barnhart et al. 2014).

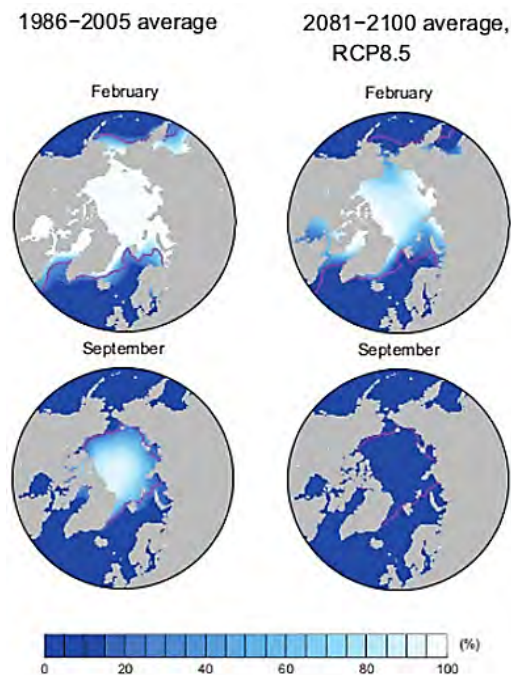
The future of Arctic sea ice depends on the state of the global climate. Figure 8 shows Arctic sea ice minimum extent based on high and low RCPs and these projections indicate that the summer sea ice minimum is likely to continue decreasing well into the 21<sup>st</sup> century. Up until approximately 2060, there remains a great deal of overlap between the two extreme RCPs, but IPCC AR5 (2013) does state that the Arctic Ocean could be nearly ice-free before 2050. Concurrently, this ‘nearly ice-free’ state is seen in the future scenario presented in Figure 9.



**Figure 8: Arctic Sea Ice Minimum Extent**

Future projected Arctic sea ice minimum extent. The projected sea ice extents are based on IPCC AR5 (2013), with high RCP (in red), low RCP (in blue), and the significant divergence region shown between them (in purple). Note that the shading in each scenario denotes a measure of uncertainty. The black dashed lines represent nearly ice-free conditions and historical temperature ranges in black are not of importance for this report.

(IPCC AR5 2013)



**Figure 9: Average Arctic Sea Ice Extents for 1986-2005 and 2081-2100**

February and September mean sea ice concentrations for 1986–2005 and 2081–2100 under high RCP. The faint pink lines indicate the observed 15% ice concentrations averaged from 1986–2005. Notice that sea ice conditions vary widely between the major Arctic routes. From navigational perspective, the Northwest Passage (NWP) will be the last area where multi-year ice remains and the Trans-Polar Passage (TPP) will not likely be a regular route (Østreng et al. 2013).

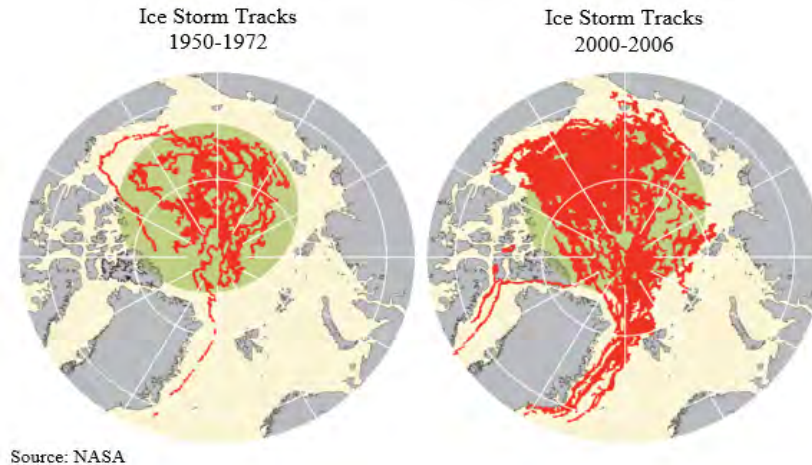
(Adapted from Vihanninjoki 2014)

Decreases in sea ice extent and thickness can open Arctic shipping routes and increase season lengths. While this reduction in sea ice extent alters the risks present in the region, the hazardous nature of Arctic shipping will remain (Arctic Council 2009). For example, Thomson and Rogers (2014) and Barber et al. (2014) found thinner ice to be more mobile, thereby increasing the complexity of ice pattern models. Highly mobile ice can be hazardous to vessel navigation and infrastructure (Barber et al. 2014, Jensen 2010).

### 3.3.2. Storminess

Historically, Arctic sea ice maximums left no large expanses of open water. An Arctic with less winter sea ice and warmer sea temperatures could experience more storms and a significant increase in precipitation by the mid-21<sup>st</sup> century (IPCC AR5 2013). Hakkinen et al. 2008 (as reported by Chatham House-Lloyd's 2012) has shown that warmer waters are increasing the number of storms in the Arctic. Figure 10 shows Arctic storm tracks since 1950, with an increasing number of storm events in recent decades. Storms are able to gain strength from strong temperature gradients between the relatively warmer ocean water and the increasing sea ice edge (Bitz 2016).

In addition to more extratropical cyclones and polar lows, Thomson and Rogers (2014) conclude that the increase in 2012 summer fetch allowed for larger wave formation. Further reductions in ice cover extents could result in larger waves throughout the 21<sup>st</sup> century affecting risks to shipping and coastal infrastructure from both waves and storm surge (Chatham House-Lloyd's 2012).



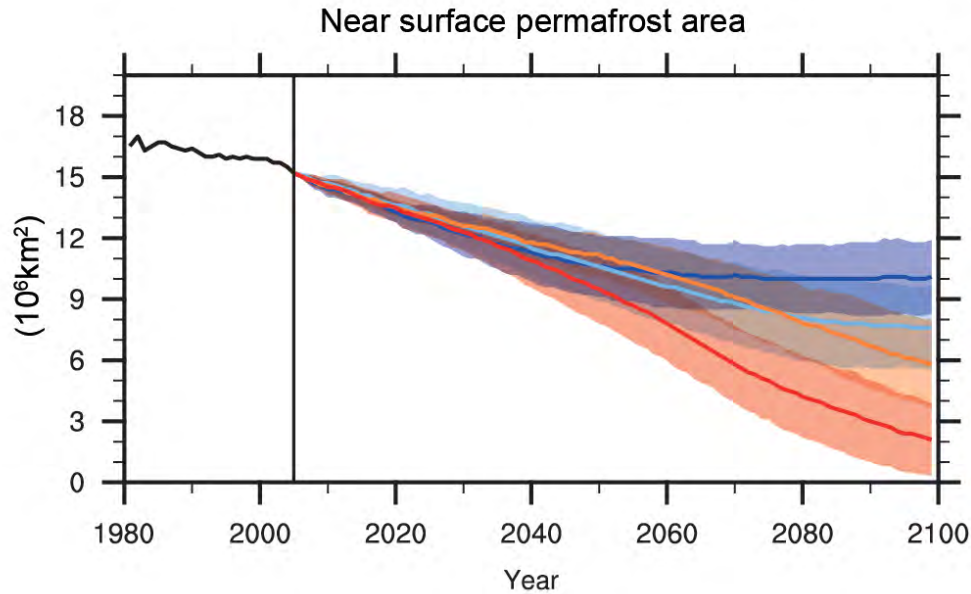
**Figure 10: Change in Historic Arctic Storm Tracks**

Arctic storm tracks are shown in red from 1950–1972 and 2000–2006. Note the increase in the number of storms occurring from 2000–2006 in comparison to the 1950–1972 tracks.

(Hakkinen et al. 2008, as reported by Chatham House-Lloyd's 2012)

### 3.3.3. Permafrost

Similar to Arctic sea ice, in recent decades near surface permafrost area has decreased (Figure 11). This decrease has caused thermokarst to become a dominant landscape feature in some areas (IPCC AR5 2013, National Snow & Data Ice Center n.d.). Thermokarst causes uneven sinking of the ground that can impact drainage, runoff, and all infrastructure (NOAA Arctic Change n.d.). Figure 11 shows that even under the low RCP, permafrost will continue to decrease into the 21<sup>st</sup> century (similar findings by Østreng et al. 2013). By 2081–2100, Arctic near-surface permafrost extent will decrease between 37–81% (IPCC AR5 2013). Beyond 2100, Figure 11 indicates a total loss of permafrost presumably early in the 22<sup>nd</sup> century.



**Figure 11: Projected Near Surface Permafrost Area**

The near surface permafrost area is based on IPCC AR5 (2013), with high RCP (in red), low RCP (in blue), and the significant divergence region shown between them (in purple). Note that the shading in each scenario denotes a measure of uncertainty. Scenarios in light blue and orange RCPs are not considered in this report.

(IPCC AR5 2013)

Sea ice extent alters permafrost’s interactions with the ocean by changing erosion rates. It has long been documented that along the Arctic’s frozen coastlines erosion can occur considerably faster than along temperate latitude coasts (Aré 1988 as cited by Guégan 2015, Reimnitz et al. 1988 and Jorgenson and Brown 2005 as cited by Jones et al. 2009, Gibbs et al. 2015) through a combination of thermal and mechanical processes. For example, the number of “nearly ice-free” days in the Beaufort Sea and northern Canada correlate with higher rates of coastal erosion (Chatham House-Lloyd’s 2012) due to increases in storm surge and wave energy (U.S. Climate Resilience Toolkit n.d.). Since permafrost will continue to decrease into the 21<sup>st</sup> century, coastlines could continue to rapidly recede, potentially impacting important shipping facilities. Examples include the Port of Churchill in Canada, where erosion threatens shipping infrastructure (Natural Resources Canada 2007).

Elements of Arctic intermodal systems (i.e., ice roads, railroads, airstrips, pipelines, and ports) that support the marine transportation network are already being impacted by thawing permafrost. Throughout this century, ice roads, railroads, and airstrips will see decreases in

permissible traffic volumes and allowable weights (Østreng et al. 2013). For example, thawing permafrost near the Port of Churchill in northern Manitoba has caused the railway line to buckle, thereby increasing rates of derailments and drastically slowing traffic. Slowing traffic decreases work periods during which intermodal systems can be used to carrying cargoes and shipments to and away from areas of sparse infrastructure. Regarding ice roads, Østreng et al. (2013) noted that the Canadian Arctic will not likely be significantly impacted prior to 2020.

#### 3.3.4. Implications

Arctic climate change will create obstacles for the marine transportation system in the 10–20+ year time frame (Table 12). At sea, the retreat of sea ice is accompanied by the increase in storms (Østreng et al. 2013), thereby increasing the risks to infrastructure from storm surge (Arctic Council 2009) and waves. On land, permafrost challenges will emerge in the 0–5 year time frame, but mitigation approaches such as use of lighter vehicles and careful selection of route can be taken. At the land-sea interface, the combination of all three Arctic pressures could alter and increase risks in the 0–5 year time frame. Further infrastructure risks can be mitigated, the nature, cost, and effectiveness of mitigation efforts will depend on the state of Earth’s future climate.

Taken together, all elements of these three Arctic pressures could lead to changes in the shipping industry’s land-ocean interactions (Table 13).

The Arctic maritime sector will require an increased level of support from icebreakers and enhanced capabilities from many other marine transportation sectors, including those in construction, maintenance, search and rescue support, and spill preparedness and response organizations. Chatham House-Lloyd (2012) states that Arctic infrastructure will be forced to adapt to a wide range of environmental conditions. The pressures of sea ice, storminess, and permafrost compound the challenges for all aspects of Arctic maritime shipping.

**Table 12: Arctic Pressures Across Examined Time Frames**

Summary of the implications of the Arctic Storminess, Sea Ice, and Permafrost pressures across the 0–5 and 10–20+ year time frames.

<i>Pressure</i>	<i>0–5 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<b>Sea Ice</b>	Total ice extent, thickness, and age will decrease while the annual ice duration gets shorter, thereby increasing the availability of marine access. Navigation conditions will not be less difficult.	Further ice extent, thickness, and age decreases while the annual ice duration gets shorter, leading to an even greater ship access to navigable waters. Shipping conditions will remain challenging. The NWP will be the last area where multi-year ice remains, from a navigational perspective.
<b>Storminess</b>	Vessels and ports in particular geographic areas are likely to encounter storms of an increased intensity, with larger storm surges and waves.	Vessels and ports in particular geographic areas are likely to encounter more storms of increased intensities, with even larger storm surges and waves. Vessels and ports will also encounter significant increases in precipitation by mid-21 <sup>st</sup> century.
<b>Permafrost</b>	Near-surface permafrost area will continue to decrease, while increases are seen in thermokarst features and erosion. The land-based infrastructure that accompanies ports is expensive and challenging to maintain.	Near-surface permafrost extent will be further reduced, while greater increases are seen in thermokarst features and erosion. The land-based port infrastructure that is likely to require additional investments and costs to maintain.

**Table 13: Changing Arctic Environment Implications**

The main pressures associated with the Changing Arctic Environment driver with a breakdown of the Causes (Permissive/Triggering) and Changes in Probability/Consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage (IDS). Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL), Loss of Infrastructure (LI). Note that an additional incident type is shown here (Loss of Infrastructure (LI)) as it is relevant to the Changing Environment driver.

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>Sea Ice</b>	X	X	X		IFI, SR, NIT, IDS	F, HD/F, ED/F, I/S, CL	NIT could develop as ice dynamics shift
<b>Storminess</b>	X	X	X	X	IFI, IDS	F, ED/F, I/S, CL, LI	Changes in Consequence develop when the pressures of Storminess and SLR combine.
<b>Permafrost</b>	X		X	X	IFI, SR, IDS	ED/F, LI	SR may occur if land-ward based infrastructure is adversely impacted



Each of the pressures presented here represents a potential permissive cause that leads to changes in probabilities of incident risks. Consequences are affected when storminess and SLR intersect. Each pressure potentially leads to an increased frequency of incidents and increased difficulty of salvage. When all three pressures intersect, equipment damage or failure could increase impacts to port and vessel operations.

## 4. PATTERNS OF TRADE

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### 4.1. Patterns of Trade Common Terms and Definitions

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Panamax: Largest fully loaded vessels that can currently traverse the Panama Canal.

Southern Sea Route (SSR): The shipping route from Asia to Europe that passes through the Suez Canal.

Suezmax: Largest fully loaded vessels that can currently traverse the Suez Canal.

New Panamax: Vessels that will be able to transit the Panama Canal post-expansion.

Malaccamax: Vessels that are able to transit the Straits of Malacca.

Chinamax: Vessels that are able to fit into ports and terminals in China.

Arcticmax: Vessels that are able to fit through narrow passages in the Arctic, such as the Kara Gate and Laptev Strait.

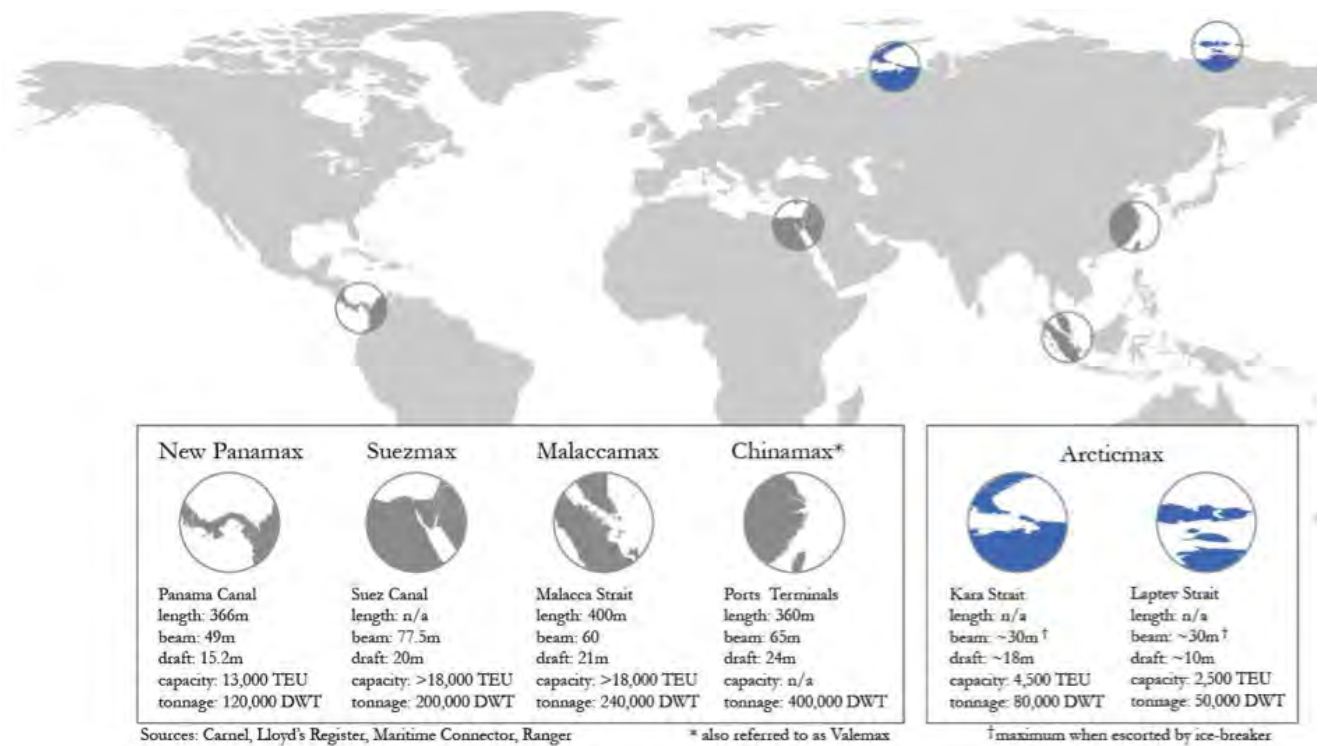
### 4.2. Chokepoints

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The U.S. Energy Information Agency (EIA) defines a chokepoint as a narrow channel along a widely-used global sea route. Some major chokepoints identified by the EIA are the Strait of Hormuz, Strait of Malacca, Danish Straits, and Suez and Panama Canals. The Suez and Panama Canals will be explored in detail later in this report (Figure 12). The nature of these chokepoints can create permissive causes of risk for the 65% of World maritime oil trade that are transported through these choke points (U.S. Energy Information Agency 2015<sup>a</sup>).

In addition to the EIA definitions, this report also considers the Arctic as a chokepoint. The traffic in this region can be funneled into tight areas due to physical geography, ice conditions, water depth, and regulatory limitations under treaties like the Law of the Sea (U.N. Law of the

Sea Convention Article 234). This increase in Arctic shipping density has the potential to create additional permissive causes of risk.



**Figure 12: Chokepoints worldwide with vessel limits.**

Worldwide chokepoints and the largest ship dimensions that may fit through them. The Northern Sea Route has two chokepoints along its length that are made more significant by its lack of infrastructure.

(Hansen et al. 2016)

The Arctic shipping area is limited not only by structural and environmental conditions like weather and ice, but also by depth and width constraints on key routes. There are only a few possible routes for traversing the Arctic (Rothwell 2010). Much of the consistently ice-free water on the NSR is less than fifty meters deep, effectively limiting areas for ship operations (Rothwell 2010). Water depth and ice limit the types of vessels that can transit Arctic routes. Out of the 2000 Panamax ships worldwide, only three have both the ice classifications and the requisite draft to transit Arctic routes

International Arctic straits are governed by the Law of the Sea Convention, including the Bering Strait in Alaska and the Kara Gate at the start of the NSR beneath Novaya Zemlya (Rothwell 2010, Peter Soles 2016). There is some debate as to the objective hazards that the Bering Strait

poses to shipping, but it is strategically important because of its position on the NSR and Northwest Passage, and its proximity to the great circle route between North American and Asian ports (Rothwell 2010). While the strait is only relatively shallow and narrow, its remoteness and extreme weather increase risk for transiting vessels.

### 4.3. Panama Canal

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The Panama Canal was first open for traffic in 1914 allowing direct passage of vessels between the Atlantic and Pacific oceans. Prior to the opening of new locks in 2016, five percent of cargo shipped globally every year passed through the Panama Canal, equivalent to 12,386 vessels in 2015 (Morefield 2012, Panama Canal Authority 2015). The numbers and types of cargoes passing through the Panama Canal are changing, in both the Atlantic to Pacific direction and the Pacific to Atlantic direction. Examining trends in the direction of travel helps to better understand the direction of travel could change in the future.

#### **Trends in Overall Traffic:**

Between 2013 and 2015, total traffic through the Panama Canal has been relatively steady. The most common route is the East Coast of the U.S. to Asia, although traffic by this route decreased 1.5% during this period (Panama Canal Authority 2015). In contrast, the use of other routes increased sharply. For example, traffic on the U.S. intercoastal route rose by 47%, on the Around the World route by 134.1%, and from the East Coast of the U.S. to the West Coast of Canada by 108%.

Ships from the U.S., China, Chile, Japan, and Peru are the most frequent users of the Panama Canal (Panama Canal Authority 2015). The U.S. is by far the largest user, shipping 162 million tons in 2015 (Panama Canal Authority 2015). The next highest, China, sent only 48.4, less than a third of the U.S. volume. The gap is likely to grow further with the removal of the U.S. oil export ban – in fact, North American shipments of petroleum products have already increased.

#### **Atlantic to Pacific:**

Between 2013 and 2015, the overall volume of container cargo shipped through the Panama Canal in this direction decreased from 23,289 long tons to 18,418 long tons. Movement of petroleum and petroleum products increased from 33,991 long tons to 36,772 long tons in the

same period. Of these products, diesel and gasoline were the main commodities shipped, with gasoline shipments rising from 5,858 long tons to 9,139 long tons. Chemical shipments also increased from 4209 long tons to 5316 long tons. Movement of ores, in contrast, decreased from 2736 long tons in 2013 to only 741 in 2015 (Panama Canal Authority 2015).

**Table 14 Atlantic to Pacific Cargo Totals in Long Tons**

Total cargoes shipped in the Atlantic to Pacific Direction. Changes in trade can be seen in the significant rises and falls in cargo types.

Cargo	2013	2015	Percent Change
<b>Containerized Cargo</b>	23,289	18,418	-21%
<b>Petroleum/Petroleum Products</b>	33,991	36,772	+8%
<b>Chemicals</b>	4,209	5,316	+26%
<b>Ores</b>	2,736	741	-27%

**Pacific to Atlantic:**

Traffic volume in this direction is much smaller overall, and total container cargo decreased from 27,122 long tons in 2013 to 21,594 long tons in 2015, while petroleum and petroleum product traffic increased from 6,942 long tons to 9,713 long tons. Shipments of iron and petroleum chemicals also increased during this period (Panama Canal Authority 2015). These data are summarized in Tables 14 and 15.

**Table 15 Pacific to Atlantic Traffic Measured in Long Tons**

Total cargoes shipped in the Pacific to Atlantic Direction. Note the increases in petroleum, petroleum products, and ores.

Cargo	2013	2015	Percent Change
<b>Container Cargo</b>	27,122	21,594	-20%
<b>Petroleum/ Petroleum Products</b>	6,942	9,713	+40%
<b>Chemicals</b>	2,324	2,533	+9%
<b>Ores</b>	3,908	4,801	+23%

## 4.4. Future Panama Canal

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The Panama Canal Authority began construction to expand the canal's capacity in 2007. The Panama Canal expansion permits increases in both the volume of traffic and the size of vessels using the canal. The expansion project included deepening Gatun Lake from 26.7 meters to 27.1 meters, deepening and widening the Pacific and Atlantic canal entrances, and construction of new, larger sets of locks which would allow passage of larger ships. The new locks began operating in June 2016. The Panama Canal Authority estimates that the larger locks will allow for 12–14 larger ships to pass per day, which together with continued usage of the smaller locks will effectively double the canal's traffic throughput (Morefield 2012). Operation of the new canal systems with larger ships brings with it more complex operations and changes in the risks associated with vessel passages in the canal (Bogdanich et. al. 2016).

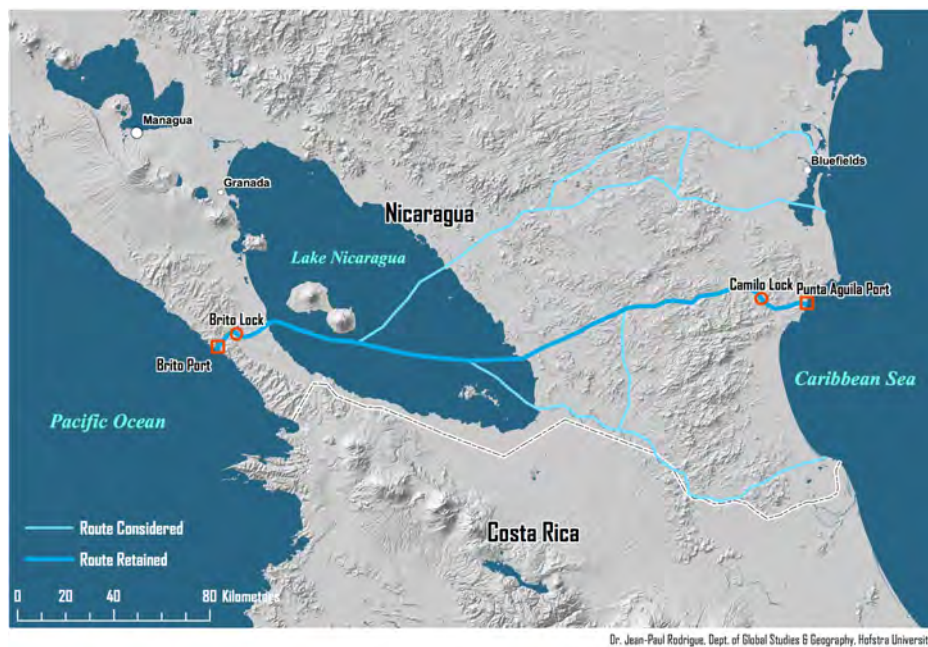
With larger vessels transiting the canal, ports at which they call might need to upgrade their channels and shore side facilities to accommodate them. The ramifications of the Canal's expansion are already apparent around the U.S. For example, Los Angeles and Long Beach have installed Panamax Super cranes to service the new larger ships, while the Port in Newark, New Jersey is raising a bridge by 60 feet to provide a sufficient air gap for larger ships. U.S. President Barack Obama has publicly called attention to the importance of port infrastructure upgrades across the country, especially in New York, New Jersey, Georgia, South Carolina, and Florida (Diaz 2015). Some studies have suggested that the use of larger ships will lead to fewer port calls with more cargo offloaded at each port, increasing the need for additional port capacity and potentially affecting the location and nature of incidents (Morefield 2012).

The expansion of the canal will increase its importance in the global marine transport system. Chinese vessels in transit to and from China are already the second-largest users of the Canal (Diaz 2015).

These changing trends affect the risk profile of the Panama Canal, as stressors like increasing vessel size and traffic density could change the nature of risk to transiting vessels. Emerging risks could include the bunkering of larger quantities of fuel and the processing of LNG near the entrance of the Canal (Levine 2016). The expansion of the Canal and the effects of climate

change will also play a role in the risk. Drought and extreme weather impacts to infrastructure associated with climate change also present risks to canal operations (IPCC 2013). Operation of canal locks rely on water from Lake Gatun. In recent years, rain fall has decreased. This, compounded by the increased water demand from the new larger locks, places greater demand on the future canal water supply (U.S. Department of Transportation 2013). Less water means that the locks might not operate efficiently and could result in vessel congestion. There is considerable debate about risks associated with passage through the new canal locks, particularly with respect to the interaction between tug boats and large vessels using the new locks (International Transport Workers' Federation 2016; Panama Canal Authority 2016).

Panama Canal traffic could also be impacted by the development of a canal in Nicaragua. In 2012, a memorandum of understanding (MOU) was signed between the Nicaraguan government and a Chinese investor to build a canal in Nicaragua that would compete with the Panama Canal. The MOU anticipated an operational date of 2020 for the new Nicaraguan canal (Yip and Wong 2015). While there is no indication of work moving forward as of 2016, a new Nicaraguan canal would change the trade dynamic in this region, especially with the growing shipping trade in and out of Asia (Yip and Wong 2015).



**Figure 13 Nicaragua Canal Proposed Location (Rodrigue n.d.)**

The blue lines show routes considered and retained for the Nicaragua Canal. Proximity to Panama could lead to increased congestion in the region.

## 4.5. Current Suez Canal

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The Suez Canal allows for efficient travel between the Far and Middle East and Europe, as well as trade bound for North America. 78% of total Europe-Far East trade and 86% of Europe-Middle East traffic goes through the canal. Overall, 20% of world trade moves through the Suez Canal (Zaafarany et al. 2014). The total tonnage of traffic coming through the canal has increased twelve-fold since 2005 (Suez Canal Traffic Statistics n.d.). Traffic in the Suez Canal passes either from north to south or from south to north.

The nature of trade through the Suez Canal is changing. Vessel transits dropped from 21,415 in 2008 to 17,225 in 2012, while in the same period the volume of all cargo increased (El-Sakaty et al. 2014).

### **Petroleum Cargoes:**

There is a higher potential for a pollution event occurring with cargo traveling north to south because of the larger overall cargo volume in that direction. In 2015, ships traveling from north to south carried 26,209 tons of fuel oil, while those traveling from south to north carried only 504. Meanwhile, there were 61,753 tons of crude oil shipped from south to north and compared to 18,966 tons of crude oil shipped from north to south. Additionally, 15,330 tons of gas and diesel was shipped from south to north with only 2,208 tons heading south (Suez Canal Traffic Statistics n.d.). Traffic data for petroleum cargoes are summarized in Table 16.

**Table 16: North to South and South to North petroleum traffic in Suez Canal**

Cargo	North to South	South to North
<b>Fuel Oil</b>	26,209	504
<b>Crude Oil</b>	18,966	61,753
<b>Gas/Diesel</b>	2,208	15,330

### **Destinations:**

Considering all cargo types, the largest users of the Suez Canal in 2015 were Northwest Europe, the UK, and Southeast Asia. The most common origins for cargo heading north to south were Northwest Europe and the U.K with 102,569 tons, the Northwest Mediterranean with 83,917

tons, and the Black Sea with 80,926 tons. The most common destinations were Southeast Asia with 114,234 tons, the Red Sea with 107,252 tons, and the Arabian Gulf with 87,386 tons (Suez Canal Authority 2016).

In the south to north direction, the origins are highly skewed to the top three area. Southeast Asia shipped 167,097 tons, the Arabian Gulf shipped 134,190 tons, and the Red Sea shipped 49,592 tons. The remaining “top routes” all shipped less than 10,000 tons. The top destinations for the south to north direction were Northwest Europe and the U.K with 118,518 tons, the east/southeast Mediterranean with 107,356, and the northern Mediterranean with 76,035 (Suez Canal Authority 2016). Traffic data for all cargos are summarized in Tables 17-20.

**Table 17: Top 3 North to South Vessel Origins for Suez Canal Traffic**

Origin	Tonnage of Cargo
<b>Europe/U.K</b>	102,569
<b>Northwest Mediterranean</b>	83,917
<b>Black Sea</b>	80,926

**Table 18: Top 3 North to South Destinations for Suez Canal Traffic**

Destination	Tonnage of Cargo
<b>Southeast Asia</b>	167,097
<b>Arabian Gulf</b>	134,190
<b>Red Sea</b>	49,592

**Table 19: Top Three South to North Origins for Suez Canal Traffic**

Origin	Tonnage of Cargo
<b>Southeast Asia</b>	114,234
<b>Red Sea</b>	107,252
<b>Arabian Gulf</b>	87,386



**Table 20: Top Three South to North Destinations for Suez Canal Traffic**

<b>Destination</b>	<b>Tonnage of Cargo</b>
<b>Northwest Europe/U.K</b>	118,518
<b>East/Southeast Mediterranean</b>	107,536
<b>Northern Mediterranean</b>	76,035

Shipping trends in the Suez and Panama Canals are evolving in a similar fashion. The Suez is working to move from facilitating traffic to facilitating trade (Zaafarany et al. 2014). The Suez Canal's safety record is strong, although incidents do occur (El-Sakaty et al. 2014). For example, a vessel grounded on February 25, 2016 after the addition of parallel canals (Suez Canal Authority 2016). Increasingly complex operations have the potential to change the canal's risk profile, but could also improve efficiency and mitigate congestion (Suez Canal Authority 2016).

#### 4.6. Future Suez Canal

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Emerging risks in the Suez Canal are subject to the geopolitical situation in Egypt and the larger region. Instability in the government of Egypt and terrorism threaten canal operations (Starr, 2014). Assessing the geopolitical situation in the Middle East is beyond the scope of this report. This section focuses on two types of change underway in the Suez Canal: capacity expansion and improvements to the logistics infrastructure. These changes will increase traffic and complexity of operations in the region. The Suez Canal Authority (SCA) expects average daily passages to rise from 49 to 97 by 2023 (Suez Canal Authority 2008).

Proposed infrastructure updates include new container hub ports in the Suez region (El-Sakaty et al. 2014). Additionally, the SCA wishes to expand traffic lanes and deepen the canal to allow two-way traffic and reduce the risk of backups and closures (El-Sakaty et al. 2014, Zaafarany et al. 2014).

Authorities in the region are also seeking to increase infrastructure for industrial activity (Zaafarany et al. 2014). For example, the SCA wants to build industrial capacity in technology, medication, and petro-chemicals, which could then be easily shipped (Zaafarany et al. 2014).

Additionally, the SCA wishes to build up the port infrastructure on the Port Said side, adjacent to an industrial free zone (Zaafarany et al. 2014).

To meet its goal of making the canal a logistics hub and facilitating industrial activity, the SCA planned changes include a moving bridge that would permit crossing at multiple locations (El-Sakty et al. 2014). Additionally, there are plans to build a liquid bulk terminal in Al Adabia Harbor. The addition of such services would make the Suez Canal more than just a passageway, increasing the complexity of activities there.

#### 4.7. North American Oil Exports/Imports

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The removal of the United States Oil Export Ban enacted in 2015 will affect the patterns of North American marine trade in petroleum. Export patterns in both Canada and Mexico have already shifted, and production in the United States Bakkan Fields and Canadian Tar Sands area has increased (UN Comtrade n.d., U.S. Energy Information Agency 2015<sup>a</sup>). Mexican oil companies are selling more oil to Asian and South American countries (U.S. Energy Information Agency 2015<sup>b</sup>). The Canadian government has also been increasing its efforts to build infrastructure to ship oil from both coasts, through measures such as a proposed trans-Canada pipeline and new port developments in Prince Rupert British Columbia (Thomas 2013).

The Aspen Institute, a U.S. think tank, released a report in 2014 that examined the future effects of the lifting of the ban. By 2020, their forecasts show that crude oil production will reach 11.6 million barrels a day. Exported oil would likely be “sweet crude” from North Dakota, which is lighter and has a lower sulfur content (Duesterberg et al. 2014). This is in part because larger refineries in the United States are invested heavily in production of heavier oil with a higher sulfur content, and although adaptation is possible, it is very expensive and with such low oil prices world-wide, it is more economical to export the oil rather than adjust their facilities (Duesterberg et al. 2014).

Shale oil is one of North America’s oil production growth sectors. Within five to ten years, North America will be the largest shale oil producer in the world. Production in other regions, most notably the Asia-Pacific, is expected to reach similar levels in ten to twenty years (BP 2016). BP’s Energy Outlook forecast that until 2025 the U.S. will make up the majority of shale oil

production and in the 2025–2035 timeframe will still account for half of production (BP 2016). An increasing proportion of the oil exported worldwide in the near future will be from areas with shale oil deposits. BP expects oil exports over the next five years to be dominated by reserves in North America, where infrastructure already exists and production has begun, with increasing production in other regions following. Shale oil will likely be the main petroleum product exported from the U.S.

Forecasting the effect of removing the U.S. export ban on crude and petroleum products on patterns of trade is complicated by the world oil trade market in which the U.S. is only one component. Annual EIA estimates of future oil and gas production in the U.S. have consistently been revised upward, as better technology has allowed greater production from existing shale formations and increased estimates of shale oil's availability (Duesterberg et al. 2014). Although investment in refineries has decreased and many U.S. refineries do not have the appropriate infrastructure for shale oil, producers are expected to take advantage of the ability to export to increase investment and industrial capacity.

The U.S. Energy Information Agency (2015<sup>a</sup>) forecast U.S. net exports for crude oil and petroleum products under four scenarios with a U.S. export ban in place (Figure 14):

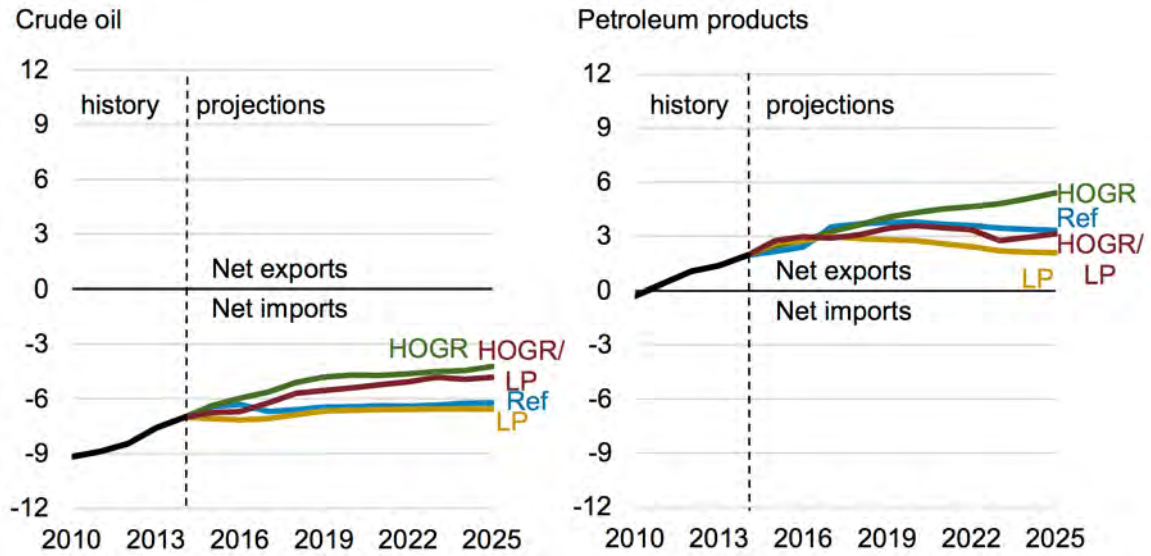
- Reference or current conditions (RF);

- Low Oil Price (LP);

- No export restrictions with High Oil and Gas Resource with Low Oil Price (HOGR/LP);

- No export restrictions with High Oil and Gas Resource (HOGR);

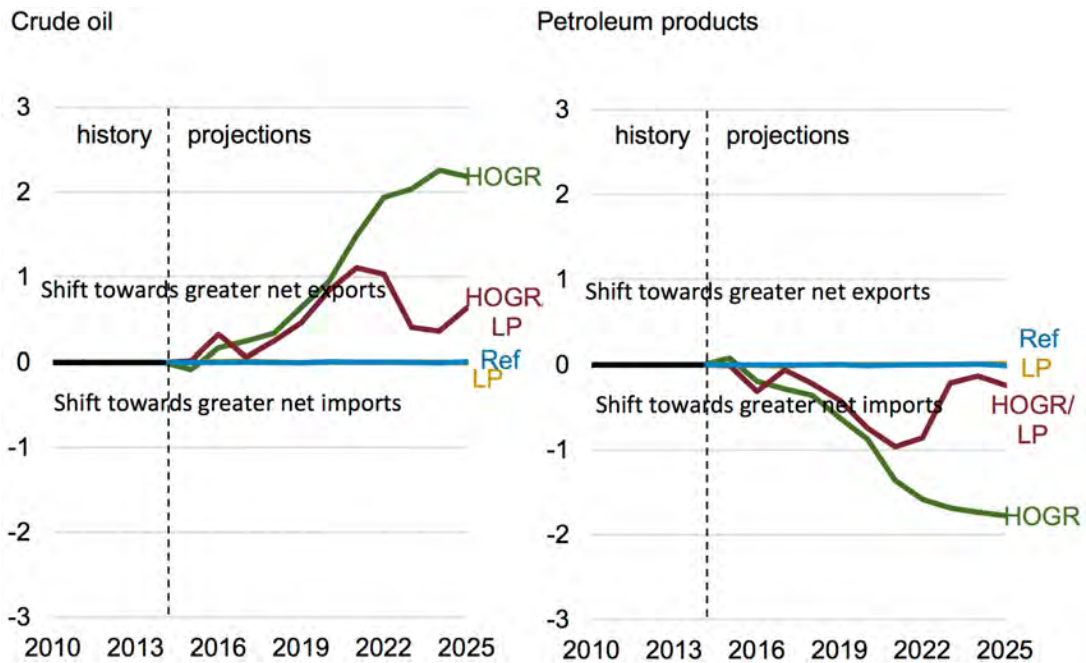
Figure 15 shows the same forecast scenarios without a U.S. export ban in place. Significant changes in import and export patterns are seen for both crude and products under the HOGR/LP and HOGR scenarios. This would impact both the pattern of tanker movements from U.S. ports and the cargos present should an incident occur.



**Figure 14: U.S. Oil Net Export Projections with an Oil Export Ban**

Crude and petroleum product net exports under four scenarios with a crude oil export ban in place. Reference (RF), Low Oil Price (LP), High Oil and Gas Resource (HOGP), and High Oil and Gas Resource/Low Oil Price (HOGP/LP). Million Barrels per day.

(U.S. Energy Information Agency 2015<sup>a</sup>)



**Figure 15: U.S. Oil Net Export Projections without an Oil Export Ban**

Crude and petroleum product net exports under four scenarios without a crude oil export ban in place. Reference (RF), Low Oil Price (LP), High Oil and Gas Resource (HOGP), and High Oil and Gas Resource/Low Oil Price (HOGP/LP). Million Barrels per day.

(U.S. Energy Information Agency 2015<sup>a</sup>)

The United Nations Comtrade service forecasts that the United States will export crude oil and refined products to Canada, Mexico, and the Netherlands, its three largest fuel-trading partners (UN Comtrade n.d.). The amount exported to Canada has shrunk in recent years, while the amount exported to the Netherlands has slightly increased since 2008 (UN Comtrade n.d.). The Netherlands is home to one of the largest ports in the world, and it re-exports some of its imports to other large Western European nations like Germany and Belgium (UN Comtrade n.d.).

## 4.8. Implications

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There are global implications of the Panama Canal expansion, Suez Canal Expansion, and the lifting of the U.S. oil export ban, Table 21. The increases in capacity of the Panama and Suez Canals and the potential creation of the Nicaraguan Canal will allow for larger ships and changing traffic patterns in the regions (Morefield 2012, Yip and Wong 2013).

The expansion of the Panama Canal will lead to increases in the size and capacity of ports on the East Coast of the United States. Port calls could become more concentrated, necessitating infrastructure improvements and potentially changing the origins and destinations of ships using the Canal. Some of the pressure from more concentrated port calls could be alleviated by the construction of a Nicaraguan canal (Morefield 2012, Yip and Wong 2013).

The expansion of the Panama Canal will also bring changes in the operation of the canal, such as the use of tug boats to pull ships through (Panama Canal Authority 2015). The Canal Authority has begun training its operators on 1:25 scale boats to prepare for the new system.

The expansion of the Suez Canal to permit two-way traffic will increase the complexity of operations, potentially requiring changing operating procedures. This can affect the nature of shipping risk in and around the canal.

Implications for new United States crude oil trade could include a reduction in U.S. Flag Jones Act tankers transporting oil in U.S. waters. This is likely to be most pronounced on the west coast of the U.S. where Alaska North Slope crude is replaced with foreign imports carried on vessels not registered in the U.S. (Miller, 2016).

These pressures are all identified as permissive causes in Table 22. Such permissive causes will require policy or regulation changes to prevent an increase in risk. Other dynamics such as increasing variability in crop yields and access to new natural resources could cause further volatility in trade patterns, putting additional strain on these routes.

**Table 21: Panama Canal Expansions, Suez Canal Expansions, and the North American Oil Trade Pressures Across Examined Time Frames**

Summary of the global implications of the Panama Canal Expansions, Suez Canal Expansions, and the North American Oil Trade pressures across the 0–5, 5–10, and 10–20+ year time frames.

<i>Pressures</i>	<i>0–5 Year</i>	<i>5–10 Years</i>	<i>10–20+ Years</i>
<b>Panama Canal Expansion</b>	The canal and destination ports (especially on East coast of U.S) will begin to see larger vessels.	Numbers of larger ships will continue to grow as routing changes. This could lead to developments of new ports of call.	Potential for congestion as destination port calls concentrate.
<b>Suez Canal Expansion</b>	An increase in ship traffic as the Canal allows for traffic in both directions.	Higher traffic flow with potential for loss of vessels to NSR. Development in the regions around the Suez Canal could open up new ports of call, Both larger and new ports in the Middle East for example, and increase complexity of trade patterns.	The canal could see lower numbers due to increased traffic on NSR.
<b>North American Oil Trade</b>	Increased shipments of oil as U.S. producers move lighter, sweeter crude to nations with refinery capabilities. Increase in non-Jones Act vessels transporting oil in U.S. waters.	Volatility in commodities markets will also lead to new needs for resources or changes in availability.	

**Table 22: Panama Canal Expansions, Suez Canal Expansions, and the North American Oil Trade Implications**

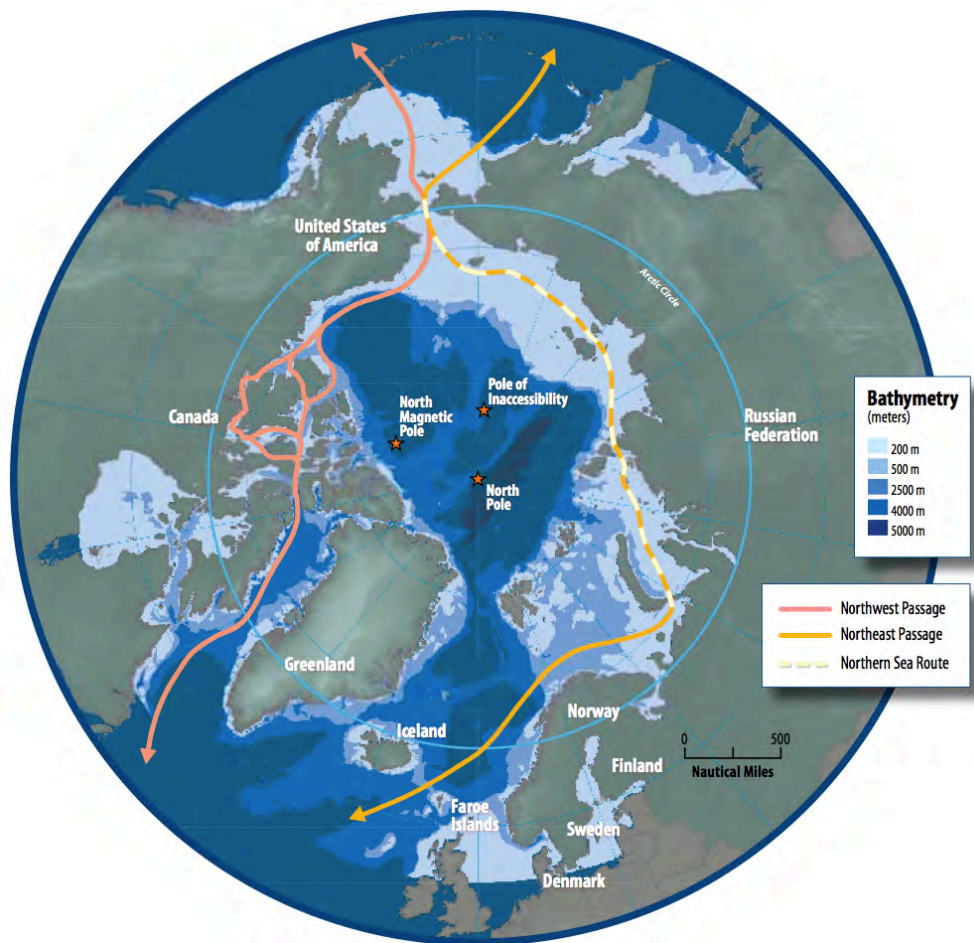
Panama Canal Expansions, Suez Canal Expansions, and the North American Oil Trade pressures with a breakdown of the Causes (Permissive/Triggering) and Changes in Probability/Consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage (IDS). Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL).

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>Panama Canal Expansion</b>	X		X	X	IFI, LA	A, C, G, HD/F, ED/F, CL	
<b>Suez Canal Expansion</b>	X		X	X	IFI, LA	G, F, HD/F	
<b>North American Oil Trade</b>	X		X	X	IFI, SR	F/E, C	This pressure is both emerging and changing because the U.S. is not new to oil transport and refining, but it is new to being a major exporter of crude oil.



## 4.9. Current Arctic Trade Patterns

While many commercial shipping routes transect the Arctic Ocean, the Northern Sea Route (NSR) is currently the most practical for transit (Figure 16). However, transits remain relatively few. The route averaged 47 transits from 2011 to 2014, with 2013 being the busiest year with 71 transits (NSR Information Office 2015). Even in the winter months, when sea ice extent is at a maximum, partial NSR transits occur in the west and central parts of the Russian Arctic coast (NSR Information Office 2015). Figure 17 below shows the NSR region and the ports along the route (NSR Information Office 2015).



**Figure 16: Major Arctic Shipping Routes**

The Northwest Passage is depicted by the red line, the Northeast passage by the orange line, and the Northern Sea Route by the dashed line.

(Arctic Council 2009.)



**Figure 17: Port Facilities on Russia’s North Coast**

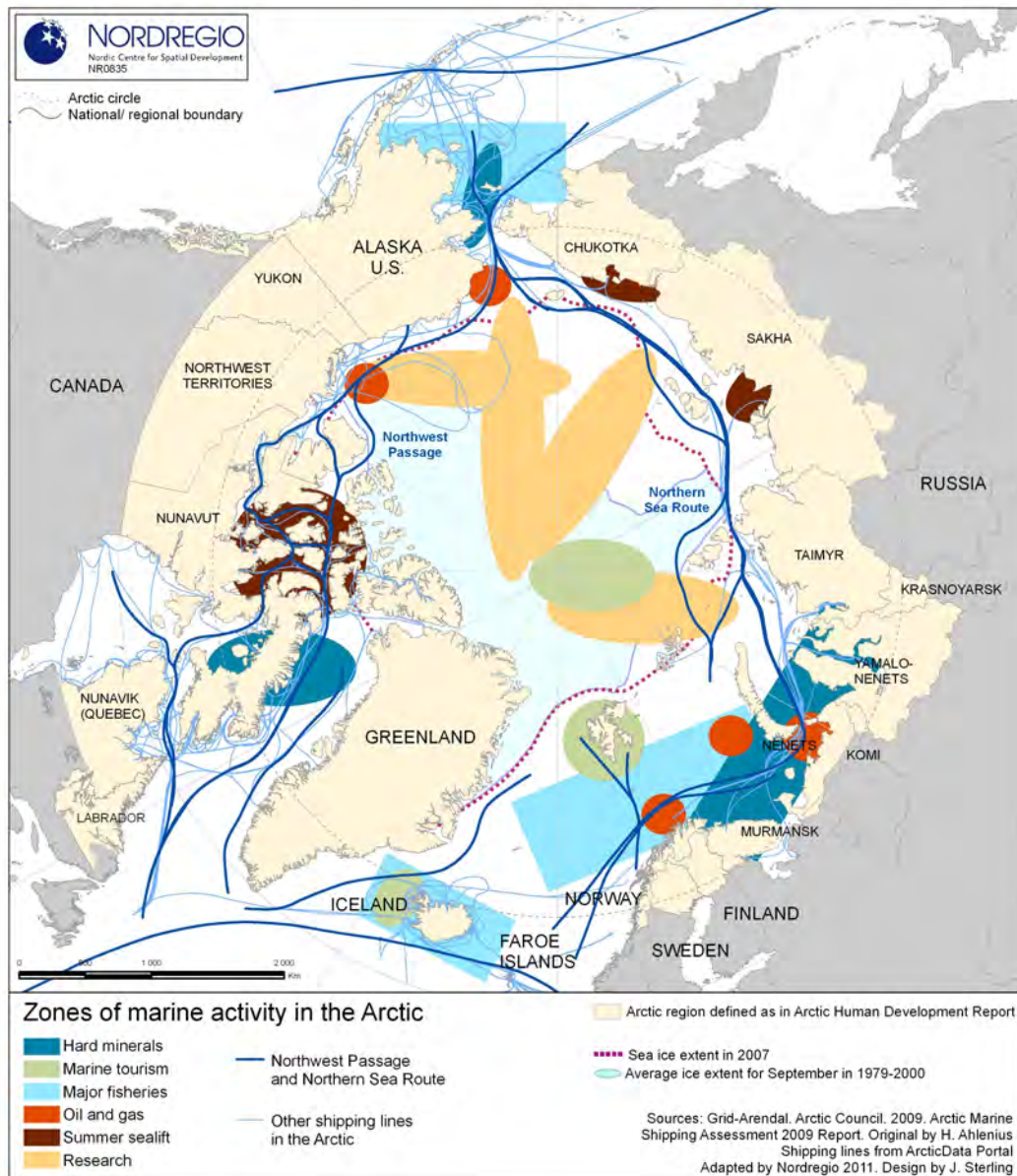
Map of the north coast of Russia and its port facilities (blue anchors). The cluster of port facilities on the west side further shows the focus of destination shipping in the western side of the route.

(NSR Information Office 2015)

The Northwest Passage through Canada’s Arctic is also seeing an increase in usage. For instance, in 2012 the route saw a record number of 30 transits. In 2013, one bulk carrier made the transit (NWT 2015). This is a single transit, but the larger size of the vessel is significant because transits by larger vessels make the lack of infrastructure and updated charts more serious issues. Most recently, the luxury cruise ship *Crystal Serenity* completed the Northwest Passage with some 900 passengers aboard, marking what appears to be the beginning of a new chapter in Arctic use (Thiessen, B. M. 2016, September 9). Most Arctic shipping is through the Northern Sea Route (NSR) and as such this route is the focus of this report.

The current Arctic shipping season runs from mid-July to early November (Arctic Council 2009) and the employment of icebreakers can lengthen this season. Since 2004, more than €4.4 billion (4.9 billion USD) have been invested in improving the deepwater port facilities of Murmansk to include new oil, coal and container terminals as well as expanded rail lines (Humpert and Raspotnik 2012). Trade routes between Asia and Europe via the NSR are approximately 40% shorter than routes that employ the Suez Canal, giving the NSR a time advantage over the more

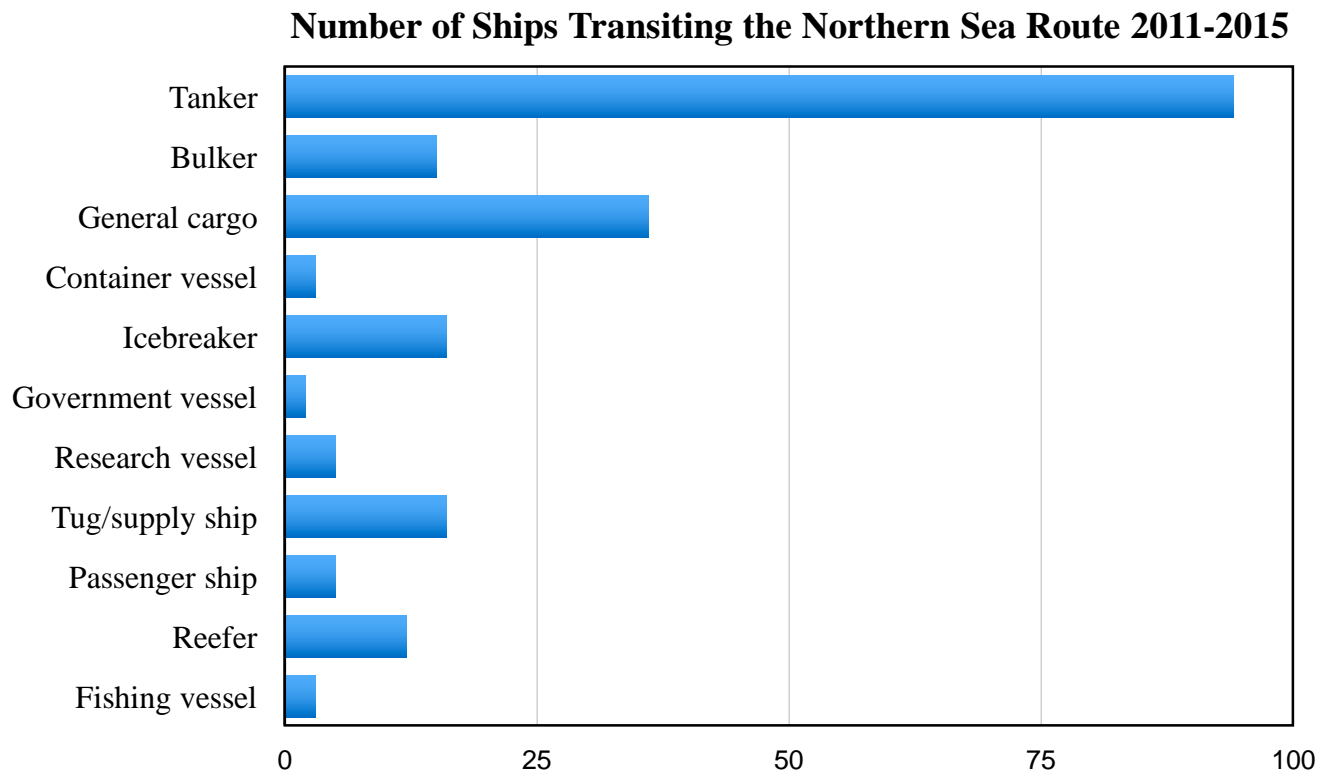
commonly used routes when conditions allow for smooth travel (Chatham House-Lloyd's 2012, Smith Stephenson 2013, U.S. Transportation Research Board 2016). Figure 18 provides an overview of selected intersecting activities in Arctic Waters. Of note for this report is the industrial activity, which includes oil and gas as well as hard minerals, along the main shipping routes.



**Figure 18: Zones of marine activity**

Types of marine activity in the Circumpolar Arctic region. The industrial focus of the current Arctic shipping dynamic is further seen in the cluster of activity on the western half of the NSR as well as its locations along the route.

Figure 19 shows the number of vessels on the NSR by cargo type. Liquid cargo is the largest portion of traffic, corresponding with findings by the U.S. Transportation Research Board that suggest tankers are increasing in numbers in the Bering Strait, the entry/exit for the NSR (NSR Information Office 2015, U.S. Transportation Research Board 2016).

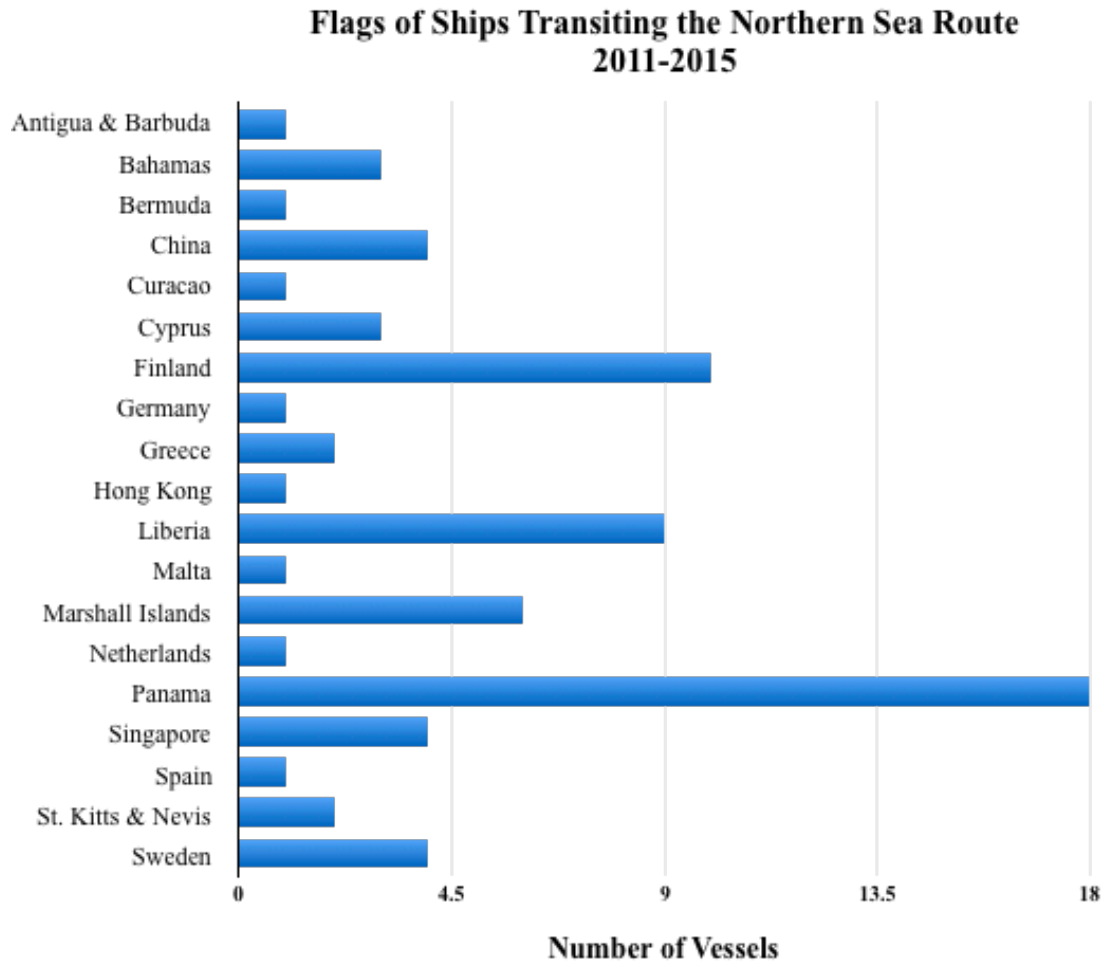


**Figure 19: Number of vessels on NSR by Cargo Type.**

Number of Vessels by Cargo Type on Northern Sea Route in both 2011 and 2012. The skew towards liquid carriers is especially important as a spill from these types of vessels would be very difficult to clean up. (Data from the Northern Sea Route Information Office: <http://www.arctic-lio.com>)

Most NSR shipping is destination, i.e., within the Arctic (Srinath 2010, Rothwell 2010). The Arctic Marine Shipping Assessment notes that nearly all the shipping in the Arctic today is destination, much of it conducted for community resupply (Arctic Council 2009). For example, in Russia resources are shipped from ports in West and Central Siberia to Northern Europe, mostly Rotterdam (Srinath 2010). Just six of the 18 vessel trips in 2015 were transits, having

their origin and destination outside the Arctic (NSR Information Office 2015). Five of these transit passages were between an Asian port and a European one (NSR Information Office 2015). Figure 20 shows that Panama is the main flag state of vessels transiting the NSR (NSR Information Office 2015). Russian flagged vessels dominate destination shipping on the NSR.



**Figure 20: Use of Northern Sea Route by Flag State**

These numbers represent the flags of ships transiting the NSR. Russian vessels dominate the regional and destination shipping along the NSR.

(Data from the Northern Sea Route Information Office: <http://www.arctic-lio.com>)

Data show that most of the shipping activity is in service of industrial activity. Of the 18 passages in 2012, 6 were tankers or general cargo ships, while one passenger ship made an Arctic transit (NSR Information Office 2015). Much of the traffic along the route is driven by

natural resource extraction, which currently makes up the greatest percentage of Arctic shipping (Arctic Council 2009). Lawson Brigham, an Arctic shipping expert and one of the Arctic Marine Shipping Assessment's authors, believes that the type of industrial activity taking place in the region will shape development of Arctic shipping into the future (Ruskin 2015).

Arctic development is being driven by industrial and commercial activity in the region. The Chinese recently entered into a \$400 billion partnership to buy LNG from Russian giant Gazprom (Associated Press 2014). This purchase is a result of the huge demand for gas in Asia. Combined with the lack of infrastructure in the North, this agreement provides an unprecedented opportunity for China to influence the speed and nature of development in the Arctic (Associated Press 2014, Byers 2014). Already, the Chinese have invested \$25 billion in a natural gas pipeline, a small example of the potentially large affect global actors could have on the Arctic through industrial business.

The Arctic is a place where both financial power and military power are important (Byers 2014). There has been increased activity in the region, especially from Asian nations looking to exploit some of its resources as well as to further development of the shipping lanes (Wanerman 2015, Rothwell 2010, Ruskin 2015). China has already built their own icebreaker and are working with Russia in the north of Russia. Because the great majority of resource wealth across the entire Arctic region lies within sovereign uncontested territory on the continental shelves, such collaborative tactics are a way for outside states to have a hand in the Arctic's development. Continuing economic development will bring more traffic and activity to the Arctic, a permissive cause of risk.

Some authors believe that the Arctic's place in global trade is changing faster than the international community can adapt (Wanerman 2015). From a risk management perspective, activity that is outside the capacity of local and state actors to manage represents a situation in which risks can be difficult to manage over time. Pro-active planning can help to mitigate these risks.

Industrial development and associated volumes of ship traffic in the Arctic contribute to a complex economic and political operational environment. Actions by outside actors can affect

the nature and location of risk in the Arctic. For example, Germany has recently developed a port in northeastern Iceland to handle shipments of oil and gas as well as facilitate search and rescue operations (Barents Observer 2015). One of the benefits of this port is its deep water and opportune position along a trans-Arctic shipping route forecasted to come into operation by mid-century (Smith and Stephenson 2013). The announcement by Crystal Cruise lines of its intention to send a large cruise ship through the Northwest Passage, the successful completion of which is noted above, caused the U.S. and Canadian Coast Guards to conduct joint planning around contingency plans aimed to prevent accidents and upgrade SAR capabilities, accelerating planning that otherwise would have occurred on a slower time scale. These kinds of activities can help mitigate risks.

Infrastructure development is not equivalent in all parts of the Arctic. Regions differ in terms of physical location, natural resource wealth, economic developments, and political cultures (Chatham House-Lloyd's 2012). For example, there is thought to be more oil in Norway and the U.S. and more natural gas in the Russian Arctic (Chatham House-Lloyd's 2012). Increased traffic combined with uncertain and changing ice conditions affect the risk to shippers, with some ports better equipped to deal with emergencies than others. For example, the port of Arkhangelsk is a developed port in a large city while the ports of Vitino and Indiga are much smaller. They nevertheless all transport oil from the west Siberian oil fields to the port of Rotterdam (Srinath 2010). Nickel, copper, and platinumoids are being shipped from Norilsk to Northern Europe (Srinath 2010). A recent report from Chatham House on Arctic development makes the point that risks associated with oil and gas development added to those associated with existing shipping of other materials are likely to amplify one another due to the potential for operational interaction (Chatham House-Lloyd's 2012).

The Arctic has passages that can be categorized as chokepoints, even though they do not fit the qualifications set for lower latitude locations. The Bering Strait, though not especially narrow, is a key point on both the Great Circle Route between the West Coast of the U.S. and Asia as well as an entry or exit point on the Northern Sea Route and the Northwest Passage (AMSA 2009). Rothwell (2010) suggests that this strategic importance and utility makes the Bering Strait a chokepoint. Rothwell also notes the proximity to Asian nations such as China, Japan, and South Korea, all of whom have taken steps to develop roles for themselves in Arctic shipping, further

increases the Bering Strait's strategic importance. The Arctic Marine Shipping Assessment makes a simpler argument for the idea that the Bering Strait is a chokepoint: it is the only exit for the NSR and is often subject to extreme weather (Arctic Council 2009). It is also a key migration corridor for marine mammals and other wildlife, increasing the potential consequences should an incident occur in this area.

The U.S. Coast Guard has been looking at formalizing shipping lanes through the Bering Strait and has sought Russian cooperation in this regard (Joling 2015). The number of vessels in the Bering Strait went from 220 in 2008 to 480 in 2012 (Transportation Research Board 2016). The increased attention on the Arctic will have ramifications for the Bering Strait region especially as it is not currently equipped to deal with large numbers of ships through such proven management measures as regularized vessel routes and other navigation controls (Rothwell 2010).

Regulatory efforts in the Bering Strait highlight an important distinction between the Bering Strait region and the Northern Sea Route and Northwest Passage. Whereas the NSR and NWP are treated as internal waters under the U.N Law of the Sea Convention, the Bering Strait and nearby Unimak Pass are international straits (Byers 2013). This means that Russia (NSR) and Canada (NWP) have a great deal more regulatory authority over the activity in these areas than the U.S. has in Unimak Pass or either the U.S. or Russia have in the Bering Strait (UNCLOS Byers 2013). The United States has limited jurisdiction over ships using international straits under normal circumstances. The U.S. also does not have a full role in efforts to establish international regulatory authorities because of its failure to accede to the Law of the Sea Treaty. As a result, the U.S. can only restrict traffic through outside agents and actions like the IMO's Particularly Sensitive Sea Area (PSSA) designation, which would allow for more control of the region's growing ship traffic (Byers 2013). PSSA designation cooperation of all parties and does not provide the same level of regulatory control that a country can exert over its internal waters (Byers 2013).

This regulatory environment in the Bering Strait presents a permissive cause of risk when combined with the other pressures at work in the Arctic.



## 4.10. Future Arctic Trade Patterns

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The uncertainty surrounding the future of Arctic shipping is extremely high. The time saved, increased international interest, and reduced fuel cost make it an attractive option. This will not be a linear process because the political, economic, and environmental factors impacting use strategies are intertwined and complicated. The Congressional Research Service believes that while the trans-Arctic shipping is subject to this uncertainty, extraction activities and interest are expected to remain steady or increase (Congressional Research Service 2015). As such, the short to medium (0–5 and 5–10 years) term future of Arctic maritime activity appears to be reliant on extraction industries as well as regional ship traffic. The trans-Arctic shipping routes might not play a significant part in the region for the next few decades. The uncertainty of ice conditions is not the only reason for this. The Congressional Research Service and Lee and Kim (2015) both identify the cost of establishing new infrastructure and vessels as well as insurance, icebreaker escorts, and ice pilots, as factors contributing shipping in the Arctic, specifically the NSR, being less advantageous than the Suez, despite the distance savings (O’Rourke 2015, Lee and Kim 2015).

Environment Canada, Canada’s environmental agency, also forecasts an increase in traffic in the Northwest Passage especially in the form of commercial traffic (NWT 2015). The Canadian government plans to upgrade the railroad to Churchill and develop a deepwater port in Nanisivik, Nunavut, Baffin Island by 2018 (Arctic Council 2009 and Rogers 2015). This port will primarily be used by the Department of National Defense as a naval fuel station (Rogers 2015). Russian ports are the most well-established along the NSR, although some require lengthy river transits to access, and are supported by the Russian icebreaker fleet (Arctic Council 2009). The Port of Murmansk is projected to increase to an annual capacity of 52 million tons by 2020.

Influences on Arctic shipping likely to be seen in the 5–10 year or 10–20+ year time frames are shown in Table 23. This list was adapted from the findings of an Arctic Marine Shipping Assessment workshop that identified elements with the potential to shape future Arctic shipping by 2050.

### *Influences on the Future of Arctic Navigation*

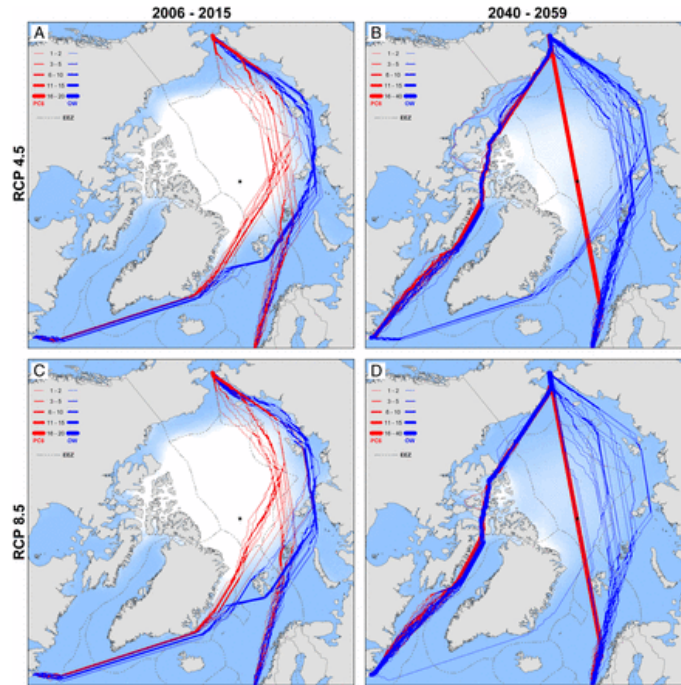
- Climate change
- Safety of other routes
- Socio-economic impact of global weather changes
- Major Arctic shipping disaster
- Global agreements on construction rules and standards (e.g., IMO)
- Arctic maritime enforcement

**Table 23: Influences on the Future of Arctic Navigation**

(Adapted from the Arctic Council 2009)

Given the trends in NSR passages since 2015, it could be that industry and resource extraction are the main activities in the region in the 5–10 year time frame, while the Europe-Asia trade will continue to grow. Francois and Romagosa (2015) suggest that as much as 15% of China’s trade will move along the Northern Sea Route in the future, further reinforcing the idea that the NSR will one day be a major route for cargo and tanker ships (Francois and Romagosa 2015).

The combination of receding ice and a growing fleet of ice-class vessels able to travel in severe conditions will allow new routes through the central Arctic Ocean as early as mid-century (Smith and Stephenson 2013). The NSR is by far the most navigable Arctic route in the near future, while the Northwest Passage has the lowest navigability in the 2040–2059 timeframe (Smith and Stephenson, 2013). Trans-Arctic routes will heavily depend on the pace of development as well as changes in environmental conditions (Smith and Stephenson 2013). Figure 21 shows how Arctic shipping could evolve as climate and sea ice conditions change through mid-century (Smith and Stephenson 2013).



**Figure 21: Potential New Arctic Shipping Routes**

Potential areas where vessels would be able to travel by mid-century. Blue lines are for the fastest available routes accessible by common open-water vessels. Red lines are the fastest available routes for Polar Class 6 vessels. These are not specific trade routes, rather they reflect ice conditions that would allow these vessels to navigate.

(Smith and Stephenson 2013)

The future of regional Arctic shipping looks to be one of industrial development and resource extraction, while the future of trans-Arctic shipping will be defined by the European-Asian trade relationship (Northern Sea Route Information Office n.d.). These regions have taken steps to increase their influence and capability in the region such as Germany with and Icelandic base and polar research, China and Korea with icebreakers, and Chinese involvement in Arctic industry to name a few, suggesting that in the future they wish to use the region as a major trade route.

#### 4.11. Implications

The increasing access to Arctic shipping routes and the distance saved makes them an attractive option. The first and most important implication of this attention is the creation and adoption of the Polar Code. This codifies the requirements for operators in Polar waters to standardize practices and equipment thus making Arctic travel safer.

Arctic shipping and the opening of the routes also is linked to industrial development in the Arctic. As stated in sections 4.10 and 4.11, industrial activity has been the bulk of activity in the region, and with this comes an increase in infrastructure which in turn makes shipping safer and more possible. This could result in changes in policy and regulation such as development of the Polar Code.

Table 24 shows how risks associated with Arctic shipping pressures could emerge over three timeframes. The pressures associated with Arctic shipping pressures generate risks that are all categorized as permissive causes as can be seen in Table 25.

**Table 24: Arctic Shipping Pressures across Time Frames.**

Pressures in Arctic shipping across the 0–5, 5–10, and the 10–20+ year time frames.

<i>Pressures</i>	<i>0–5 Year Time Frame</i>	<i>5–10 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<b>Arctic Shipping</b>	Northern Sea Route increasing in relevance. Increase in focus on Arctic infrastructure.	Arctic Shipping will be increasingly prevalent. Increased infrastructure and response capabilities.	Potential trans-polar routes.
<b>Political Tensions</b>	Tensions over access to resource markets, especially in the Arctic.	Continuation of Arctic tensions as well as resource access world-wide	Increasing tension over access to crops, freshwater, and energy.

**Table 25: Arctic Shipping Pressures Implications**

Pressures associated with Arctic Trade Routes with a breakdown of the causes (permissive/triggering) and changes in probability/consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage. Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL).

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>Arctic Trade Routes</b>	X		X	X	SR, NC/NF, LA, IDS	HD/F, ED/F, I/S	
<b>Political Tensions</b>	X		X				Political tensions function as a background for other more specific events, hence the Change in Consequence section is blank.

## 5. DEVELOPING TECHNOLOGIES

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This section explores three areas of technology developments that are occurring within the marine transportation system. Technology is constantly evolving and while the goal of technology is to make marine transport safer and more efficient, it sometimes creates new or unforeseen risks. This section will look at how vessel-related marine technology is changing, and how risks associated with these technologies are changing. This section is divided into three parts: vessel developments, vessel automation, and new propulsion fuels. The time frame used for vessel developments is 0–5 years as these are risks that are already emerging. The time frame used for both vessel automation and new propulsion fuels is 10–20+ years as these risks might emerge depending on the developments and decisions on adopting and implementing these technologies. The sections consider information from Allianz Global Safety and Shipping Review 2015, Lloyd’s Register Marine Technology Trends 2030, Lloyd’s Register Marine Fuel Trends 2030, among others. These reports each offer a comprehensive outlook of the marine transportation system and forecasts of future shipping trends.

### 5.1. Developing Technologies Common Terms and Definitions

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International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) – A code that is kept under constant review in order to provide safe marine transport of bulk liquefied gases such as LNG as well as provide vessel requirements and safe handling procedures. This code considers new information as well as new technologies regarding liquefied gases (IMO<sup>a</sup> 2016).

International Safety Management Code (ISM Code) – An international code that is set up to provide a standard for the safe operation and management of vessels as well as for pollution prevention (IMO<sup>b</sup> 2016).

“Mega-Containership” – For the purposes of this report, a “mega-containership” will be considered a containership that is able to handle greater than or equal to 18,000 TEUs.

“Mega-Ship” – Most commonly used to describe the newer, larger containerships, however, depending on the time period as well as the geographical location, may be used to describe larger ships than seen in that area before (OECD 2015).

TEU – Twenty-foot equivalent unit, or the number of twenty-foot containers a vessel is able to carry. This is how containership size is most often referenced (OECD 2015).

Very Large Ore Carrier (VLOC) – Any bulk carrier with a capacity of 300,000+ dwt (Allianz 2015)

## 5.2. Vessel Developments

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### 5.2.1. Mega Container Ships

Vessels are getting larger across vessel types, but the trend is most notable in the containership fleet. The largest containership to date is approximately 400 meters in length with a 19K TEU capacity (OECD 2015, Lloyd’s Register 2016). With the increasing size of containerships come changes in the risks previously presented by containerships. Although these vessels are designed to be safer in operation as well as to have a reduction in the risk of a structural failure, the potential risk of human error presents itself in both the ports that have adapted to accept mega-containerships as well as onboard the mega-containership itself through increased technologies and smaller crew sizes (Allianz 2015, Lloyd’s Register 2016, UNCTAD 2014). It is important to note that although the hulls of these ships have been reinforced, there is a concern that because their size could subject them to additional bending and therefore hull damage from storms. The MOL Comfort, an 8110 TEU container ship sank in 2013 in seas with 5.5m waves and Beaufort force 7 winds. The sinking was due to a structural failure associated with the ship design and construction (Committee on Large Container Ship Safety, 2013). There have been other less catastrophic vessel casualties involving mega container ships that highlight the kinds of incidents that are emerging (ITOPF 2016):

- *CSCL Indian Ocean* – 2016 – Grounding in Elbe river on the way to Hamburg Port



- *Al Zubara* – 2016 – Damaged by rough weather and taken to Malaga where special equipment had to be brought to assist the recovery
- *MSC Fabiola* – 2016 – Hard aground in the Suez Canal

Containerships are designed to transport goods throughout the world, and are intricately linked to ports with the infrastructure to load and unload them in a safe, yet timely manner. In his interview for Lloyd’s List Containers, Tom Boardley stated that “there’s twice as much tonnage afloat today as there was in 2001, but there are only 25% more hulls, and it’s in containerships where this expansion in scale is most acute” (Boardley 2014). This is a relatively short period of time for all ports that accept containerships to have adapted and due to this rapid growth, these vessels have been mostly limited to Asia-Europe routes (OECD 2015). The main adaptations that ports must make to handle these vessels include:

- Addition of cranes that can reach across to lift the container that lies the furthest from the vessel berth
- Deeper access channels
- Increased shore side container handling capacity
- Wider basins for vessels to turn

Assuming a port has made the necessary adaptations, the operating times for unloading/loading containerships are expected to increase the vessel’s time in port. The necessary operation cranes are also expected to be taller because they have a greater reach, and are therefore less-stable in high winds. These variables increase the complexity of operations while a mega-containership is in port, which could ultimately lead to an incident (Allianz 2015, UNCTAD 2014).

Although mega-containerships are known for being much more fuel-efficient than their smaller counterparts and some are being constructed with the option of being LNG propelled, they can still carry large amounts of liquid fuel (OECD 2015, Lloyd’s Register 2016). If a mega-containership were to be involved in an incident that leads to a fuel spill, the potential volume of oil that could spill would be larger compared to a smaller containership involved in a similar incident (Allianz 2015). Table 26 compares the amount of fuel different ships carry, including a mega-containership. Additionally, the increase in cargo container capacity increases the potential

for involvement of hazardous material containers if the ship were to lose its cargo overboard due to a grounding, sinking, or any other incident type. Part of the requirements of containership operations include declaring the weights and cargo that are onboard, however in the past there have been incidents where correct weights and hazardous cargoes have not been declared, increasing risks of cargo loss or vessel damage, problems that could be magnified on a mega-containership. The IMO introduced new rules on July 1, 2016 for verification of container weights to reduce the occurrence of inadequate reporting.

**Table 26: Approximate Amount of Fuel Carried by Vessel Type**

Volumes of fuel that various vessels carry. Notice the large difference between the amounts of fuel a Panamax containership carries versus a new mega-containership.

<i>Vessel Type and Length (m)</i>	<i>Fuel Carried (gallons)</i>
Ocean-going Tugboat (27–46m)	90,000–190,000
Large Cruise Ship (274–335m)	1,000,000–2,000,000
Panamax Containership (5k TEU, 292m)	1,500,000–2,000,000
<i>Vale Brasil</i> , Very Large Ore Carrier (362m)	2,900,000
<i>Benjamin Franklin</i> , Mega-Containership (18k TEU, 400m)	4,500,000
<i>Exxon Valdez</i> and similar sized oil tankers (300m)	55,000,000

(Adapted from Cadre Inc. 1996, Helton 2016, Vale 2011)

Due to their size, mega-containerships are limited to specific trade routes, mostly Asia-Europe routes. They are not able to transit the Panama Canal, but can transit the Suez Canal (OECD 2015). Even with the expansion of the Panama Canal, the largest containerships will not be able to transit. Future trade routes and locations of these vessels will be dictated by the available infrastructure, the further adaptation of ports, and market conditions (Boardley 2014, OECD 2015, UNCTAD 2016). The number of mega-containerships in existence and expected in the coming years is not large. However, the idea with mega-containerships is to have fewer yet larger, more efficient vessels. For example, there are three new containerships between 20K and

21K TEU expected to be in operation by 2017 (OECD 2015, Lloyd's Register 2016). Experts expect that after 22K–24K, these vessels will no longer be cost effective or able to operate within the available infrastructure, which will limit in their size (Boardley 2014, Lloyd's Register 2016, OECD 2015).

### 5.2.2. Bulk Carriers

Bulk carriers are designed to transport bulk cargo that is not containerized such as grain, ore, cement, etc. (UNCTAD 2014). The U.N. Review of Maritime Transport (2014) breaks bulk carriers into four categories dependent on size:

- Handysize (10,000–39,999 dwt)
- Handymax (40,000–59,999 dwt)
- Panamax (60,000–99,999 dwt)
- Capesize (100,000+ dwt)

For this report, a fifth category of Very Large Ore Carriers (VLOC), any bulk carrier with a capacity of 300,000+ dwt, is also considered (Allianz 2015). Two recent vessel casualties involving mega bulk ships highlight the kinds of incidents that are emerging (ITOPF 2016):

- *Vale Beijing* had structural integrity issues in 2011 and was unable to unload due to lack of local facilities. Repairs had to be completed at sea;
- *Vale Indonesia* ran aground in 2013 in Brazil with damage caused to the ballast tanks.

Risk is also changing in the bulk carrier trade due to the transport of potentially unstable cargo. The dry-bulk market has been on a downward trend and larger bulk carrier operators are having difficulty keeping their carriers full with cargo. To maintain profits, larger bulk carriers have been more willing to transport these inherently risky cargoes when they have already been exposed to moisture, aggravating the possibility of a liquefaction event while on board (Allianz 2015, Joint Hull 2012, UNCTAD 2014, Andrei and Pazara 2013). Some bulk cargoes (e.g., nickel and iron ore<sup>11</sup>) behave as solids until moisture is introduced and can then affect the

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<sup>11</sup> The IMO regulates bulk cargoes for safe transport under the International Maritime Solid Bulk Cargoes Code. For more information, please see [www.imo.org/en/OurWork/Safety/Regulations/Pages/BulkCarriers.aspx](http://www.imo.org/en/OurWork/Safety/Regulations/Pages/BulkCarriers.aspx)

cargo's characteristics under certain conditions. Many ore mine terminals from which bulk carrier cargo is loaded are uncovered and can become damp during rain events or from high humidity. Waves and mist onboard the carrier may also influence the moisture content of cargo (Allianz 2015, Andrei and Pazara 2013, Joint Hull 2012). If enough moisture is introduced to the cargo prior to loading or during the voyage and it is then subject to vessel movements at sea, friction between the cargo's particles can be lost and the particles push apart and begin behaving as a liquid. This process is usually a very rapid occurrence resulting in vessel instability with the possibility of sinking (Andrei and Pazara 2013, Joint Hull 2012). Per the IPCC AR5 (2013), rain events and storminess at sea are predicted to increase, which will require more attention paid to the loading and handling of bulk carrier cargo.

Rapid liquefaction on a bulk carrier such as a VLOC could ultimately result in sinking, which presents the risks of loss of life as well as environmental damage, not only from the cargo, but also the propulsion fuel onboard these vessels (Andrei and Pazara 2013, Allianz 2015). Although the incident types affecting bulk carriers remain the same, the emerging risk consequences increase with VLOC.

### 5.2.3. LNG Carriers

Depending on the development and market trends LNG follows, the ports handling this cargo could change. Qatar is the biggest exporter of LNG today, with the United States building as a potential leader in LNG exports. Qatar is expected to grow even more as an exporter, while Australia and Nigeria are forecasted to become bigger players in the export of LNG within the coming decade. Russia is developing LNG facilities in the Arctic. Japan and Europe lead in imports, with India, China, and South Korea are forecasted to increase imports over the next decade (Lloyd's Marine Trends 2013, Kumar et al. 2011). With more countries becoming involved in the importing and exporting of LNG, it will be important for their ports to develop the necessary infrastructure and training for safe-handling of the cargo (Lloyd's Marine Trends 2013, UNCTAD 2014). Although to date, no major LNG carrier incidents have occurred, the extent of the potential impacts of incidents will be important to consider as LNG carrier traffic continues to increase. For example, UNCTAD forecasted that LNG cargo would increase 5% in the year 2014 (UNCTAD 2014) and another study forecasted that between 2008 and 2035, LNG

demand would increase by 44%, or an average of 1.4% per year (Kumar et al. 2011). Additionally, Lloyd's Register forecasts that by 2030 LNG carriers will amount to about 5 million gross tons (GT) compared to just less than 4 million GTs in 2010. This will come in both the form of larger and more LNG carriers (Lloyd's Marine Trends 2013). As of 2013, there were 357 LNG carriers in operation, with more orders for new builds placed each year (IGU 2014). This includes ice-classed LNG carriers for trade on Arctic routes (Maritime Executive 2016).

In the last 15 years, there have been four LNG carrier total losses, a remarkably low number compared to other vessel types. Although LNG carriers are generally safely designed and carefully operated, there are still concerns regarding the risks of LNG carriers (Hightower et al. 2004, Vanem et al. 2008). The continuing increase in LNG carrier traffic as well as the proper handling of LNG has prompted a revised International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk<sup>12</sup> (IGC Code). The revised code, which became effective January 2016, address concerns about the impacts a collision of an LNG carrier could cause (Allianz 2015, IMO<sup>a</sup> 2016). There have also been several risk analyses performed in order to decipher the risks of LNG to both the environment as well as to humans. Due to the lack of accidents and spills that have occurred from LNG carriers, there is a high degree of uncertainty associated with the consequences of an LNG incident and as well as the potential salvage required, however LNG is not flammable in its liquid form, will not persist in a marine environment, and is non-toxic. Subsequently it is not considered a high environmental risk, but rather a safety concern. Although LNG is not flammable in its liquid state, it is flammable as a vapor, creating the concern that if LNG were to be spilled, for example due to a collision or in port during loading/unloading, the possibility of fire and/or explosion would be present.

With LNG trade projected to increase in the future (Allianz 2015, Kumar et al. 2011, UNCTAD 2014) and begin operations in new areas, there will be a change in the probability of risks occurring. Although the concern for the transport of LNG continues to be the possibility of fire and/or explosion, the emerging risk consequence can be considered new cargoes due to the lack of incidents involving LNG cargo (Hightower et al. 2004, Vanem et al. 2008). The full extent of what an incident with an LNG carrier could mean is not fully understood and will therefore have

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<sup>12</sup> For more information concerning the IGC Code, please visit:  
<http://www.imo.org/en/OurWork/Environment/PollutionPrevention/ChemicalPollution/Pages/IGCCode.aspx>

to continue to be monitored as well as safely handled while in port and throughout transit (Hightower et al. 2004, Vanem et al. 2008).

#### 5.2.4. Floating Production Storage and Offloading Vessel

Floating production storage and offloading vessel (FPSO) orders are forecasted to increase globally between 67 and 94 units by 2018, mostly in Brazil and Africa, and in the North Sea (McCaul 2014).

FPSOs are being deployed in the oil and gas sector due to their ability to be unmanned, their large storage capacity, their ability to operate at extreme depths where pipelines are not able to reach, and their ability to be constructed using decommissioned tanker hulls (McCaul 2014, Wodehouse et al. 2007). FPSOs are also, if designed with the correct attributes, able to be disconnected and moved if adverse weather approaches. In general, once an FPSO has been moored, it is considered to have been permanently located (Murugason 2012).

FPSOs have been operating with few incidents since the 1970s. One notable incident that occurred was the Texaco Captain FPSO, where almost 4,000 barrels of oil were spilled due to human error in the late 1990s (Rigzone 2016). Aside from this incident, only minor incidents have occurred with FPSOs. Some FPSO units are as large as VLCCs, meaning the storage capacity of oil or gas is large and the resulting impacts to the surrounding environment could be significant if a spill occurs (McCaul 2014). With increasing deployment of these units, the risk of an allision or collision between loading/unloading shuttle tankers increases.

Although FPSOs have been deployed in the North Sea, the concerns of low temperatures, iceberg collisions, ice accretion, and heavy ice affecting operations are still present. The FPSOs have to be able to function in the extreme conditions of the Arctic (Li 2012, Yu 2008). With the expected increase in the number of FPSOs deployed in the North Sea, the probability of incidents occurring increases. The emerging risk consequences associated with FPSOs are increased frequency of incidents, shifting routes, and an increased difficulty of salvage. With future placement of FPSOs in the Arctic, the incident type “equipment damage/failure” is introduced, due to the possibility of the unit being affected by the harsh environment (Li 2012, Yu 2008).

### 5.2.5. Implications

Vessel developments manifest their risks to the marine transportation system mostly in the 0–5 year time frame. Future risks associated with vessel developments depend on the continuing increase of mega-containership sizes, further regulation of the cargoes of bulk carriers, the increase of LNG trade, and the placement of FPSOs in the Arctic (Table 27). The mitigating actions taken in the 0–5 year time frame will determine what risks will occur in later time frames. For example, with the IMO and other regulatory organizations continuing to increase the regulations on the hazardous cargo that bulk carriers transport, it is expected that liquefaction events will become less of an issue in the future (UNCTAD 2014, Joint Hull 2012).

Table 27 identifies each pressure as either permissive or triggering, if the incidents that result from each pressure is changing in probability and/or consequence, and the incident consequences and incident types associated with each pressure.

With the introduction of mega-containerships, experts state that the structure of the vessel has been reinforced, reducing the probability of an incident, however, if an incident does occur, the consequences of pollution are increased due to the larger amounts of fuel and cargo that these ships carry and could therefore be released (Allianz 2015, Lloyd’s Register 2016). Some experts counter the argument of incident probability being reduced by stating that storminess at sea is forecasted to increase, and these longer ships may be subject to bending and therefore hull damage (Cassidy 2016, IPCC AR5 2013). Additionally, there is also an increased difficulty of salvage in the event of an incident as these vessels are larger than their previous counterparts, carry larger amounts of fuel, and have more cargo to be safely removed (Allianz 2015, Schuenemann 2015, Tsaviliris 2012).

Mega-containerships and other large vessels increase the complexity of salvage operations. There is more cargo to be removed, including hazardous cargoes, and more fuel to remove. In addition, sheer vessel size increases difficulties in refloating or removing the vessel. For example, possessing a crane with sufficient lift capacity (Schuenemann 2015, Tsaviliris 2012).

Salvors in general have a large amount of expertise, however, with the increasingly larger vessels such as the mega-containerships that have emerged onto the market, there is a limit to the amount of expertise that is available (Tsaviliris 2012). In general, there is a lack of investment in

new technologies and equipment as well as a lack of equipment kept on standby in case of a needed salvage operation (Lloyd's Challenges 2013, Tsavlis 2012). When there is a lack of salvage equipment kept on-hand, and the equipment that does exist might not be located near a vessel casualty, transporting equipment to the area could delay salvage operations (Lloyd's Challenges 2013, Schuenemann 2015, Tsavlis 2012).

Contingency planning and joint training between salvors and response agencies can help to overcome limitations in expertise and experience. Cataloging equipment inventories at local, regional, national, and international levels can help response teams combat the lack of expertise that they may have with a specific vessel size or geographical location (Lloyd's Challenges 2013, Schuenemann 2015, Tsavlis 2012).

Bulk carriers, and more specifically VLOCs, increase both the probability and consequence of risk. The change in probability is due to the dry-bulk market being on a downward trend and vessel operators of VLOCs being more willing to transport inherently risky cargo. This is further compounded by climate change impacts with expected increase of rain events and storminess on the sea. The change in consequence is due to potential quantity of fuel oil and hazardous cargo that VLOCs transport as well as the possibility of the loss of the lives onboard the vessel (UNCTAD 2014, Joint Hull 2012).

The risks that LNG carriers present are a bit more difficult to discern due to a lack of LNG carrier incidents that have occurred to date. However, as LNG transport continues to increase, routes and traffic will also increase, creating an increase in the probability of an LNG carrier incident. The consequences associated with an LNG carrier incident are not fully understood and should continue to be monitored as this trade increases (Lloyd's Marine Trends 2013, Hightower et al. 2004, Vanem et al. 2008).

The increased placement of FPSOs changes both the probability and consequence of an incident. For example, there could be an increased frequency of allisions/collisions with the shuttle tankers that offload these vessels or other vessels navigating in areas where these units are deployed (McCaul 2014, Mahoney 2012) Their placement further into the North Sea and eventually into the Arctic brings shifting routes and in the case of a needed salvage operation, and increased salvage difficulty due to the harsh Arctic environment (Li 2012, Yu 2008).



**Table 27: Vessel-Development Pressures Across Examined Time Frames**

Summary of the implications of the mega-containership, bulk carrier, LNG carrier, and FPSO pressures across the 0–5, 5–10, and the 10–20+ year time frames.

<i>Pressure</i>	<i>0–5 Year Time Frame</i>	<i>5–10 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<b>Mega-Containership</b>	Increased technologies, coupled with required port developments, increases the possibility of human error. Increased vessel size increases difficulty of salvage.	Further increases in vessel size increases difficulty of salvage.	Vessels will eventually reach the maximum size possible.
<b>Bulk Carrier/VLOCs</b>	Larger bulk carriers transporting hazardous cargo increases likelihood of a liquefaction event leading to sinking, pollution event, and loss of life.	Further risk will depend on regulations and policies.	Further risk will depend on regulations and policies.
<b>LNG Carrier</b>	There is a lack of experience with an LNG carrier spill incident and what the potential implications could be. High degree of uncertainty surrounding implications.	Further increase in the exporting/importing of LNG. This will require training for safe handling and port adaptations. This also leads to further congestion of LNG carriers traversing the seas.	Further increase in the exporting/importing of LNG. This will require training for safe handling and port adaptations. This also leads to further congestion of LNG carriers traversing the seas.
<b>Floating Production Storage and Offloading vessels (FPSOs)</b>	Further placement of FPSOs increasing the possibility of potential allision/collision with shuttle tankers.	Further placement of FPSOs in the Arctic will require the capacity and ability to reach these units at all times of the year in case of a spill or required maintenance.	Further placement of FPSOs in the Arctic will require the capacity and ability to reach these units at all times of the year in case of a spill or required maintenance.

**Table 28: Vessel Developments Implications**

Pressures associated with ship developments with a breakdown of the Causes (Permissive/Triggering) and Changes in Probability/Consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage (IDS). Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL).

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>Mega-Containers</b>	X			X	LA (fuel and cargo), IDS	Incident types remain the same	Human error is a continuing concern. Ports also need to adapt infrastructure. Larger amounts of fuel and cargo carried increase the consequences of a pollution incident. Some experts believe in increasingly stormy seas, vessels could be subject to more frequent damage.
<b>Bulk Carriers/ VLOCs</b>	X		X	X	IFI	Incident types remain the same	Potential consequence increase with both hazardous cargoes and large amounts of fuel.
<b>LNG Carriers</b>	X		X		NC	F/E	Fire/Explosion is of concern, although the extent to what an

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
							incident could mean is not fully understood.
<b>FPSO</b>	X		X	X	IFI, SR, IDS	ED/F	Placement in the Arctic requires “winterized” equipment. If not properly winterized, there could be equipment failure. Allisions/Collisions with shuttle tankers may increase with increased placement.

## 5.3. Vessel Automation

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### 5.3.1. Crew Fatigue

Human error is one of the leading causes of marine casualties (Butt et al. 2012, Corovic and Djurovic 2013, Ugurlu et al. 2013). A review of the IMO guidelines on fatigue was initiated in 2015 in recognition of the connection between crew fatigue and human error in ship casualties (IMO, 2015). Vessel size, minimum crew standards, trade patterns, and short port calls can all contribute to crew fatigue (Grech 2016).

In January 2015, amendments to the International Safety Management Code (ISM Code) were made regarding safe manning levels of vessel operation. The amendment requires that vessels be operated with higher crew numbers than the “minimum safe manning document” and the responsibility of this requirement has been placed on the owner of the vessel (Allianz 2015, IMO<sup>b</sup> 2016). Although these amendments have been introduced and port state controls have been enforcing stricter policies, the problem of vessels operating with minimally manned crews is still prevalent (Allianz 2015). Fatigue combined with adverse conditions (permissive risk) increases the likelihood of a mistake caused by human error contributing to an incident (Allianz 2015, Veysey 2013).

Believed to be partially due to economic factors, there is a lack of direct, practical crew training occurring and most training for some vessels is being completed using simulators. Although simulators can be useful, without direct training, there is a lack of rapid decision-making learned as well as other possible key skills missed (Hindley 2015, Veysey 2013). Human error and equipment failure are two of the leading causes of marine casualties. The lack of direct training coupled with possible equipment damage/failure increases the risk of human error (Veysey 2013). Training crews helps mitigate risks and if training is inadequate, incidents will occur that would normally be avoided with proper training. In the future of increasing bridge automation, direct training will remain imperative for developing the ability to make crucial decisions without the aid of technology, if necessary, and to mitigate risks (Hindley 2015).

Although it is true that in many cases automation reduces risk, crews still need to maintain manual navigation capabilities and skills. (Allianz 2015). The Arctic is an excellent example of

where additional technology is a necessity for safe and reliable operations, but this can sometimes provide a false sense of security and it is important that crewmembers still be trained not only on how to operate the equipment, but also how to make crucial decisions without the equipment (Hindley 2015, Veysey 2013).

### 5.3.2. Vessel Automation and Cybersecurity

The automation of vessels and their operation, including the potential for fully autonomous operation creates the potential for a range of risks to emerge (Lloyds 2016<sup>a</sup>, Lloyds 2016<sup>b</sup>). One risk of concern emerging from the further implementation of bridge and vessel automation is compromised cybersecurity and the possibility of a cyber-attack. This is where the vessel's technology is intentionally compromised and the vessel is forced into an incident that could lead to a spill or loss of life. Plans for increasing automated vessels create opportunities for compromising vessel operations if the proper cybersecurity measures are not implemented. Current vessel operators are not fully prepared for a breach in cybersecurity and regulators will need to play an integral role in further cybersecurity protection (Lloyd's Technology 2015). Cyber protection and scenario simulations need to be provided to further mitigate the risk of a cyber-attack (Allianz 2015, Lloyd's Technology 2015).

With bridge and vessel automation forecasted to increase in the future, vessels will become even more complex and the potential lack of technical skills among crew members will need to be addressed. It is forecasted that 10% of vessels being built in the year 2030 will be "smart ships," or vessels that operate mostly on their own without the constant need of human-computer interaction (Lloyd's Technology 2015). Although the idea of this technology is to make shipping even safer, the two mitigating actions of further crew training and increased cybersecurity will need to continue to be implemented to further lessen risks. Compromised cybersecurity prompts the emerging risk category of "new incident triggers" because of the potential for unintended consequences occurring as these technologies come into use. The IMO through the Facilitation and Maritime Safety Committees and the U.S. Coast Guard (Office of the Federal Register, 2015) are developing cybersecurity standards for vessels to help mitigate these risks.

### 5.3.3. Vessel Automation Implications

Vessel automation manifests its potential risks mostly in the 10–20+ year time frame, although some of its risks are occurring today as evidenced in Table 29. While crew fatigue and bridge automation are risks on their own today, the combination of these two pressures lead to the greatest concern in present day. For example, if a vessel is being operating by a “minimally-manned crew,” it is possible that the members of the crew are not meeting required rest hours, introducing fatigue (Allianz 2015, Veysey 2013). In a situation where a fatigued crewmember is operating automated equipment on the bridge, human error can be introduced. If that piece of equipment being operated also fails, the fatigued crewmember must rely solely on their technical skills. To reduce the implications that these two pressures present, regulatory organizations such as the IMO will need to continue to regulate crew fatigue and vessel owners will need to provide the in depth hands-on training required for bridge automation (Grech 2016, Allianz 2015, Hindley 2015, Veysey 2013). Compromised cybersecurity, although not currently a significant risk today, will become a major concern in the future if the proper mitigation measures, such as increased cybersecurity, are not introduced before vessels become further automated (Allianz 2015, Lloyd’s Technology 2015).

Table 30 identifies pressure as either permissive or triggering causes, if the incidents that result from each pressure are changing in probability and/or consequence, and the incident consequences and incident types associated with each pressure.

Compromised cybersecurity creates a triggering cause that can lead to a change in both the probability and consequence of an incident. Deficiencies in current vessel cybersecurity increase the probability of a compromised cybersecurity incident as vessel automation increases (Allianz 2015, Hindley 2015).

Crew fatigue and vessel automation are both permissive causes that result in a change in probability. Although vessel automation is ultimately meant to make vessel operations safer, when combined with a fatigued crew, the possibility of an incident occurring due to human error is increased (Allianz 2015, Veysey 2013). Crew training and improved cybersecurity are important factors in mitigating risks associated with automation. Without the proper crew training, there is a lack of technical skills and a false sense of security with vessel technology, increasing the probability of an incident occurring from human error (Grech 2016, Hindley 2015, Veysey 2013). Crew fatigue, vessel automation, and cybersecurity pressures all present the consequences of new incident triggers due to their susceptibility to human error.

**Table 29: Vessel Automation Pressures Across Examined Time Frames**

Summary of the implications of the Crew Size, Vessel Automation and Compromised Cybersecurity pressures across the 0–5, 5–10, and 10–20+ year time frames.

<i>Pressure</i>	<i>0–5 Year Time Frame</i>	<i>5–10 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<b>Crew Fatigue</b>	Fatigue and fatigue management, compounded by adverse weather contribute to vessel incidents.	Further risk will depend on regulations and policies.	Further risk will depend on regulations and policies.
<b>Vessel Automation</b>	Further increase in technologies on ships causing heavy reliance on electronics, potentially changing the nature of human error risks.	Further increase in technologies on ships will require training and risk mitigation measures.	Further increase in technologies on ships will require training and risk mitigation measures.
<b>Cybersecurity</b>	Potential for problems to become more prevalent as adoption increases in the future.	Will become a risk as ships are further automated and cyber hacking becomes more prominent.	Future plans for unmanned ships provide for more opportunities of vessel hacking if the proper cybersecurity measures are not taken.



**Table 30: Vessel Automation Implications**

Pressures associated with Crew Fatigue and Automation with a breakdown of the Causes (Permissive/Triggering) and Changes in Probability/Consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage (IDS). Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL).

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>Vessel Automation and Crewing</b>	X		X	X	NIT	All incidents are possible due to human error.	Human error from fatigued crew is the main concern. A false sense of security from automation potentially contributing to incidents. If equipment is damaged or fails, crew may not be able to manually operate due to a lack of direct, practical training.
<b>Cyber-security</b>		X	X		NIT	ED/F	Increased cyber technology on vessels increases concern of cyber hack or attack, initiating an incident.

## 5.4. New Propulsion Fuels

An emerging area of vessel operations involves changes in propulsion fuels. Lloyd's Register (2013) has used the technique of scenarios to explore the possibilities of future fuel adoption, which allows for a broader consideration of fuels. Lloyds considered three scenarios for exploring future marine fuel trends are Status Quo, Global Commons, and Competing Nations. These scenarios were applied to the different propulsion fuels being considered for vessel operations in the 10–20+ year time frame.

### 5.4.1. LNG

The conclusions made by Lloyd's Register concerning the adoption of LNG as a propulsion fuel under the three different scenarios are shown in Table 31. Heavy fuel oil (HFO) is widely used under each scenario. LNG adoption is highest in the Global Commons scenario due to stricter carbon policies.

**Table 31: LNG Adoption Under Three Different Scenarios**

Three scenarios for the adoption of LNG by 2030. In the global commons scenario, the highest adoption of LNG is seen due to stricter carbon policies.

2030 Scenario	Result of LNG Adoption
<i>Status Quo</i>	HFO is still heavily used; Smaller bulk carriers/chemical tankers adopt LNG the most due to their lower capital costs for LNG adaption. Containerships see lowest percent of uptake due to having a new fleet as well as a focus on having fewer, larger ships.
<i>Global Commons</i>	HFO still used, but offset more by LNG. LNG is still adopted the most by bulk carriers/chemical tankers, although it is not limited to smaller sizes. Changes are due to stricter carbon policies.
<i>Competing Nations</i>	Lowest adoption of LNG. HFO remains most cost effective option for most ships.

(Adapted from Lloyd's Register Global Marine Fuel Trends 2030)

The concerns associated with LNG as a propulsion fuel are similar to those of LNG as a cargo. LNG is a more greenhouse gas efficient fuel than HFO, but the concerns of fire and explosion are still present, making it primarily a safety concern as opposed to an environmental concern (Hightower et al. 2004, Vanem et al. 2008). The IMO adopted the International Code of Safety

for Ships using Gases or other Low-flashpoint Fuels<sup>13</sup> (IGF Code) in June 2015, which mandates requirements for the installation and monitoring of systems that are using low-flashpoint fuels. This code focuses mainly on LNG in order to minimize risks to the marine transportation system and the environment (Allianz 2015 pp 15, IMO<sup>c</sup> 2016). Additionally, the United States Coast Guard has developed a policy letter entitled “Equivalency Determination – Design Criteria for Natural Gas Fuel Systems”<sup>14</sup> in which design criteria for natural gas fuel systems, including LNG, are established in order to “provide a level of safety that is at least equivalent to that provided for traditional fuel systems by existing regulations” (USCG Policy 2016). Most LNG propelled vessels are dual-fueled and so although there is not much of an environmental concern surrounding a spill of LNG, there is an environmental concern surrounding the spill of the other fuel, which is usually diesel fuel (DNV<sup>a</sup> 2015).

The likelihood of adoption of LNG as a propulsion fuel depends on its future market price, possible changing global policies including emission control regulations, and the vessel and port adaptations that will be required to utilize LNG fuel (Lloyd’s Fuel 2014). With increased uptake of LNG as a propulsion method, the vessel crews and port crews will also require training for the safe handling and transport of the fuel, which may introduce new incident causes or incidents occurring in new places (Lloyd’s Technology 2015). As both an emerging and changing fuel, the probability of an incident occurring will rise as LNG becomes more widely adopted as a propulsion method. This is especially important to consider with respect to shore side infrastructure and fueling operations (DNV 2014). Many ships will use LNG in conjunction with fuel oil during voyages, which will require handling of both fuels in ports and while underway. The consequence of an LNG fuel incident increases due to the high degree of uncertainty of the conditions of an incident. Since LNG can be considered an emerging risk, it falls into the “new fuels” emerging risk consequence. Ports will need to carefully consider safety and security of LNG operations including inland, shore side, and on water operations (DNV 2014).

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<sup>13</sup> For more information on the IGF Code, please visit [www.imo.org/en/MediaCentre/PressBriefings/Pages/26-MS-C-95-ENDS.aspx](http://www.imo.org/en/MediaCentre/PressBriefings/Pages/26-MS-C-95-ENDS.aspx)

<sup>14</sup> For more information of the Equivalency Determination – Design Criteria for Natural Gas Fuel Systems, please see [www.uscg.mil/hq/cg5/lgcncoe/designLNGfuel.asp](http://www.uscg.mil/hq/cg5/lgcncoe/designLNGfuel.asp)

## 5.4.2. Alternative Propulsion Fuels

In addition to HFO and LNG, Lloyd’s Register has investigated the use of four other alternative fuels in the future including:

- Marine Diesel Oil/Marine Gas Oil (MDO/MGO)
- Low Sulphur Heavy Fuel Oil (LSHFO)
- Methanol
- Hydrogen

These alternative fuels were evaluated with the same three scenarios used in Section 5.4.1, the results are shown in .

**Table 32: Alternative Propulsion Fuel Adoption Under Different Three Scenarios**

Three scenarios of the adoption of alternative propulsion fuels other than LNG in 2030. MDO/MGO alongside HFO remains the most widely used fuels in all three scenarios. Global commons scenario results in considerable adoption of hydrogen, which could increase potential risks from this propulsion fuel.

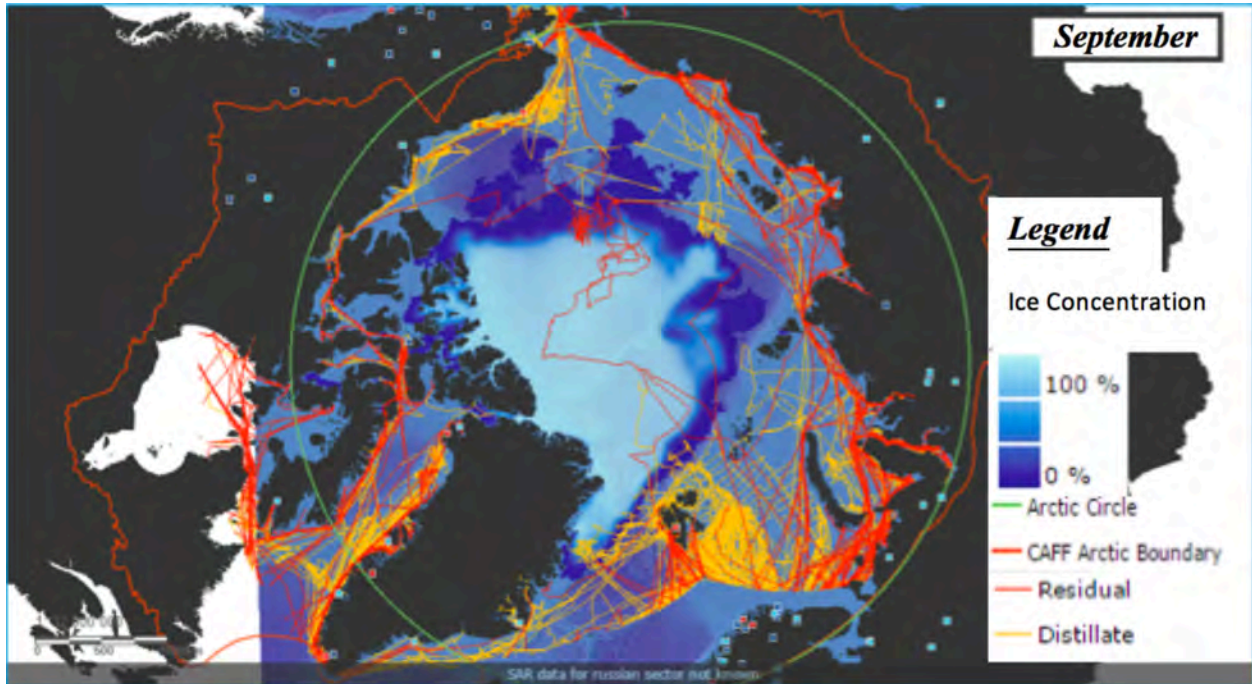
2030 Scenario	MDO/MGO	LSHFO	Methanol	Hydrogen
<b>Status Quo</b>	Older tonnage (a large proportion of the current fleet) will rely on this fuel coupled with HFO.	Will slowly increase in use between 2020 and 2025, resulting in a large proportion in 2030. Mostly in containerships.	No significant uptake.	No significant uptake.
<b>Global Commons</b>	Primarily used for smaller ships and remains rather consistent from 2010 to 2030.	No significant uptake due to higher cost. More cost efficient to use scrubbers.	No significant uptake.	Considerable uptake across all ships beginning in 2025; Continues to offset the use of HFO paired with LNG.
<b>Competing Nations</b>	Slowly begins to replace HFO, but less so than in the status quo.	Enters after 2025 and is paired with MDO/MGO and slowly begins decreasing HFO reliance.	No significant uptake.	No significant uptake.

(Adapted from Lloyd’s Register Global Marine Fuel Trends 2030)

According to Lloyd's, aside from HFO, MDO/MGO is used most across all three scenarios. The only difference is in the Global Commons scenario where hydrogen would have a significant uptake. Apart from the increased usage of LNG and the possible introduction of hydrogen as a fuel, liquid fuel usage will remain similar under future scenarios as it is used today, however, the number of vessels that use liquid fuel may fluctuate. For example, the reliance on HFO may decrease and there may be an increase in the reliance on MDO/MGO.

While the risks of LNG as propulsion fuel should be considered further, the risks of hydrogen as a propulsion fuel may need to begin to be considered depending on how global carbon policies may change in the 10–20+ year time frame. The likelihood of adoption of these fuels depend on their future market prices, possible changing global policies, as well as the ship adaptations that need to be made to utilize propulsion fuels other than HFO (Lloyd's Fuel 2014).

Another factor that may affect the uptake of alternate propulsion fuels is concern about black carbon pollution from vessels, which could result in emission control areas (ECA). ECAs could specifically affect propulsion fuel requirements for Arctic vessel operations, because the mandate would cause a shift from residual fuels such as HFO towards “cleaner” propulsions such as distillates or LNG (Transportation Research Board 2016, Lloyd's Technology 2015). Figure 22 maps the location of residual fuel and distillates being used in September 2011, throughout the Arctic. Figure 22 also shows that the amount of distillates being used is already comparable to the amount of residual fuel being used.



**Figure 22: Residual and Distillate Fuel Used Throughout Arctic in September 2011**

This map shows the usage between residual and distillate fuels throughout the Arctic in September 2011. Residuals are shown with the thin, red lines, while distillates are shown with the thin, yellow lines.

(Generated using DNV Arctic Risk Map 2015<sup>b</sup>)

As both emerging and changing fuels, the consequence of an alternative fuel incident could increase due to the high degree of uncertainty surrounding the impacts of an incident and there may be unrealized response gaps associated with potential fuels such as hydrogen. Since these alternative fuels can be considered emerging risks of the future, they fall into the “new fuels” emerging risk consequence.

### 5.4.3. Implications

New propulsion fuels manifest their potential risks mostly in the 10–20+ year time frame. LNG is not widely used today as a propulsion fuel, and therefore there is uncertainty surrounding the probability and consequences of an event. As LNG propulsion fuel becomes more adopted, infrastructure should be updated. Training for the safe handling and transport of the fuel will also need to be further introduced to crews and ports to mitigate the possible risks. Alternative fuels adoption rates will depend on the costs and the market prices, emissions regulations coming into force, as well as future global carbon policies. As adoption increases it will be necessary to

monitor risks to determine the implications of their use (Lloyd's Fuel 2014, Lloyd's Technology 2015).

Table 33 is a summary of the implications of the LNG propulsion fuel and alternative propulsion fuels pressures across the 0–5, 5–10, and the 10–20+ year time frames. Table 34 identifies each new propulsion fuel pressure as either permissive or triggering causes, if the incidents that result from each pressure are changing in probability and/or consequence, and finally the incident consequences and incident types associated with each pressure. The adoption of alternative propulsion fuels might change the consequence of incidents. The consequence of an incident involving one of these new propulsion fuels changes due to the lack of experience with these fuels. Training in safe handling and transport of these fuels could mitigate future risks. Response gaps could emerge if these fuels require new equipment or measures for containment and cleanup. The adoption of these fuels ultimately depends on a variety of factors including future market prices of the fuels, the required vessel modifications needed to utilize these propulsion fuels, and global carbon policies that may be adopted in the future (Lloyd's Fuel 2014, Lloyd's Technology 2015).

**Table 33: New Propulsion Fuel Pressures Across Examined Time Frames**

Summary of the implications of the LNG Propulsion Fuel and Alternative Propulsion Fuels pressures across the 0–5, 5–10, and the 10–20+ year time frames. Human error proves to be a continuous concern well into the future as technologies increase. There is an increased difficulty of salvage due to the size of mega-containerships as well as the amount of fuel and cargo they carry. LNG as both a cargo and a propulsion fuel will require safe handling training as well as proper port adaptations as LNG becomes more widely used as well as increases as a cargo. A lack of experience with a major spill of LNG brings about concerns over what the potential implications could be.

<i>Pressure</i>	<i>0–5 Year Time Frame</i>	<i>5–10 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<b>LNG Propulsion</b>	Lack of experience with an LNG fuel incident and what its implications could be. Interaction between fuel oil and LNG bunkering activities.	Greater uptake of LNG as propulsion fuel further emphasizes the lack of experience with an LNG fuel incident and what its implications could be.	Further uptake of LNG as propulsion fuel depends on global carbon policies and economics.
<b>Alternative Propulsion</b>	Not yet a risk.	Not yet a risk.	Uptake of alternative fuels will depend on global carbon policies and economics.



**Table 34: New Propulsion Fuels implications**

Pressures associated with new propulsion fuel with a breakdown of the Causes (Permissive/Triggering) and Changes in Probability/Consequence of each pressure. The pressures are then further partitioned to examine the Emerging Risk Incident Consequences (noted in table as Incident Consequences) and the Incident Types (noted in table as Incident Types) associated with each. Emerging Risk Consequences: Increased Frequency of Incidents (IFI), Shifting Routes (SR), New Cargoes/New Fuels (NC/NF), Larger Amounts (LA), New Incident Triggers (NIT), Increased Difficulty of Salvage (IDS). Incident Types: Allision (A), Collision (C), Grounding (G), Foundering (F), Hull Damage/Failure (HD/F), Equipment Damage/Failure (ED/F), Fire/Explosion (F/E), Instability/Sinking (I/S), Cargo Loss (CL).

<i>Pressure</i>	<i>Permissive Cause</i>	<i>Triggering Cause</i>	<i>Change in Probability</i>	<i>Change in Consequence</i>	<i>Incident Consequences</i>	<i>Incident Types</i>	<i>Clarifying Notes</i>
<b>LNG Propulsion Fuel</b>		X	X	X	NF	F/E	Probability of incident will rise as fuel becomes more widely adopted. Fire/Explosion are concerns although the extent of what an incident could mean is not fully understood
<b>Alternative Propulsion Fuels</b>		X		X	NF	F/E	Fire/Explosion are concerns, although the extent of what an incident could mean is not fully understood. Response gaps may be associated with potential fuels such as hydrogen.

## 6. CHALLENGES OF RESPONSE IN THE ARCTIC

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A projected increase in Arctic-shipping traffic over the coming years poses the potential for new risks of pollution incidents. Many organizations are working to analyze these risks, reports from seven of these organizations are reviewed in Table 35. In *Responding to Oil Spills in the U.S. Arctic Marine Environment* (Ocean Studies Board 2014), U.S. organizations collaborated to identify challenges and provide recommendations for future responses to oil spills in the Arctic (see Table 35 for a summary of work on the subject). Additional organizations and groups are also working to identify gaps of pollution response in the Arctic. The Arctic Council's Emergency Prevention, Preparedness and Response Working Group (EPPR) is working to exchange information on best practices, as well as conducting risk assessments and training. Most recently, the EPPR has been conducting an oil spill response viability analysis for the Arctic. This analysis aims to identify how various response operations may take place in the Arctic as well as identifies any remaining response gaps (DNV 2015<sup>c</sup>). Other efforts led by the Arctic Council include: the Arctic Contaminants Action Program (ACAP), the Arctic Monitoring and Assessment Programme (AMAP), the Protection of the Arctic Marine Environment Working Group (PAME), and the Sustainable Development Working Group (SDWG)<sup>15</sup>. Each of these groups within the Arctic Council focuses on specific details surrounding the navigation in and the protection of the Arctic region (Arctic Council 2015). These efforts should be followed closely for future information regarding challenges of pollution response in the Arctic.

A major challenge facing pollution response in the Arctic is the lack of infrastructure for incidents. Given the current infrastructure, it is highly unlikely that response teams could arrive at the site of a pollution incident in time to prevent serious consequences (Congressional Research Services, Ocean Studies Board 2014). As shipping expands, the complexity of ice conditions at the end or beginning of a season has the potential to make follow up rescue and response very difficult and limited. Figure 23 shows the current search and rescue coordination areas in the eastern section of the Northern Sea Route. The Russian Federal Institution oversees this area, with a goal to ensure ship safety and environmental protection in the Northern Sea Route (Hansen et al. 2016).

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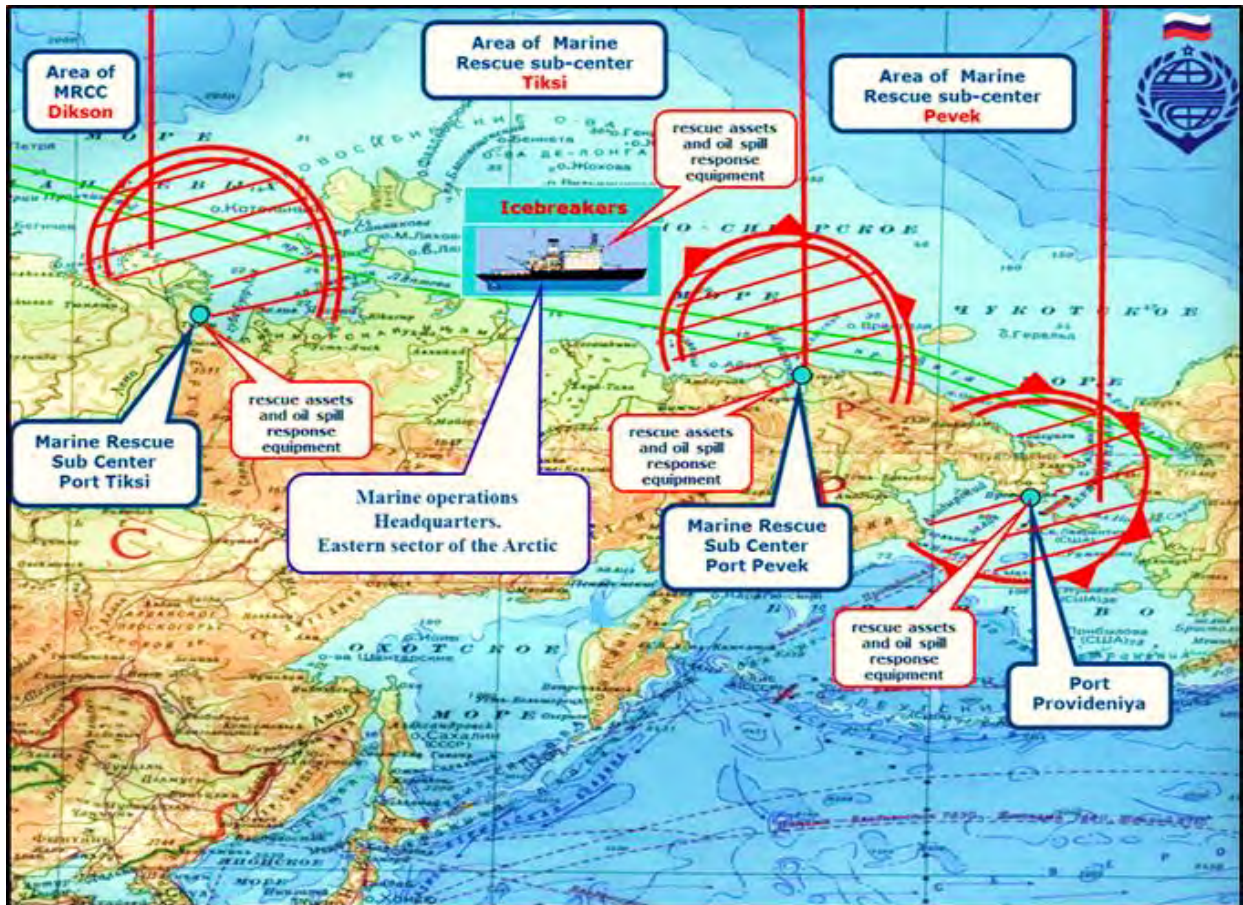
<sup>15</sup> For more information on any of these programs and working groups, please visit <http://www.arctic-council.org/index.php/en/about-us/working-groups>

**Table 35: Reports Reviewed and the Identified Challenges to Pollution Response in the Arctic**

Reports reviewed for this report and the challenges to pollution response in the Arctic identified by each. Lack of infrastructure, international collaboration, and better equipped response organizations rank as the most-identified challenges.

	Lack of Infrastructure	Inclusion of Local Knowledge	International Collaboration	Better Equipped Response Organizations
<b>Responding to Oil Spills in the U.S. Arctic Marine Environment</b>	X	X	X	X
<b>Arctic Shipping – Commercial Opportunities &amp; Challenges</b>	X		X	
<b>Lloyd’s Register Challenges &amp; Implications of Removing Shipwrecks in the 21<sup>st</sup> century</b>				X
<b>Report to Congress on Changes in the Arctic 2015</b>	X		X	X
<b>Arctic Council Agreement on Cooperation on Marine Oil Pollution Preparedness &amp; Responses in the Arctic</b>		X	X	X
<b>PEW Arctic Standards: Recommendations on Oil Spill Prevention, Response, and Safety</b>	X			X
<b>Arctic Marine Shipping Assessment 2009 Report</b>	X	X	X	X

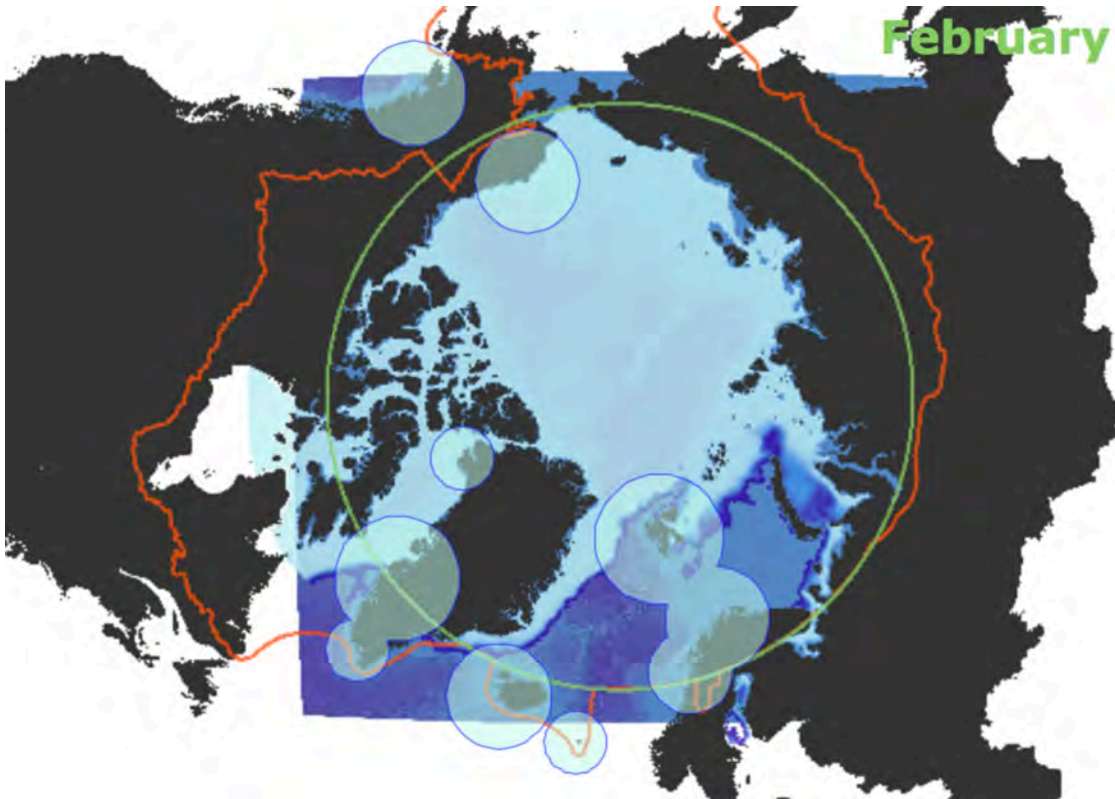
Figure 24 shows the helicopter response range of the Arctic during the month of February, when ice coverage is at its greatest. It is evident from this figure that response ranges are limited and significant gaps exist. Investments will need to be made in order to provide the necessary infrastructure and personnel for a pollution incident in many areas of the Arctic, as Russia has already attempted to provide in the eastern section of the Northern Sea Route (Arctic Council 2009, Ocean Studies Board 2014).



**Figure 23: Search and Rescue Coordination Areas in the Eastern Section of the NSR**

Available rescue locations in the Eastern Section of NSR, includes only Russian response locations and shows three available ports as well as the Marine Operations Headquarters.

(Hansen et al. 2016 sourced from Gosmorspassluzhba 2013)



**Figure 24: Helicopter Rescue Range across the Arctic in February**

This map shows the range that helicopters are able to travel for rescue operations in the Arctic in February. This map does not include data from Russian Intelligence, but this information can be compared to Figure 23 for the Russian rescue operations.

(Generated using DNV Arctic Risk Map 2015<sup>b</sup>)

It is important to include local Arctic communities' knowledge to ensure that all relevant environmental information is addressed in developing contingency plans. Many local communities depend on Arctic marine resources as well as feel a cultural connection to the environment. Local communities have knowledge of areas that could be affected more than others as well as how to safely navigate to an incident area. The community might also be directly affected by an incident, which provides further reason to incorporate their knowledge and thoughts into preparedness and response plans (Arctic Council 2013, Arctic Council 2009, Ocean Studies Board 2014). The Arctic Waterway Safety Committee is one example where local knowledge has been incorporated in planning activities. This Committee was developed to include local marine knowledge and interests of the Alaskan Arctic to provide safe and efficient transportation for all waterway users in the Committee's area of responsibility (USCG 2015).

Local Arctic community knowledge will need to be incorporated in order to provide effective contingency plans (Arctic Council 2013, Arctic Council 2009, Ocean Studies Board 2014).

Strong collaboration programs and joint contingency planning among the involved Arctic nations can help in identifying, mitigating, and responding to potential pollution incidents. (Arctic Council 2013, Arctic Council 2009, Congressional Research Services 2015, Hansen et al. 2016, Ocean Studies Board 2014). The EPPR established the Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic in 2013. It was signed by the eight member states of Arctic and its goal is to strengthen the collaboration and assistance of each of the parties in order to provide better preparedness and response to oil pollution in the Arctic (EPPR 2013). This agreement is an excellent step in joint planning among the Arctic nations and can serve as an example for future agreements among the nations.

National response organizations, including the military will need to be prepared for response in the Arctic. Jensen and Hønneland (2015), for example, recommend bilateral activities by the U.S. Navy and Coast Guard with Russia's Navy and Border Guard that would improve Arctic preparedness. Current equipment, personnel, training, navigation, and safety resources are not adequate for responding to a potential incident. Furthermore, because of conditions in the Arctic, existing equipment will have to be adapted for the extreme climate of the Arctic in order to function properly (Arctic Council 2013, Arctic Council 2009, Congressional Research Services 2015, Lloyd's Challenges 2013, Ocean Studies Board 2014). Table 36 provides an overview of environmental conditions within an arctic town in Alaska, U.S.A., highlighting the percentage of time in each season that no response would be possible (Pew 2013).

**Table 36: Response Limitations in Arctic Alaska**

The data presented in this table is for the towns of Barrow and Wainwright in Alaska, USA. It shows the percentage of time that response organizations would be unable to respond to an incident in the Arctic due to ice presence, darkness, wind, fog, and low temperatures. Spring and summer at this time seem to be the only time of the year that would possibly allow for a response, although there still may be issues with ice, darkness, wind, and/or fog.

	<i>Winter (Jan–Mar)</i>	<i>Spring (April–June)</i>	<i>Summer (July–Sept)</i>	<i>Fall (Oct–Dec)</i>
<b>Ice Cover (Percentage)</b>	Solid (100%)	Solid (80%) Broken Ice (20%)	Broken Ice (60%) Open Water (40%)	Open Water (20%), Broken Ice (60%), Solid (20%)
<b>Darkness</b>	81%	21%	13%	77%
<b>Wind</b>	22%	13%	21%	33%
<b>Fog</b>	57%	58%	48%	55%
<b>Temp. &lt;-37° C</b>	37%	0	0	4%

(Adapted from Pew Charitable Trusts 2013)

## 7. FINDINGS

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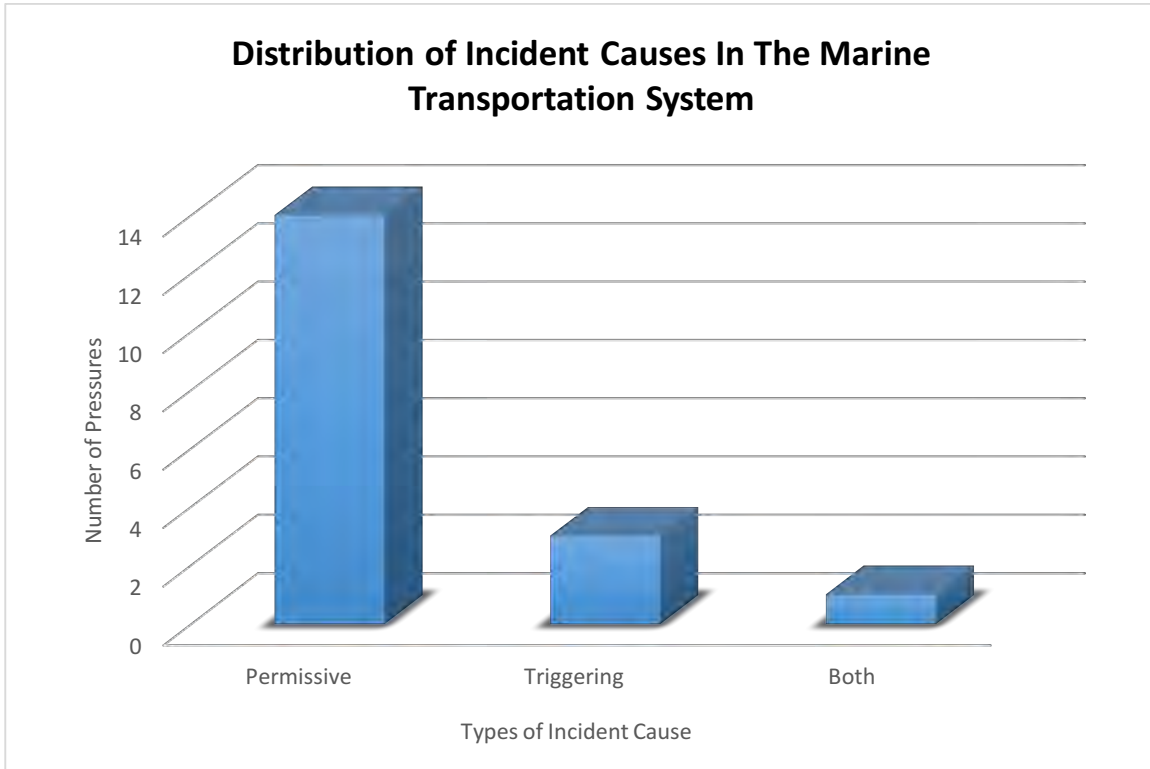
The preceding sections of this report identify a range of environmental, economic, and technological factors affect the marine transportation system. This section provides an analysis of the identified pressures to help spill preparedness and response organizations understand how to best prepare for efficient and effective response for this changing marine transportation system.

### 7.1. Results

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Permissive and triggering causes of risk differ in how they influence an incident. A permissive cause is the background or context that increases the likelihood that an incident will occur, whereas a triggering cause leads directly to an incident at a specific point in time (Mitchell 2010). Figure 25 shows the number of pressures that have the potential for creating permissive causes, triggering causes, or both (Columns 2 and 3 in Tables 11, 13, 22, 25, 28, 30, 34). From Figure 25 we see that permissive causes are by far the most abundant type. Three pressures have the potential to create triggering causes and one pressure has the potential to create both permissive and triggering causes. For triggering causes, mitigation strategies might already exist or be simpler to manage than broader, underlying permissive causes. For example, compromised cybersecurity can be addressed through enhanced computer communication systems. This would decrease the likelihood of a successful attack occurring on a vessel. Permissive causes, however, include the reality of a highly connected internet and the rise of a hacking culture worldwide, which is more difficult to address. Permissive causes are generally more complex. To cite another example, with the introduction of mega-containerships, larger amounts of fuel and cargo onboard could increase both the consequences of the resulting pollution as well as the difficulty of salvage in the event of an incident. This requires mitigation across the marine transportation system such as stronger hulls, highly trained crews, and appropriate salvage equipment and knowledge, among other strategies. Figure 25 is a summary of types of potential consequences that could stem from the emerging risks this report evaluates (Column 6 in Tables 11, 13, 22, 25, 28, 30, 34).

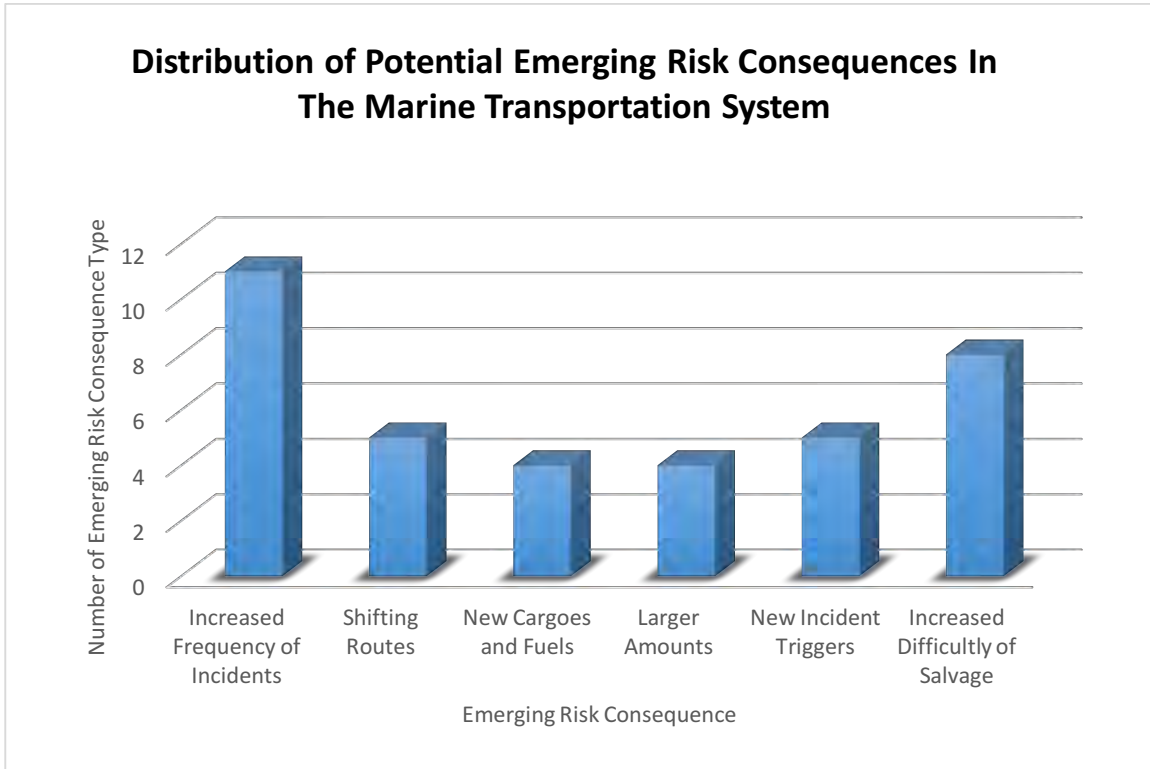




**Figure 25: Distribution of Types of Incident Causes in the Marine Transportation System**

Counts of permissive and triggering causes as well as causes that may be both permissive and triggering across all identified pressures. These causes were summed from Tables 11, 13, 22, 25, 28, 30, 34 in the Implications sections of the report.

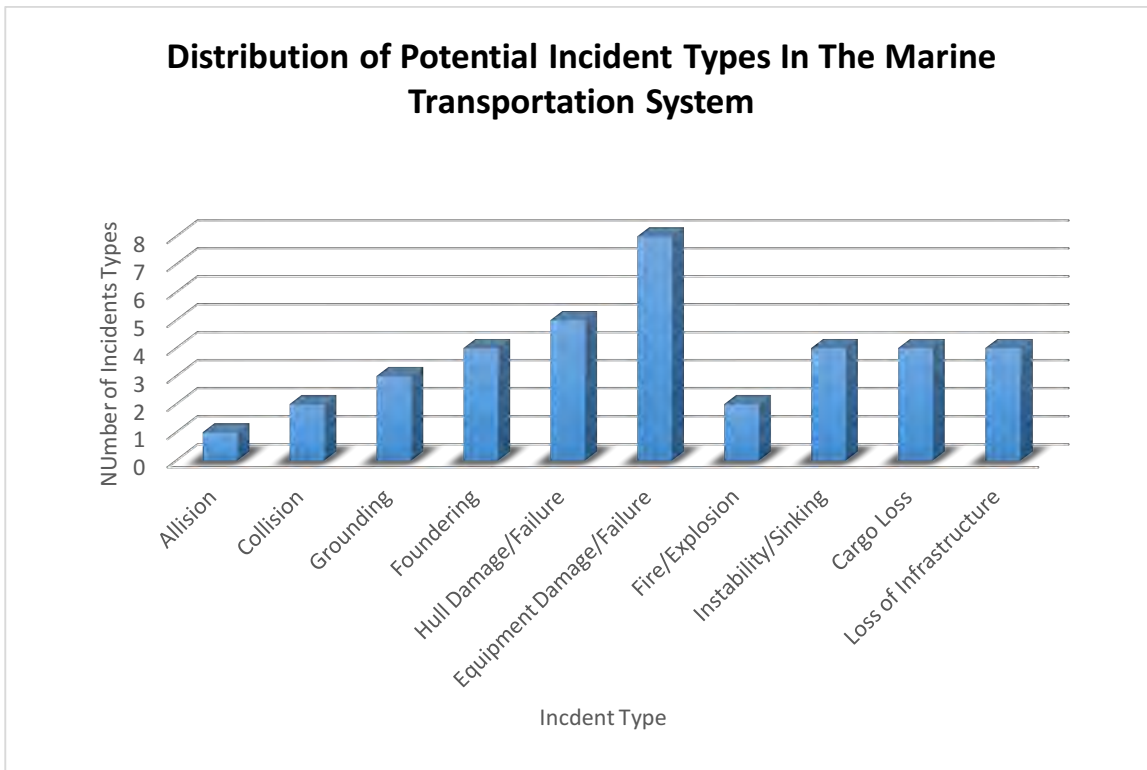
Figure 26 is a summary of the types and frequencies of potential emerging risk consequences that could result from pressures evaluated in this report (Column 6 in Tables 11, 13, 22, 25, 28, 30, 34). Increased frequency of incidents and increased difficulty of salvage are the two emerging risk consequences with the largest number of associated pressures. Increased frequency of incidents could, for example, emerge from greater congestion of vessels, perhaps in a chokepoint or in or around an expanded canal, or at a port following a major storm event that disrupted operations. Increased difficulty of salvage is pertinent because it arises in multiple pressures for all three drivers.



**Figure 26: Distribution of Potential Emerging Risk Consequences in the Marine Transportation System**

Counts of emerging risk consequences across all pressures considered in the report. These causes were summed from Tables 11, 13, 22, 25, 28, 30, 34 in the Implications sections of the report.
















Figure 27 describes the distribution of potential incident types across all pressures considered in the report (Column 7 in Tables 11, 13, 22, 25, 28, 30, 34). Equipment damage/failure is the most prevalent incident type, consistent with many authoritative sources.

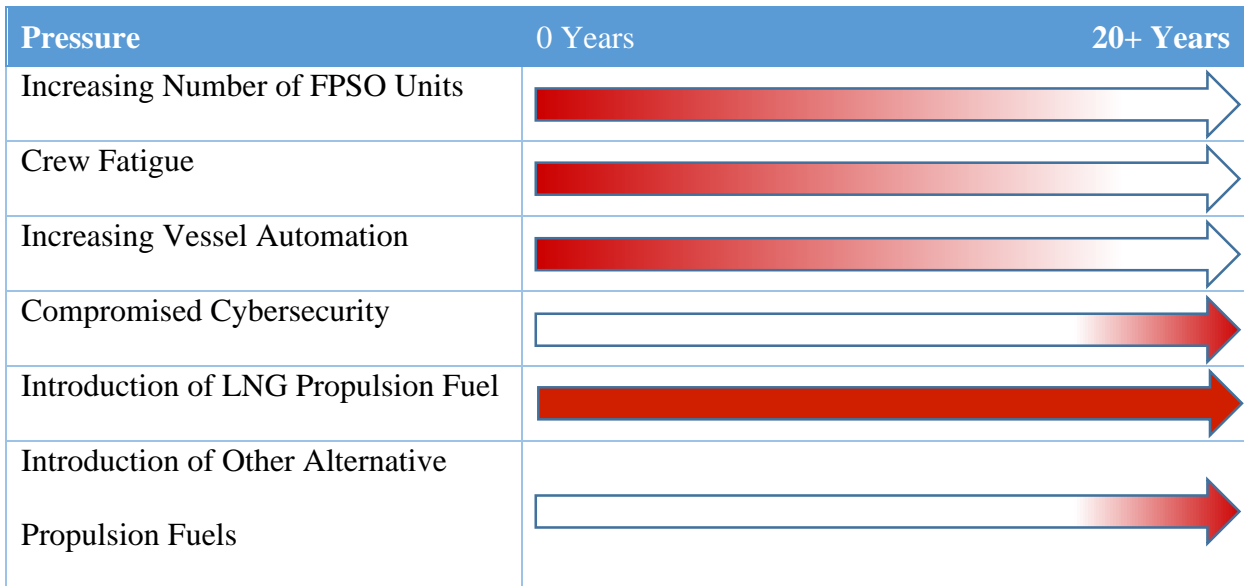


**Figure 27: Distribution of Potential Incident Types in the Marine Transportation System**

Counts of potential incident types across all pressures considered in the report. These causes were summed from Tables 11, 13, 22, 25, 28, 30, 34 in the Implications sections of the report.

Figure 28 considers all the pressures across the three drivers and designates their first appearance as a risk to the marine transportation system. The arrows represent time, while the color within the arrow conceptually represents the level of risk deriving from the associated pressure. In some cases, our research suggests that as the pressure moves further into the future, mitigation actions will decrease the associated risks indicated by the red color of the arrow fading into white. For example, that the pressure ‘Increasing Automation’ is to an extent present today is indicated with a solid red arrow. However, as time progresses, the arrow begins to fade in the 10–20+ year time frame. This is not because the pressure itself disappears, but rather because mitigation will continue to decrease the risks that vessel automation presents to the marine transportation system. In other cases, such as thawing permafrost, the risks presented do not begin to change from the baseline risk until further into the future and is indicated with white coloration in the present time and with red coloration as time progresses.

Pressure	0 Years	20+ Years
Increasing Intensity of Storms & Precipitation		
Changing Global Net Frequency of Storms		
Changing Global Net Frequency of Precipitation		
Poleward Shift of Storms		
Increased Rate of Sea Level Rise		
Melting Arctic Sea Ice		
Increasing Arctic Intensity of Storms & Precipitation		
Thawing Permafrost		
Expanded Panama Canal		
Expanded Suez Canal		
Increased use of Arctic Trade Routes		
Increased Export of North American Oil		
Introduction of Mega-Containership		
Increased Usage of Bulk Carriers to Transport Hazardous Material		
Increasing Use of LNG Carriers		



**Figure 28: Expected Evolution of Pressures Over Time**

Each arrow represents time, from present day to 20+ years, and the coloration within the arrows indicates the level of risk presented from each pressure. White within an arrow indicates that there is no change from the current baseline risk. This does not indicate that the risks resulting from the pressure are not present, but rather that there is little to no change from the current baseline risks. Red within an arrow indicates the potential for emerging risks to increase from the current baseline.

## 7.2. Materiality of Risks

This report’s evaluation of pressure on the marine transportation system considers the strength of evidence and uncertainty, and the degree that these two attributes help to determine the materiality of a risk. By assessing the strength of evidence for a risk’s existence as well as the uncertainty involved, it can be determined how “real” or material a risk is for the marine transportation system. Strength of evidence and uncertainty are based on the type, amount, quality, relevance, and consistency of the evidence documented in the literature (IPCC AR5 2013, Majchrzak and Markus 2014). Strength of evidence and uncertainty for this report were determined by the team based on three considerations: the triangulation or agreement of the data across multiple sources, convergence of the evidence, and scientific consensus. Triangulation of data is achieved through reliance on multiple sources that use different approaches, while convergence of evidence is achieved through agreement across multiple sources that use similar approaches. Finally, scientific consensus is developed out of the collective opinion and judgment of scientists or other experts in a field. Of these considerations, scientific consensus is the strongest, then convergence of evidence, and finally, triangulation of data.

This report follows the common practice of ranking strength of evidence based on whether available evidence is limited or robust (adapted from IPCC AR5 2013, Majchrzak and Markus 2014) (Table 37 and Table 38).

- *Limited Strength of Evidence* – Low number of available studies, sources generally of limited scope, and agreement among studies is inconsistent. Often involves trade press or sources that are journalistic in nature. Generally speaking, there are at best triangulation of data and information from multiple sources, more robust evidence is lacking.
- *Robust Strength of Evidence* – High number of available studies and full syntheses, sources consider a global scope, and there is agreement and consistency among studies. Of the three considerations, the robust category includes convergence of evidence and scientific consensus.

Uncertainties within the changing environment driver were assessed using IPCC AR5 likelihood and confidence terms given the highly authoritative nature of that source (Table 37). Uncertainty is categorized as high, medium, or low based on the following definitions:

- *Low Uncertainty* – High Confidence or Likelihood of the Outcome  $\geq 90\%$
- *Medium Uncertainty* – Medium Confidence or  $33\% > \text{Likelihood of the Outcome} < 90\%$
- *High Uncertainty* – Low Confidence or Likelihood of the Outcome  $\leq 33\%$

**Table 37: Strength of Evidence & Quantitative Uncertainty of the Environment**

Individual pressures were assessed based on the on the type, amount, quality, and consistency of the evidence documented in the literature (IPCC AR5 2013, Majchrzak and Markus 2014). Pressure uncertainty was assessed as high, medium, or low uncertainty based on IPCC AR5 (2013) assessments.

<i>Pressures</i>	<i>Strength of Evidence</i>	<i>Uncertainty</i>	<i>Notes</i>
Increasing Intensity of Storms Events	Robust	Medium to Low	50–100% probability in the northwestern Pacific and northern Atlantic Oceans.
Increasing Intensity of Precipitation Events	Robust	Medium to Low	66–100% probability

<i>Pressures</i>	<i>Strength of Evidence</i>	<i>Uncertainty</i>	<i>Notes</i>
Increasing Global Net Frequency of Storms Events	Robust	High	Although Low Uncertainty in the northern Atlantic Ocean
Increasing Global Net Frequency of Precipitation Events	Robust	Medium to Low	66–100% probability over many regions
Poleward Shift of Storm Events	Robust	Medium to Low	66–100% probability with more robust evidence in the Northern Hemisphere than the Southern Hemisphere
Increased Rate of Sea Level Rise	Robust	Low	
Melting Arctic Sea Ice	Robust	Low	
Increasing Intensity of Arctic Storm Events	Robust	Low	Not explicitly stated, but inferred through inter-judge comparison
Increasing Intensity of Arctic Precipitation Events	Robust	Low	Not explicitly stated, but inferred through inter-judge comparison
Increasing Frequency of Arctic Storms Events	Robust	Medium to Low	Not explicitly stated, but inferred through inter-judge comparison
Increasing Frequency of Arctic Precipitation Events	Robust	Low	Not explicitly stated, but inferred through inter-judge comparison
Thawing Permafrost	Robust	Low	

For uncertainty within the drivers changing patterns of trade and developing technology, statistical analyses are not available, therefore uncertainty for these drivers was evaluated based

on qualitative evidence found in the literature. First, sources and information surrounding each identified pressure were evaluated through the use of inter-judge calibration among the authors. Reports that produced or referred to global syntheses were weighed more heavily than sector or regionally focused papers. Global syntheses that focused on the marine transportation system were relied upon rather than papers that focused on one specific element of the system. Each report’s qualitative assessment of uncertainty was used if present; in some cases, uncertainty was explicitly addressed, while in others inference was required. The terms high, medium, and low were then applied judgmentally to uncertainty. The combination of robust evidence and low uncertainty was taken to mean that the associated risks were likely to emerge, while limited evidence coupled with high uncertainty were taken to mean associated risks were less likely to emerge.

- *High Uncertainty* – Authors are not confident that risks will occur based on lack of convergence of evidence, conflicting evidence, or information gaps.
- *Medium Uncertainty* – Authors conflicted on whether the risks will occur based on inconclusive evidence.
- *Low Uncertainty* – Authors are confident that the risks will occur based on conclusive evidence and conclusive opinion of experts.

Table 38 provides a summary of the strength of evidence and uncertainty associated with the pressures reviewed in this report.

**Table 38: Strength of Evidence & Qualitative Assessment of Uncertainty in Evolution of Marine Transportation System**

Individual pressures were assessed based on the on the type, amount, quality, and consistency of the evidence documented in the literature (IPCC AR5 2013, Majchrzak and Markus 2014). Pressure Uncertainty was assessed as High, Medium, or Low Uncertainty based on whether the risks are seen as likely to occur or not from authoritative sources and inter-judge comparison. Low Uncertainty means that the risk will emerge, Medium Uncertainty means that there are inconsistencies amongst the experts on whether the risk will emerge, and High Uncertainty means that experts are not confident that the risk will emerge.

<i>Pressures</i>	<i>Strength of Evidence</i>	<i>Uncertainty</i>	<i>Notes</i>
Changing Patterns of Trade Primarily Associated with the Panama Canal Expansion	Robust	High	The occurrence of risks associated with this pressure will depend on future mitigation measures and trade policies.



<i>Pressures</i>	<i>Strength of Evidence</i>	<i>Uncertainty</i>	<i>Notes</i>
Changing Patterns of Trade Primarily Associated with the Suez Canal Expansion	Robust	High	The occurrence of risks associated with this pressure will depend on future mitigation measures and trade policies.
Increased Usage of Arctic Trade Routes	Robust	Low	While the evidence suggesting increasing Arctic trade and the emergence of new routes for ice-class vessels is very strong, there is some uncertainty on the pace and location of development. The occurrence of risks associated with this pressure will depend on future mitigation measures, policies, and technology.
Increased Import/Export of North American Oil	Limited	High	The occurrence of risks associated with this pressure will depend on future mitigation measures and trade policies.
Introduction of Mega-Containership	Robust	Medium	Risk appearance depends on if there is an incident that leads to a spill or needed salvage operation.
Increased Usage of Bulk Carriers to Transport Hazardous Material	Robust	Medium	IMO has amended codes regulating transport of hazardous cargoes.
Increased Usage of LNG Carriers	Robust	Medium	To date, no major incidents involving LNG carriers have occurred.
Increasing Number of FPSO Units	Limited	Medium	To date, no major incidents involving FPSOs have occurred.
Crew Fatigue	Limited	Medium	IMO has recently amended codes and increased enforcement of minimally manned crew numbers.

<i>Pressures</i>	<i>Strength of Evidence</i>	<i>Uncertainty</i>	<i>Notes</i>
Increasing Vessel Automation	Robust	Low	To date, incidents have occurred. The future occurrence of risks associated with this pressure will depend on mitigation measures and policies.
Compromised Cyber-security	Robust	High	The occurrence of risks associated with this pressure will depend on future mitigation measures, policies, and technology.
Introduction of LNG Propulsion Fuel	Robust	Low	The occurrence of risks associated with this fuel will depend on future mitigation measures and policies.
Introduction of Other Alternative Fuels	Robust	Low	The occurrence of risks associated with these fuels will depend on future mitigation measures and policies.
Challenges of Response in the Arctic	Robust	Low	The occurrence of risks will depend on future technology, capacity, and accessibility.

In summary, we believe the pressures listed in Table 39 will require the most attention from spill preparedness and response organizations, targeted especially on the time frames where each is listed. This table was constructed based on the expected evolution of each of the pressures over time presented in Figure 28 and the strength of evidence and uncertainty analysis presented in Table 38.

**Table 39: Time Frames in Which Pressures Have the Potential to Emerge**

Summary of time frames over which pressures of most concern have the potential to emerge. Pressures in this table have Strength of Evidence categorized as robust and Uncertainty categorized as low.

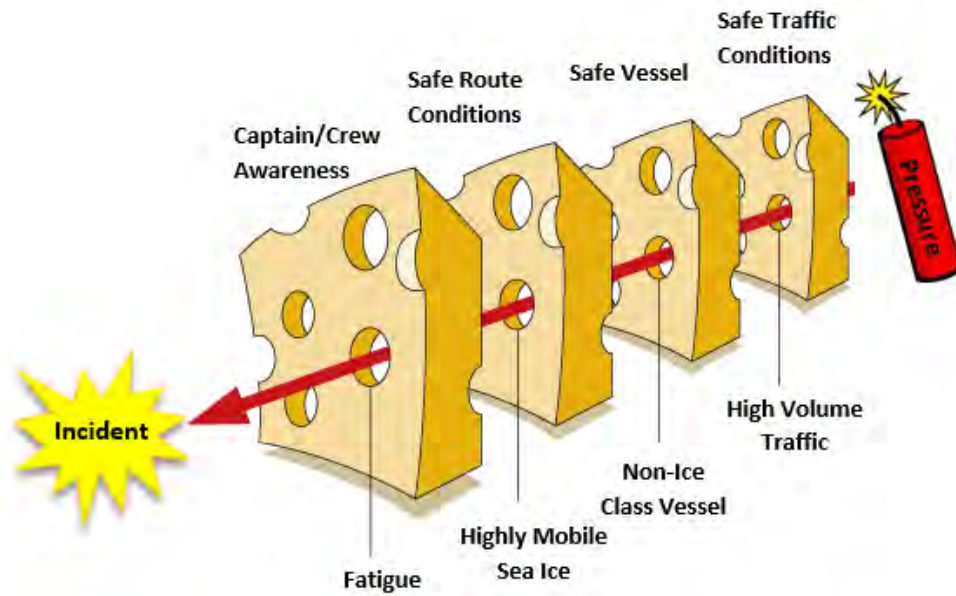
<i>0–5 Year Time Frame</i>	<i>5–10 Year Time Frame</i>	<i>10–20+ Year Time Frame</i>
<ul style="list-style-type: none"> <li>Storminess<sup>16</sup></li> <li>Vessel Automation</li> <li>LNG Propulsion Fuel</li> </ul>	<ul style="list-style-type: none"> <li>Storminess in combination with SLR</li> <li>Sea Ice</li> <li>Permafrost</li> <li>Use of Arctic Trade Routes</li> </ul>	<ul style="list-style-type: none"> <li>Alternative Propulsion Fuels</li> </ul>

### 7.3. Pressure Interactions

Pressure interactions can be thought of as the result of the intersection of multiple pressures within the maritime transportation network. Each pressure described in this report is made up of underlying mechanisms that require different approaches to risk management. As seen in Figure 29, both individual pressures and interactions of multiple pressures can lead to a system failure. When multiple system failures or a key system failure occurs, an incident is the likely result.<sup>17</sup> Interactions among pressures sometimes fall into the category of “unknown unknowns,” modes of system failure that experts hadn’t considered until confronted with them.

<sup>16</sup> The pressure of Storminess considers both storm events and precipitation events.

<sup>17</sup> For further information, see Reason (1997).



**Figure 29: James Reason Accident Model: Layers of Safety and How They Can Fail**

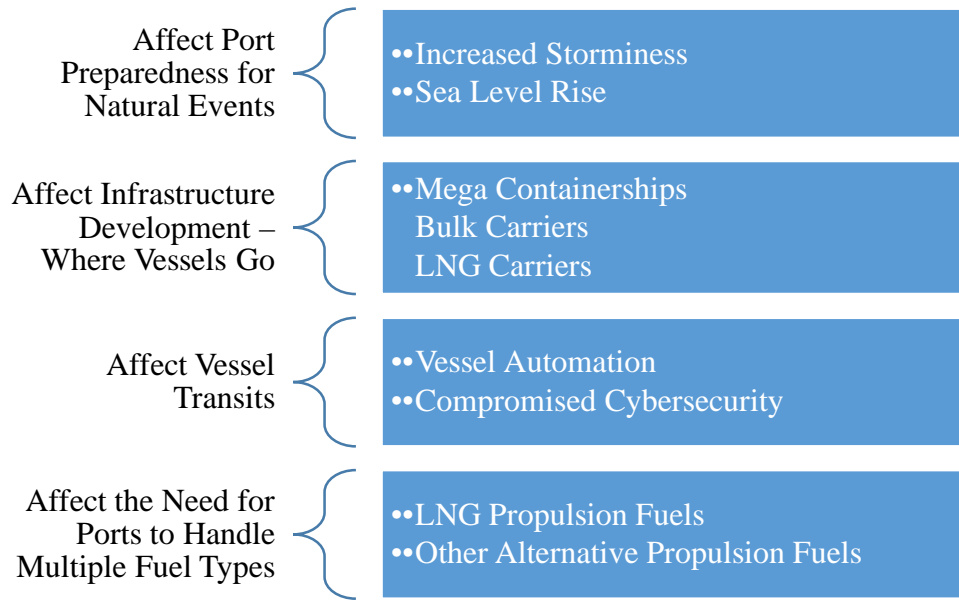
The James Reason Accident Model of incident causation depicts layers of mitigation techniques (i.e., layers of safety) that when aligned perfectly result in system failure. A pressure may allow a risk to pass through a hole in one layer, but in the next layer the hole alignment varies and in theory this mitigates the risk. Each layer is a defense against potential pressures impacting the outcome.

(Adapted from Reason 1997)

The pressure interactions considered in this section include those for global ports and Arctic shipping.

### 7.3.1. Ports

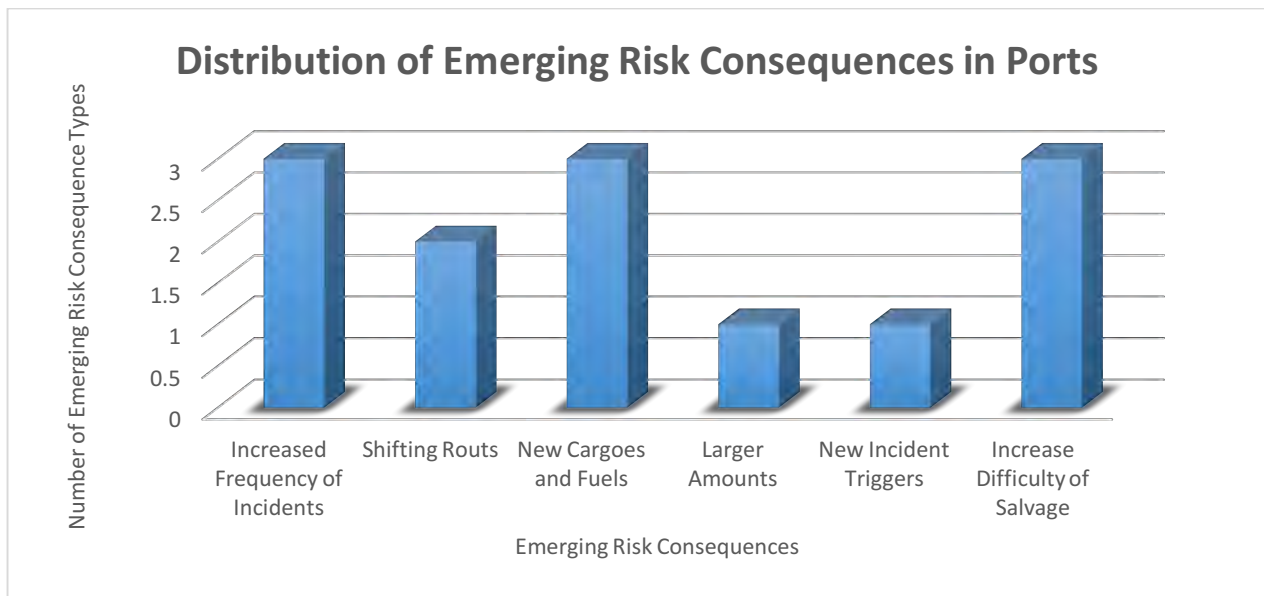
Ports and port systems continually face a variety of external pressures, some of which contribute to the riskiness of port operations. Pressures that increase the “hole alignment” illustrated in Figure 29 could lead to more incidents over time. Four types of pressures described in this report are particularly germane to emerging risks potentially affecting ports (Figure 30). Although these pressures are nominally independent of one another, they will likely be experienced in combination. For example, recall the oil tanker traffic jam that occurred off the port of Houston, Texas in 2015 due to economic circumstances. The resulting congestion was conducive to increased probability of allisions and collisions. Now suppose this event were to happen as a massive storm is approaching. Efforts would be made to move vessels out of the storm path, but the probability of accident heightens as more vessels are in harm’s way and more of the risk mitigation “holes” align.



**Figure 30: Pressures of Concern to Ports**

The pressures of most concern for global ports are bulleted in the blue boxes. These pressures are grouped into aspects of port operations they will directly affect. In the future, ports could need to deal with each of these changes.

Impacts from any of these pressures could have serious and broad repercussions for infrastructure, equipment, and cargo, and consequently, preparedness.



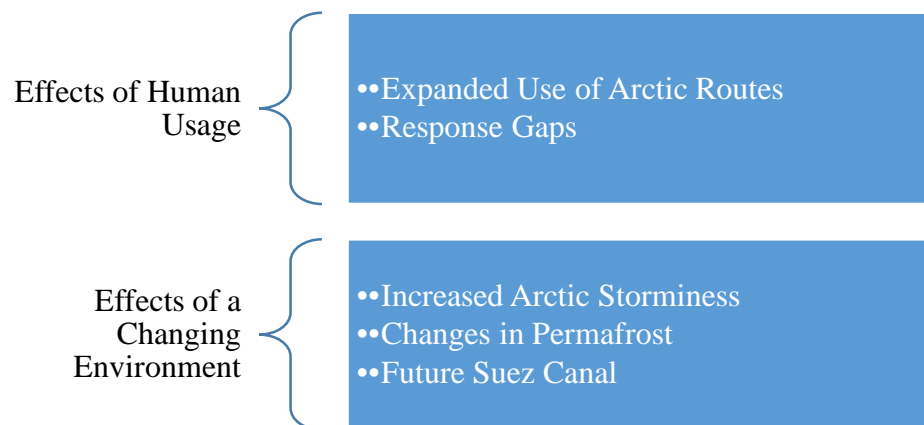
**Figure 31: Distribution of Emerging Risk Consequences in Ports**

Counts of emerging risk consequences across all pressures considered in the report. (Column 6 in Tables 11, 22, 28, 30, 34)

### 7.3.2. Arctic Shipping

The Arctic has long been used for shipping and mineral extraction, but diminishing ice extent, thickness, and age provide the foundation for an increase in maritime access for shippers and resource extractors. The pressures affecting the Arctic can be broken into two categories: the effects of human usage and the effects of the changing environment. Pressures most affecting Arctic shipping are shown in Figure 32.

While it is increasingly busy in the Arctic, the region is by no means fully developed. There are both infrastructure and search and rescue gaps as use outpaces the existing infrastructure. Furthermore, these activities take place in a rapidly changing environment, which adds layers of complexity to the situation. For example, the development of infrastructure and search and rescue capacity are further affected by thawing permafrost that makes building more difficult and can weaken existing foundations and roads. The interaction of these risks can lead to more incidents. Figure 33 provides a summary of potential emerging risk consequences that could result from changes in Arctic shipping.



**Figure 32: Pressures Arctic Shippers Should Consider**

Important pressures Arctic Shippers should consider are bulleted in the blue boxes. Pressures are grouped to reflect the aspects of Arctic shipping they will directly affect.

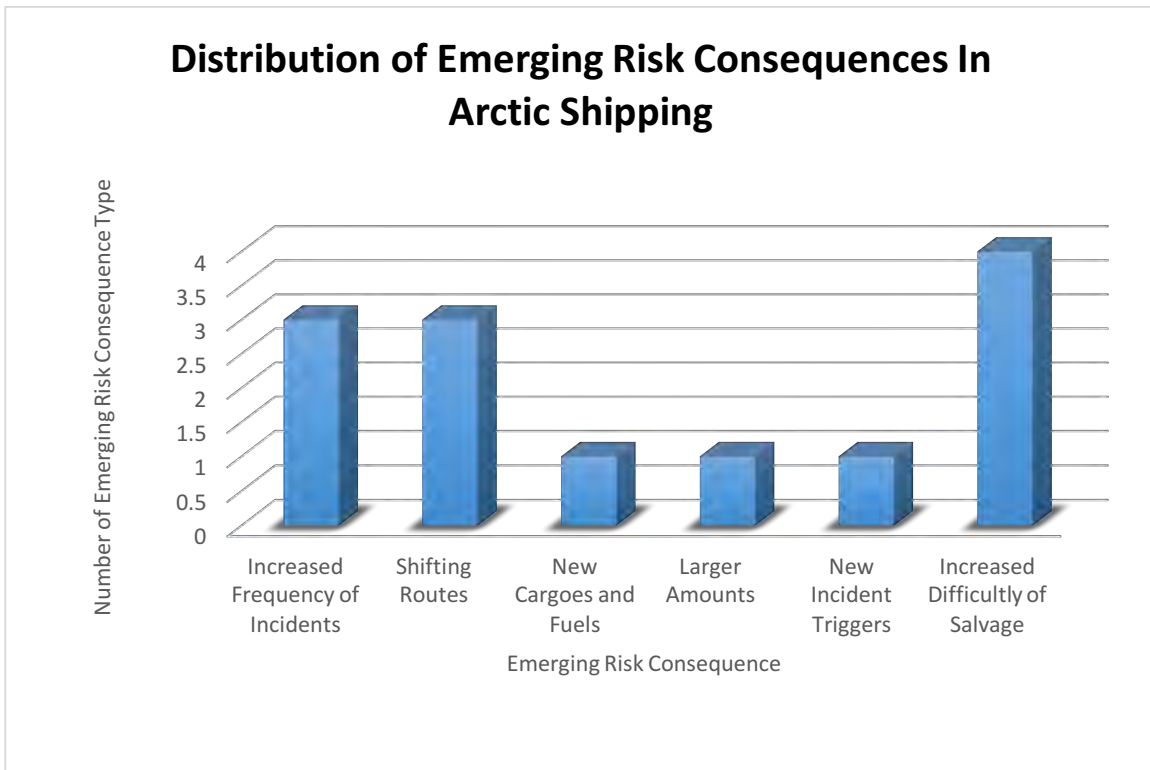
The melting of sea ice is not a linear or consistent process, the melting and breaking up of sea ice is less predictable as a result. The same phenomenon that makes Arctic shipping possible simultaneously makes it riskier because while there is less ice overall (allowing for more

shipping), the melting of that ice creates unpredictable patterns. Less ice means greater expanses of open water as well, with implications for storminess in the Arctic, further illustrating the complexity of the underlying interactions.

While climate change has made Arctic shipping possible, issues of remoteness and response to potential incidents are a major concern. Response gaps are a result of multiple factors including remoteness, increasingly violent storms, unpredictable ice, and extreme weather conditions. As Arctic shipping expands, there is the potential for accidents that are of greater consequence than those present with lower levels of and less complex shipping activity.

Looking more globally, the Arctic is also affected by developments in other regions. The expansion of the Suez Canal could affect usage in the Arctic either due to shippers wanting to save time and distance or to avoid congestion. It could also mean less shipping through the NSR. This is another example of pressures interacting across categories. The pressures and factors affecting the Suez come into play for Arctic shipping. If fewer ships go through the canal, more might go through the Arctic.

The 2004 incident of the *Selendang Ayu* is an example of pressure interactions. The vessel was larger than responders and available tugs were equipped to deal with, there was a storm coming in, and the ship's own anchors failed in the rough weather. The result was that the vessel split in half (Ropeik 2014). The human and environmental factors in the Arctic can interact, with the potential to increase the uncertainty and complexity of shipping conditions and the resultant risks.



**Figure 33: Distribution of Emerging Risk Consequences in Arctic Shipping**

Potential emerging risk consequences across all pressures considered in the report. (Column 6 in Tables 13 and 25)

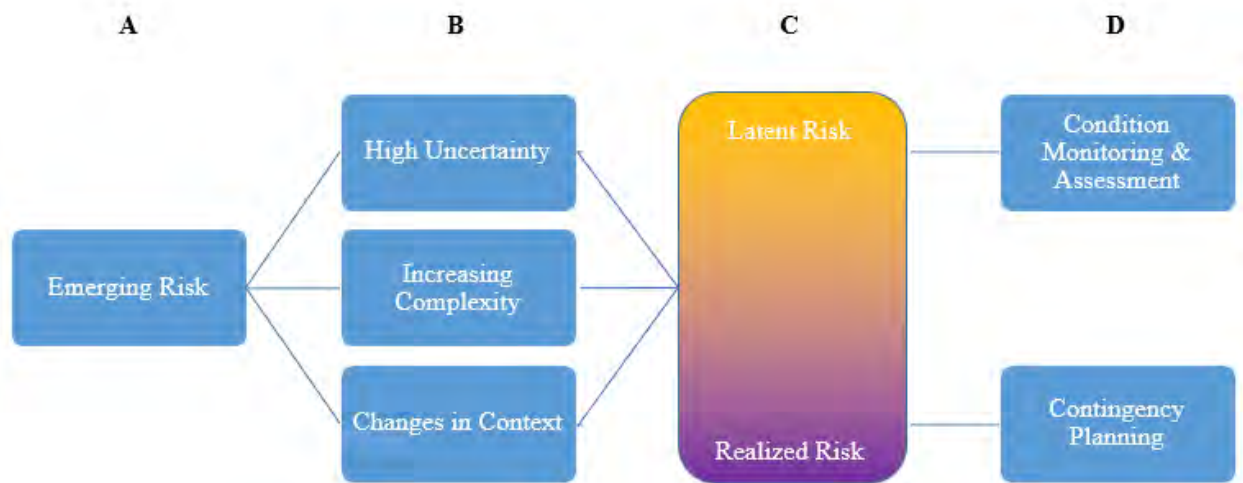
## 8. CONCLUSIONS

With unprecedented global change the marine transportation network must mitigate the impacts of emerging risks and anticipate those that have yet to be observed. From a management perspective, the International Risk Governance Council (2010) provides a useful definition of emerging risk (Figure 34, column A). They characterize emerging risk as one that is defined by: high uncertainty, increasing complexity, and changes in context (Figure 34, column B).

Examining risk in these terms helps inform response organizations responsible for developing plans appropriate to the emerging risks they perceive. At one end of the risk spectrum (realized risk) lie present or near-term risks that have robust evidence and low uncertainty surrounding their emergence and likely impacts. At the other end of the spectrum (latent risk) lie distant-future risks that have higher uncertainty surrounding their emergence and possible impacts (Figure 34, column C).



Where a risk lies along this spectrum will determine the actions that the response organization will need to take: condition monitoring and assessment at one extreme, contingency planning, at the other, or a mix of the two strategies in between (Figure 34, column D). The distinction between contingency planning and condition monitoring and assessment is important because it changes the way a response organization manages emerging risk. Contingency planning can take place in the present, whereas there are various methods for approaching condition monitoring and assessment. Response organizations might actively monitor and assess actions that are being taken by third party entities to learn more about risks, they might monitor and assess the underlying conditions that are creating risk, or they might participate in or lead the development of mitigation actions.

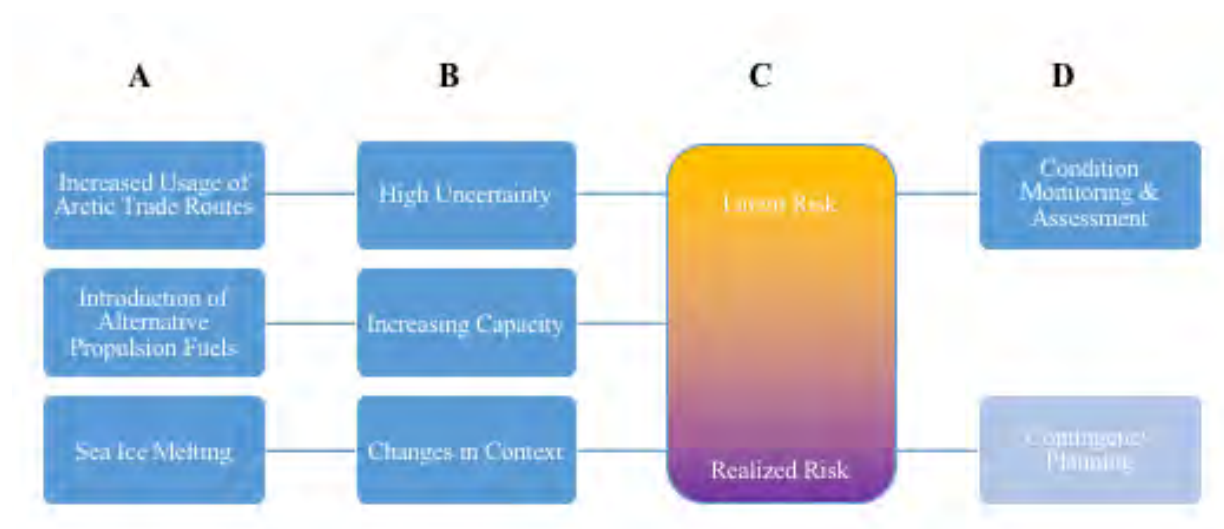


**Figure 34: Strategies for Managing Emerging Risk**

A conceptual diagram for managing emerging risks (column A) that are found to be highly uncertain, increasingly complex, or changing in context (column B). Each of these three categories, then lie along a spectrum (column C) where the bottom of the spectrum would result from present or near-future risks (0–10 year time frame) that have robust evidence and low uncertainty surrounding their emergence and impacts (realized risk). The top of the spectrum would result from distant-future risks (20+ year time frame) that have higher uncertainty surrounding their emergence and impacts (latent risk). Where a risk lies on the spectrum determines the actions that the response organization will need to take, a combination of contingency planning and condition monitoring and assessment (column D).

For each of the three characteristics of emerging risk (column B) examples from the report can help to clarify the processes. Figure 35 traces examples of latent risks identified in the report. The increased usage of Arctic trade routes, introduction of alternative propulsion fuels, and Arctic sea ice melting are all examples of risks that are of concern, but that will likely be fully realized in a more distant time frame. Condition monitoring and assessment would be the primary focus, even

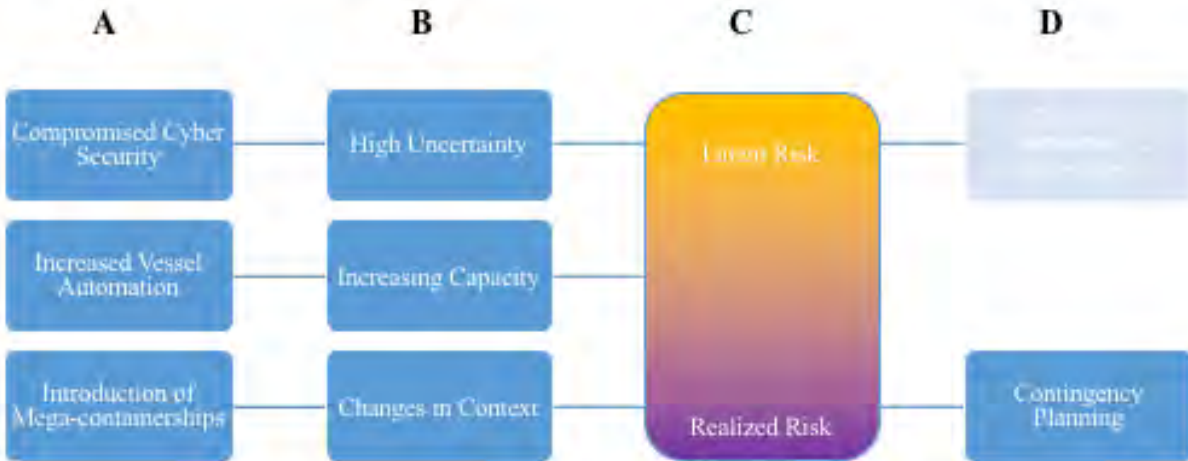
though current contingency planning will also be necessary (an example being the voyage of the Crystal Serenity through the Northwest Passage in 2016).



**Figure 35: Examples of Latent Risk and How to Manage Them**

A conceptual diagram for managing three examples of latent risks (column A) that are found to be either highly uncertain, increasingly complex, or changing in context (column B). Each of these three categories lies along a spectrum (column C) in the distant-future. These risks have higher uncertainty surrounding their emergence and impacts. Where a risk lies on the spectrum determines the actions that the response organization will need to take. In this case, the response organization would prioritize condition monitoring and assessment while also considering contingency planning needs (column D).

Figure 36 traces examples of risks that can be identified as already realized risks. Compromised cybersecurity, possible risks associated with increasing vessel automation, and the introduction of mega-containerships are all examples of risks of concern in the present. These risks require an emphasis on current contingency planning by ports to ensure efficient and effective mitigation. Monitoring and assessment would also take place to understand how risks might continue to evolve. In cases like these, efforts might focus on the learning period during which new technologies and changes in context can affect operators in unexpected way.



**Figure 36: Examples of Realized Risk and How to Manage Them**

A conceptual diagram for managing three examples of emerging risks (column A) that are found to be either highly uncertain, increasingly complex, or changing in context (column B). Each of these three categories then lies along a spectrum (column C) in the present or near-present time frame. These have robust evidence and low uncertainty surrounding their emergence and impacts. Where a risk lies on the spectrum determines the actions that the response organization will need to take. In this case, the response organization would prioritize contingency planning while also considering conducting monitoring and assessment (column D).

With many emerging risks being permissive, response organizations need to plan accordingly. For example, taking potential interactions among pressures affecting ports explicitly into account can lead to more comprehensive plans and actions that reduce the likelihood of future incidents occurring. This contrasts with Arctic mitigation approaches, where response organizations can emphasize monitoring of both the environment and mitigation planning undertaken by third-party entities that plan to frequent the region. The emphasis would be on steps that lead to safe Arctic shipping and effective search and rescue, salvage, and pollution response. Prevention planning should consider risks emerging in both current and future time frames.

While there is no one solution for addressing emerging risks, this report offers a guideline for collaboration amongst various sectors of the maritime transportation network. By forging relationships across sectors, organizations will be able to better develop the most comprehensive responses to address pressures and gaps associated with Changing Environment, Changing Patterns of Trade, Developing Technologies.

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