Project Start Date: 1.9.2018

Project Duration: 60 months

T3.1 (Report on definition and characterization of potential seaborne disasters, catastrophic incidents, and security threats in the ANA region)

Deliverable details	
Deliverable number	D3.1
Author(s)	Ashraf Labib, Dylan Jones, Kevin Willis, Joe Costello, Djamila Ouelhadj, Michael Tipton
Due date	30th of October 2022
Delivered date	8th of November 2022
Reviewed by	Tore Wangsfjord
Dissemination level	Public
Contact person EC	Patricia Rischitor

History of Changes			
Date	**Version**	**Person in Charge**	**Description**
20.04.2020	V1.0	Ashraf Labib	Draft of Deliverable
13.08.2020	V2.0	Rob Lynch	Draft delivered to coordinator
21.08.2020	V3.0	Ashraf Labib	Third draft after comments
28.08.2020	V4.0	Rob Lynch	Fourth draft
28.08.2020	V4.1	Natalia Andreassen	Changes to theory
28.08.2020	V4.2	Irene Andreassen	Additional information
31.08.2020	V4.3	Emmi Ikonen	Final version
11.2022	V4.4	Simon Patterson, Kevin Fitzgibbon	Amendments

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

EXECUTIVE SUMMARY

As shipping activities continue to experience growth across a multitude of sectoral components within the Arctic, so too will the risks and likelihood of accidents and incidents occurring. As a region, which is well renowned for posing challenges in relation to transportation and human existence as a result of extreme climates and environmental conditions, the complexities associated with the major emergencies within the maritime domain, are amplified when operating within the ANA. The definition and characterisation of potential seaborne disasters, catastrophic incidents, and security threats in the ANA region is critical component not only in paving the way for further ARCSAR research efforts, but also in providing a critical tools for SAR and emergency management practitioners beyond the lifetime of the ARCSAR project.

In this report we therefore provide a list of potential seaborne disasters, catastrophic incidents, and security threats in the ANA region (from a set of workshops and the literature) such as a cruise ship incidents, oil leak, radiological leak, and fishing boat groundings. We also provide root cause analysis techniques, and tools for strategic decision-making. We demonstrate how such tools can be used by applying some of them to selective case studies and drawing lessons learned which can help emergency response organization with preparedness work and more efficient response. In doing so, we provide a set of tools that can used as mental models for strategic and operational learning. Such approaches can help standardise the definition and characterisation of potential seaborne disasters, catastrophic incidents, and security threats in the ANA region in both prospective and retrospective analysis. These approaches will also maximise the potential impact of this report. Not only will SAR and emergency management practitioners have a consolidated source of potential seaborne disasters and catastrophic incidents available to them, but the risk and root cause analysis tools presented within the report can be applied by practitioners when attempting to learn from future seaborne disasters, catastrophic incidents, and security threats.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Table of Contents

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

List of Figures

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

1 Introduction

This report has been completed to fulfil the requirements of ARCSAR Deliverable 3.1 – Report on definition and characterisation of potential seaborne disasters, catastrophic incidents, and security threats within the ANA due in M24. The report has been designed to present a summary literature review of disasters, incidents and threats within the ANA, apply risk analysis methods to seaborne case studies, and present summary findings from stakeholder engagement workshops.

1.1 Report Scope

This report (D3.1) forms part of ARCSAR WP3, which encompasses future needs for innovation and knowledge within ANA SAR and emergency management contexts. In terms of specific focuses, the report contributes to WP3 objectives by determining and presenting examples of seaborne disasters, catastrophic incidents, and security threats which have been prioritised by SAR and emergency management practitioners within the ANA. In fulfilling this requirement, D3.1 will pave the way for future WP3 efforts such as:

- T3.2 Catastrophic incident simulations and live exercises;
- T3.3 Needs and barriers analysis;
- T3.4 Future needs for innovation and knowledge

Beyond WP3, D3.1 will inform efforts related to T4.1 Priorities for security and standardisation, while also aligning with WP5 as the results are disseminated and communicated to relevant stakeholders.

The report itself represents the culmination of significant bi-lateral engagement between the ARCSAR WPs, namely WP2 and WP5, while also leveraging the extensive ANA stakeholder network present throughout the consortium.

1.2 Background

There is evidence that the lessons that could have been gained from major disasters have not always been learnt by the very same organizations (or industries) involved in those disasters, as demonstrated by the multiple disasters that have occurred in oil spills, nuclear power, etc. although such industries are claimed to be part of the High Reliability Organisations (HRO) status. This argument is particularly relevant to seaborne disasters, catastrophic incidents, and security threats in the ANA region, which have

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

been observed from a set of workshops (described in detail in ARCSAR deliverable D2.1) and literature, such as cruise ship fire, oil leak, radiological leak, terrorist incident or fishing boat groundings.

In order to draw lessons learned from real-life incidents and demonstrate the threat that disasters pose to the ANA region, we have chosen six case studies that could have major consequences to both human life and the environment in the ANA region.

1. Exxon Valdez Oil Spill Disaster (1989, Alaska)
2. BP Deepwater Horizon Oil Spill Disaster (2010, Gulf of Mexico)
3. MS Estonia Ferry Incident (1994, Baltic Sea)
4. Norilsk City Oil Spill Disaster (2020, Russian Arctic)
5. The Viking Sky Cruise Ship Incident (2019, North Sea)
6. Le Boreal Cruise Ship Incident (2015, South Atlantic)

One of the most significant case studies of oil spills, in terms of significance in terms of cost and environmental damage the ANA region, is the Exxon Valdez oil spill. We will use it as a classical case to demonstrate some of the root cause analysis techniques covered in this report.

Some of these case studies were examined during the ARCSAR workshops attended by SAR practitioners and ARCSAR partners. Other relevant case studies investigated during the group work session of our set of workshops included cases, which may have relevant features to accidents and disasters in the ANA region:

- Costa Concordia Incident (2012, Italy).
- Vessel Grounding in ANA region (General).
- Elgin Oil Platform Incident (2012, Scotland).
- Nuclear Incident in ANA region such as potential hazard from nuclear powered icebreakers, or mobile nuclear power stations (general).

So why do organizations fail to learn? When accidents happen, what are the factors that can lead to the unlearning process? What are the mechanisms, in routine dynamics, for feedback and change? How can organizations learn, and change their routines, through feedback? Here, the role of dynamic organizational routines in learning and unlearning from failures is investigated and a framework developed in order to address the above questions, and to provide a mechanism for feedback and change in routine dynamics with special emphasis on issues related to maritime safety and security hazards in the Arctic Circle.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

1.3 Proposed Methodology

It can be argued that industry incident reports render "*thin descriptions*" out of "*thick descriptions*", not only because of inabilities to conceptualize real-time data but also because of inabilities to represent findings with relevant contextual data and as narrative, thus making it difficult to make adequate sense of events. So, in terms of learning and unlearning from failures, an important question is posed: why do some routines stay the same when we want them to change, while other routines change when we want them to stay the same? To address this we will challenge the traditional understanding of organizational learning from major disasters in particular by taking account of the rarity of such events.

A disaster is, by definition, a rare event of high impact. Here, we shall examine this rarity aspect and argue that, at a certain level of analysis, disasters are not rare in the sense that generic lessons can be learned and embedded in the form of dynamic routines that are continuously updated using feedback mechanisms. In other words, organizations can vicariously learn from others (March, 1991; Levitt and March, 1988). For example, when analyzing Deepwater Horizon it can be seen that it was closer to the Apollo 13 accident than to the Exxon Valdez accident (Fowler, 2010) in that it involved having to manage systems without human eyes on the scene. We will adapt the Decision-Making Grid (DMG) model to build a theory that explains why organizational unlearning from failures occurs. We will also demonstrate how the DMG model can provide suitable strategies for cases of high severity low frequency as well as cases of high frequency low severity.

We will explore similarities between the Risk Matrix approach used for classifying risks in the arctic shipping (Marchenko et al, 2018) and compare it to the proposed DMG framework, which uses a risk assessment framework to provide decision support for selection of most appropriate strategies in order to cope with different degrees of risk. One of the alternative strategies is an investigative strategy based on root cause analysis tools. So, we will then provide some background about root cause analysis tools and demonstrate how they can be applied to cases related to threats similar to those identified with partners from the workshops carried out with stakeholders in Arctic Circle. Finally, an overview of the prioritised definitions and characterisations of potential seaborne disasters, catastrophic incidents, and security threats within the ANA derived from the lit review, risk analysis and stakeholder engagement workshops is presented.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

2 Literature Review

2.1 ANA SAR Practitioner Priorities

In a recent report by the USCGA and Centre for Arctic Study and Policy (CASP) titled 'The Future of Shipping in the Arctic: New Perspectives on the Next Frontier' (Cottle, and Kern, 2020) an assessment of incidents that are most likely to occur in the ANA Region was presented. It is the intention of this report to extend such analysis and provide tools and techniques that can systematise the learning and the decision making process to learn from incident in order to prevent, mitigate and respond to future ones.

Specifically, the USCGA/CASP report was based on a set of interviews with key stakeholders in the ANA region and highlighted important themes in answering the following questions:

- *Is Arctic Shipping Increasing?* Although everyone interviewed felt that shipping in the Arctic was increasing, there was some disagreement as to the extent.
- *What are the current changing trends?* The top ones captures were: increased in tourism, increased interest deployment by Russia, and increased regulations. Also, with respect to industrial developments in the region, the main areas highlighted were: oil and gas, including offshore development, mining, fishing, and cruise/tourism.
- *What are the critical gaps and failures in governance structure in the ANA region?* The most common responses referenced a greater need for search and rescue assets (e.g., helicopters, infrastructure, individuals with sufficient SAR training, etc.), a need for stricter requirements regarding environmental protection (e.g., pollution, heavy fuel oil, grey water, research on oil in icy areas), and/or a need for stricter regulations as far as crew training for those operating in the area.
- *Which Incidents are Most Likely to Occur in the ANA Region?* Interviewees were asked to rank the likelihood of three events presented to them, including seaborne disasters (e.g., collisions or groundings), catastrophic incidents (e.g., including cruise ship accident or oil spill), and soft security threats (e.g., human trafficking, piracy, transport of illegal goods, or failure to adhere to polar code). There was a lot of variability in responses to this question as well, indicating a lack of consensus among experts as to which incidents would be most likely. 'Examining the nature of their responses, it was also evident that our interview participants had difficulty separating out the issue of likelihood from consequence. Understanding that *risk = probability x consequence*, many preferred to focus more on the consequence

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

portion of the equation, rather than the most likely event from a probabilistic viewpoint. In fact, a few of our respondents told us explicitly that looking at risk **of** an event was less useful than looking at the risks stemming **from** a particular event' (Cottle, and Kern, 2020). As will be shown in our report in later sections, we propose one of the anytical tools for assessing risk a tool named the Decision Making Grid (DMG). It can be noticed that such grid is similar to a risk assessment of frequency x severity, or some would rather frame it instead as *risk = probability x consequence*. However, the main difference is that here it is of a '*prescriptive*' nature. As in a classical risk assessment a score of high frequency low severity is equal to a score of high severity low frequency, whereas in a prescriptive approach both types of risk require different strategies. In the USCGA/CASP report the most likely incidents were ranked based in the graph below.

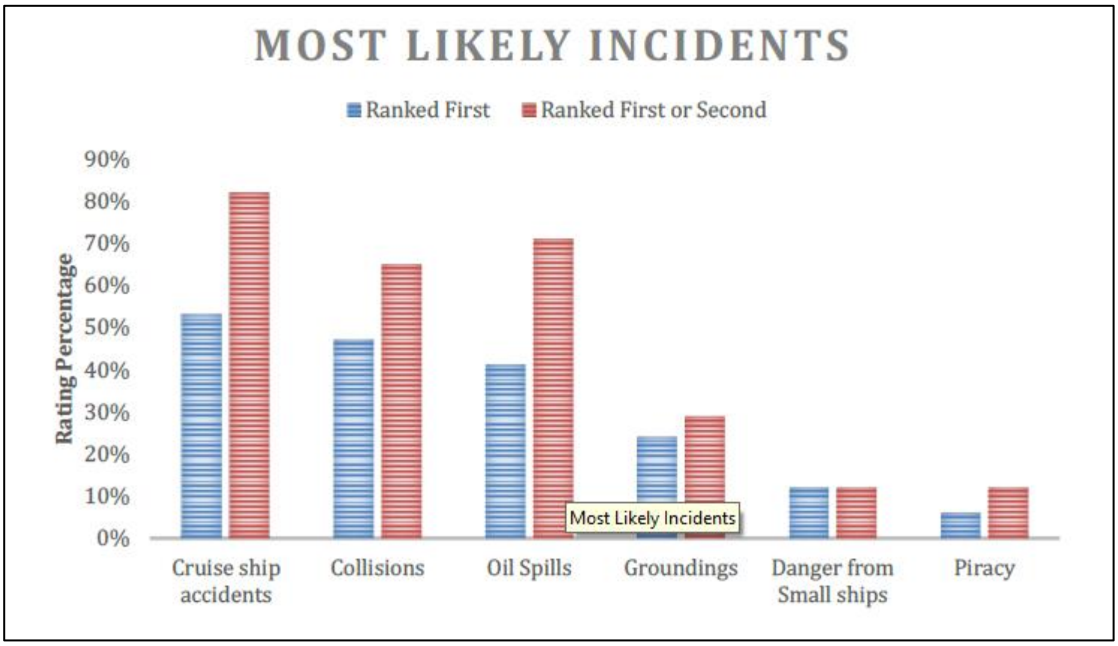


Figure 1: Most likely incidents in the ANA Region - Ref: USCGA/CASP report (Cottle, and Kern, 2020)

- *What are the best ways to prevent accidents from occurring in the first place?* Answers ranged from improved weather and ice modelling for the region, to the role of insurance agencies, but most respondents indicated that the best way to prevent a disaster is to train for one.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

- *Are there any additional perceived threats?* The main two recommendations were; the introduction of new operators in the region and hard security threats.

The main recommendations from the interviews conducted by the USCGA/CASP report (Cottle, and Kern, 2020) are itemised below:

1. Explore public private partnerships in emergency management.
2. Explore potential inherent in vessels of opportunity.
3. Establish unsecured channels of communication for information sharing among Arctic States.
4. Enhanced data sharing and establish a repository of openly accessible data on ship incidents.
5. Expand training exercises (to non-summer months, and to include more participation by industry and non-governmental groups).
6. Increase coverage of Polar Code (to include fishing vessels, and to include incident prone regions that are not currently covered by the Polar Code.
7. Expand training requirements of the Polar Code to include actual ice experience, and expand to include all crew.
8. Look for ways to engage expertise of local communities regarding safe zones, weather trends, etc. Capture existing "institutional knowledge" while exploring opportunities for strengthening ties to Indigenous groups, and providing real avenues for stakeholder inclusion.
9. Communities should consider adopting their own regulations and mechanisms of enforcement to suit their own regions and zones to capture the unique needs of each area while working to ensure that ships do not have too many disparate regulations to deal with as they cross areas.
10. Increased funding for research to examine the effects of oil spills in these areas, including continued investigation of the role of HFO in international shipping in general (not just Arctic).
11. Continue strengthening ties through existing organizations (e.g., Arctic Council EPPR and ACGF). Work to streamline operations so each has clear, minimally overlapping duties.

Beyond the USCG perspective, research published by the MARPART project (MARPART, 2016) present a number relevant components which relate to the definition and characterisation of ANA themed challenges. In considering maritime activity and risk patterns in the High North, (MARPART, 2016) review these concepts on a regional basis, presenting findings associated with key Arctic regions such as Russia, Norway, Iceland, and Greenland. The research suggests that traditional cross-cutting challenges associated with the High North and Arctic such as extreme environments,

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

remoteness/vast distances, sea ice conditions, ecological sensitivity, and high levels of public attention continue to be at the fore when it comes to the maritime domain. Furthermore, increasing access to regions as a result of climate change, technology limitations such as reduced satellite communication and GNSS coverage, and limited a hydrographic survey efforts further amplify the challenges associated with ANA operations, while also increasing the potential likelihood of accidents or incidents occurring.

In terms of more localised causal factors of seaborne incidents, MARPART analyses highlight a number of crosscutting challenges which manifest themselves with greater prominence depending on the region. Human factors such as lack of experience within the High North, navigational competence, and crew fatigue feature significantly across all regions, but were suggested to be of particular prominence within Russian seaborne contexts. Extreme variations in seasonal conditions particularly during winter months were highlighted, and suggested to be of significant prominence within regions of Norway. While vast distances have been highlighted in all geographical contexts, these challenges were proposed to be amplified within Greenland as a result of vast areas of responsibility, combined with the disbursement of SAR and emergency preparedness infrastructure. Similar challenges were highlight in Iceland, while also suggesting that developments in international trade and increased shipping activity would likely result in monitoring and surveillance challenges.

In considering the risks and potential severity associated with seaborne disasters, (Borch et al, 2016) present a number of extremely relevant findings to this deliverable, focusing on individual vessel types, associated risk factors, and the potential consequences of each throughout the varying geographical focal points. Groundings were suggested to be the most frequent types of incidents occurring throughout the study, highlighting the amplified consequences of such incidents within the high north as a result of unprotected coastlines and limited salvage options as a result of vast distances within the Arctic. The likelihood of collisions between vessels was suggested to be relatively low as a result of improvements in navigation, collision avoidance, and ice forecasting technology. However, as an area which is experiencing a continuous increase in maritime activity across a multitude of shipping domains, the research suggests that the probability of collisions could increase as a result of these increases in activity. Research completed by the SEDNA project (Lynch, 2020; Staganos et al., 2018) lend support to these proposed increased in maritime transport activity, citing how increases in shipping activity, particularly mainstream cargo handling/trade, poses a number of challenges and increased likelihoods of incidents such as this occurring within the Arctic.

The research suggests that there is a high probability associated with potential fires on board vessels. Similar to collisions, Arctic specific considerations such as vast distances and limited salvage options

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

further amplify potential risks/consequences of such seaborne incidents as depending on the severity of an incident, a lack of assistance could result in a significant escalation in terms of the severity of potential outcomes.

MARPART et al. (2016) present findings associated with vessel types in the context of potential seaborne disasters, highlighting considerations associated with fishing fleets, dry cargo vessels, liquid cargo, and cruise ships. Fishing vessels were highlighted as a vessel with a strong likelihood, citing challenges associated with other mainstream fishing sectors as the primary causal factors were related to variations in vessel characteristics, technical capacities, and a cultural willingness within the sector to push the limits of their vessels within extreme environments. Cottle, and Kern. (2020) lend support to these findings, citing a 47% increase in incidents within vessels fishing within the Arctic. The research highlights gaps within the global regulators as one of the key overarching shortcomings, suggesting that Arctic fishing vessels should be considered within the Polar Code or other similar goal based regulations.

While (MARPART et al, 2016) would concur with the increased prevalence of incidents on board fishing vessels, due to their size and limited crew numbers while the frequency of incidents are suggested to be high, consequences are deemed low. Dry cargo vessels were suggested to demonstrate a relatively low frequency and potential consequence, however (Cottle, and Kern, 2020) did suggest a 17% increase in incidents throughout the last 60 years. In terms of liquid cargo, specifically oil and chemical tankers, (Borch et al, 2016) suggest that improvements in international cooperation and technologies have reduced the likelihood of incidents such as collisions or groundings occurring on board these vessels. These improvements are as a result of significant investment in oil and gas exploration efforts within the ANA. Lynch and Griew (2019) highlight examples such as the significant investment in geographical areas such as the NSR (Northern Sea Route), presenting how increased hydrographic survey efforts in areas associated with oil and gas exploration have reduced the likelihood of incidents on board tankers occurring. While the likelihood of navigation themed incidents has reduced, (Borch et al, 2016) highlight technology shortcomings in cargo handling equipment, particularly in terms of adapting to extreme cold climates poses a number of challenges, particularly if dealing with large volumes of materials such as crude oil.

Finally, (MARPART et al, 2016) highlight the significant increases in cruise traffic, lending support to the previously cited findings of (Cottle, and Kern, 2020) citing incidents relating to cruise ships/passenger vessels being an area of extreme concern for SAR/emergency management practitioners within the ANA. These concerns align with the findings of (Jones et al., 2018), in which numerous maritime stakeholders across a number of domains including SAR practitioners,

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

commercial operators, technology developers and policy makers all highlighted their concerns in relation to the potential severity of consequences associated with cruise ship incidents within the ANA, citing an increase in tourism as a major contributing factor.

While the research outlines the numerous developments which have occurred within the cruise/passenger ship sector such as regulatory guidelines from the polar code and improvements in technology, the continuing increased prevalence of extreme tourism within the Arctic suggests that the probability of incidents occurring within the Arctic are likely to increase. These increased likelihoods are further amplified by the nature of the activities associated with these vessels, as they can often seek novel tourism experiences in areas which may be limited in valid hydrographic survey data. When combined with the fact that these vessels can transport large quantities of passengers to remote areas within the Arctic, while regulatory improvements and technology developments have reduced the frequency incidents occurring, the potential consequences are extremely high due to the nature of passengers transported on these vessels (sometimes elderly) and the complications associated with evacuations within the extreme environments of the ANA. Furthermore, as cruise ship scenarios have the potential to evolve in complexity to multifaceted incidents resulting in extensive pollution and damage to local eco-systems, emergency management practitioners rate cruise/passenger ships incidents as one of their primary concerns within SAR contexts.

2.2 Traffic in the Arctic region

Vessel activity trends indicate an increase in resupply shipments, activities in support of mining, oil, and gas exploration, and even touristic activities (Gunnarsson, 2021). A study that highlights such trend, Sheehan et al, 2021 is depicted in Figure 2.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

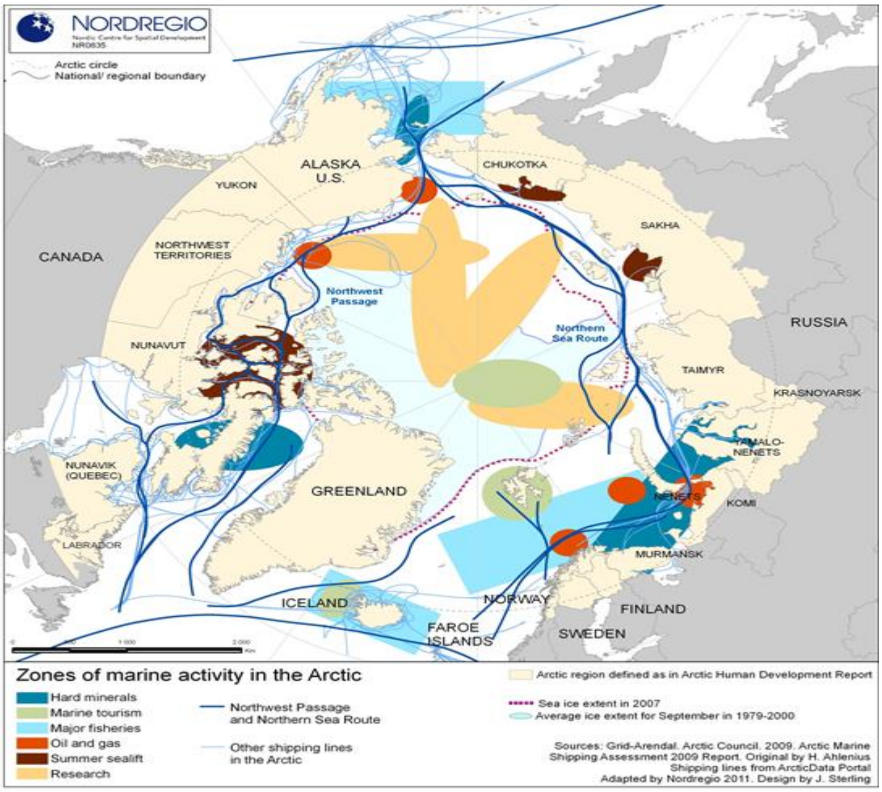


Figure 2: Zones of marine activities in the Arctic (Sheehan et al, 2021)

Figure 3 shows the number of unique vessels entering the Arctic Ocean (the Polar Code area) between 2013 and 2019, by category of vessel type (Statista, 2022)

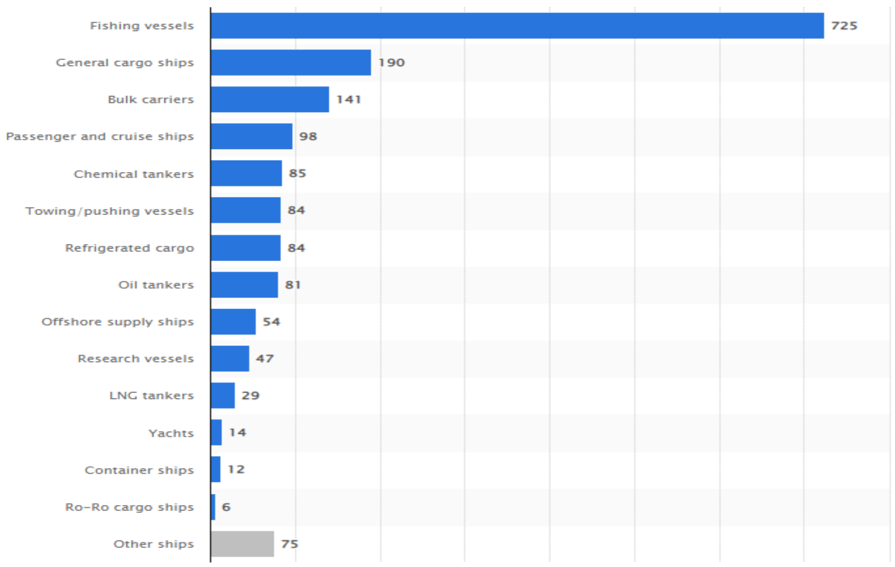


Figure 3: Number of unique vessels entering the Arctic Ocean (the Polar Code area) between 2013 and 2019, by vessel type

In addition, Figure 4 shows number of different types of ships entering the polar code area from 2013 to 2019.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

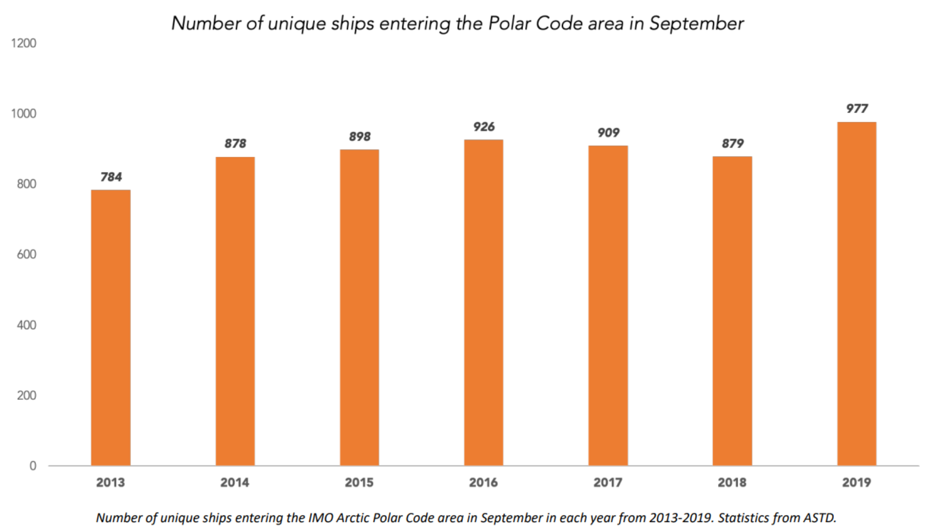


Figure 4: Number of different types of ships entering the polar code area from 2013 to 2019.

According to the Arctic Council (2022) the Arctic marine environment is experiencing dramatic environmental and developmental changes. The ability to access to the Arctic Ocean is developing rapidly the extent of sea ice decreases and weakens, this is enabling extended seasons of ship navigation and new access to previously unreachable regions. "*The Arctic is home to significant natural resources, high commodity prices and a growing worldwide demand. The promise of shorter shipping routes and growing access and demand for natural resources is piquing the interest of nations and industries around the globe*" - the Arctic Council (2022) . Ship traffic in the Arctic has been increasing steadily for the last 20 years, leading to implications for Arctic populations, who may become burdened by marine disruption and the risk of increased pollution. This highlights the importance for the fostering of cooperation between the Arctic States, Indigenous permanent Participants and stakeholders in the shipping industry. While the implications of a more heavily trafficked Arctic Ocean are not yet fully understood, the first step is to fill a critical knowledge gap in shipping trends in the Arctic.

According to PAME (2022), over the past several decades, diminishing Arctic Sea ice has coincided with a moderate but notable increase in the region's marine activity. *"Between 2013 and 2019, the number of ships entering the Arctic—as defined by the International Maritime Organization's International Code for Ships Operating in Polar Waters, or the Polar Code—increased by 25 percent, from 1,298 ships to 1,628 ships"* - PAME (2022).

The majority of ships (41 percent) entering the Arctic are commercial fishing vessels. Other types of ships that commonly navigate in the region include bulk carriers, icebreakers, and research vessels. Growing Arctic marine tourism also has its share – 73 cruise ships sailed in Arctic waters in 2019.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

The total distance sailed by ships in the Arctic during this period increased by 75 percent, from 6.5 million nautical miles to 10.7 million nautical miles.

Also, it should be noted that even with this increase, Arctic ship traffic is comparatively lower than other regions of the world—at least for now. Most Arctic ship traffic is also seasonal, taking place during summer months when the sea ice retreats. During winter months, when much of the Arctic Ocean ices over, Arctic ship traffic dwindles. However, as global populations, national economies, and maritime trade grow, and as the annual average extent of Arctic Sea ice trends lower, regional ship traffic will undoubtedly increase in the coming years.

Another interesting trend is provided by PAME with respect of analysis of trends of Fuels used by ships in the Arctic. PAME's second Arctic Shipping Status Report provides information on fuels used by ships in the Arctic in 2019 with a focus on heavy fuel oils (HFO). HFO is extremely viscous and persists in cold Arctic water for weeks or longer if released, increasing potential to cause damage to marine ecosystems and coastlines. In ice-covered waters, an HFO spill could result in oil becoming trapped in and under the ice. When burned as fuel by ships, HFO has some of the highest concentrations of hazardous emissions among marine fuels. PAME's second Arctic Shipping Status Report shows that around 10 percent of ships in Arctic waters burned HFO as fuel in 2019.

While the number of unique ships in Arctic waters in 2016 is nearly identical to the number of unique ships in those waters in 2019, fuel consumption grew by 82 percent. In 2016, there were no liquid natural gas (LNG) tankers in Arctic waters as compared to 29 LNG tankers in 2019. These 29 LNG tankers consumed over 260,000 tons of fuel, making up the greatest portion of total fuels consumed by ships in the Arctic in 2019.

In order to quantify the number of voyages and better understand the potential environmental impacts of Arctic marine shipping operations. An investigation was carried out by Silber and Adams (2019) to examine the shipping activity in the Arctic between 2015 and 2017, based on Automatic Identification System (AIS) data. Here the aim was to identify areas where shipping concentrates and provide monthly and yearly assessments of the spatial distribution of ship density in the circumpolar Arctic. Accordingly, table 1 was produced to examine the trend if vessels traffic in the region.

Table 1: Annual Arctic-wide vessel traffic metrics, 2015–2017 (Silber and Adams, 2019).

Vessel traffic metric	2015	2016	2017	Average
Number of unique vessels	5,437	5,475	5,606	5,506
Transit counts	116,317	140,105	142,062	132,828
Operational hours	3,752,055	3,053,909	2,820,561	3,208,842
Transit distance (nm)	24,536,244	19,865,667	18,299,701	20,900,537

Silber and Adams also collected data by vessels hours of operation, by month and vessel class. This is shown in Figure 5.

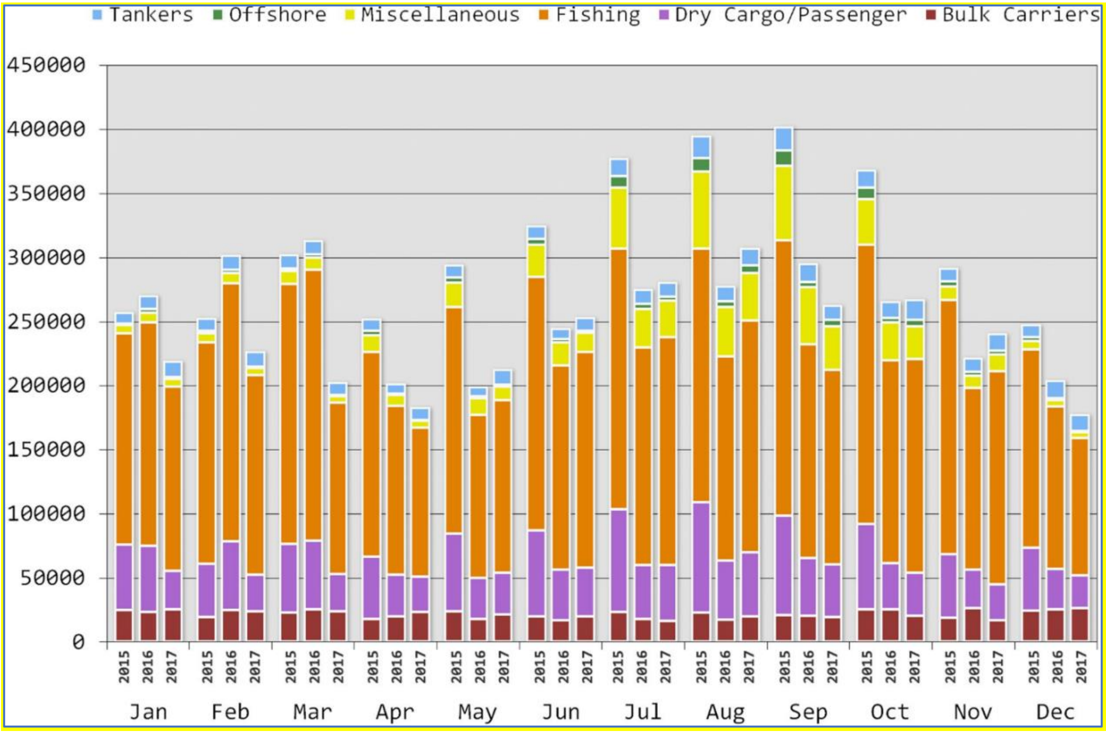


Figure 5: Vessel hours of operation, by month and vessel class, in 2015, 2016, and 2017 (Silber and Adams, 2019).

The vessel types making the most trips in different regions were also investigated as shown in Table 2.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Table 2: Two most common (as measured by number of trips) vessel classes in each Arctic waterway studied.

Location	Vessel type	Trips	% of total	Mean	SD	Operation hours
Norwegian Sea	Passenger/Ro-Ro ship (vehicles)	20,452	14	6,817	±3,498	177,261
	General cargo ship	19,305	13	6,435	±825	244,188
Barents Sea	General cargo ship	7,939	7	2,646	±345	126,207
	Research survey vessel	3,148	3	1,049	±417	93,215
Bering Sea	Bulk carrier	8,628	9	2,876	±241	554,950
	Container ship (fully cellular)	6,731	7	2,244	±121	274,134
Greenland Sea	Passenger/Cruise	3,740	15	1,247	±121	34,914
	Research survey vessel	1,156	5	385	±38	21,030
Kara Sea	General cargo ship	3,748	22	1,249	±318	75,009
	Tug	1,676	10	559	±71	27,733
Davis Strait	General cargo ship	778	8	259	±91	5,141
	Container ship (fully cellular)	670	7	223	±10	5,896
Baffin Bay	General cargo ship	597	11	199	±40	126,207
	Refrigerated cargo ship	502	9	167	±13	3,759
White Sea	General cargo ship	2,318	50	773	±210	18,942
	Products tanker	372	8	124	±21	2,532
Chukchi Sea	Tug	1,464	37	488	±122	26,944
	General cargo ship	430	11	143	±26	6,833
Arctic Ocean	Passenger/Cruise	790	22	263	±65	7,191
	Research survey vessel	551	16	184	±32	12,673
Laptev Sea	General cargo ship	1,284	43	428	±99	17,481
	Research survey vessel	400	13	133	±62	8,329
East Siberian Sea	General Cargo Ship	876	43	292	±82	15,835
	Research survey vessel	253	13	84	±49	5,474
Northwest Passage	Passenger/Cruise	384	21	128	±8	4,282
	Bulk carrier	341	18	114	±53	2,767
Beaufort Sea	Tug	570	40	190	±81	6,600
	Pusher tug	204	14	68	±12	2,482

Values here include all vessel types, except fishing vessels. Total number of transits, 3 year mean (± standard deviation) number of transits by vessel class, and percent of total trips by all vessel types in specified body of water are indicated.

In a study to examine risk of events in the Arctic insurance perspective as a source of information Johannsdottir et al (2021) focussed on cruise ships tourism incidents and analysed 11 case studies from an insurance perspective. They argue that the consequence of such risk can range from economic, business, environmental, sociocultural, and security impacts, which may unfold in the Arctic, presenting risks that may be considerably worse than in other parts of the world. They list the potential consequences of major cruise ships incidents in the Arctic as summarised in Figure 5. They also provide an overview of selected cases as shown in Table 3.

Table 3: Overview of selected cases. (Johannsdottir et al,, 2021).

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Arctic and Antarctica Cases	Location	Cause of Accident	Year of Accident	Dead or Missing	Rescued Alive
TS Maxim Gorky	Svalbard	Collision with an iceberg	1989	n/a	953
MS Explorer	Southern/Antarctic Ocean	Collision with an iceberg	2007	n/a	154
M/V Clipper Adventurer	Coronation Gulf, Nunavut	Grounding on a shoal	2010	n/a	197
M/V Akademik Ioffe	Northwest Passage –Gulf of Boothia	Grounding on a shoal	2018	n/a	162
Viking Sky	Norwegian sea	Engine shutdown; bad weather	2019	n/a	1,373
Non-Arctic and Antarctica cases					
Costa Concordia	Mediterranean Sea	Collision; grounding	2012	32	4,197
MV Estonia	Baltic Sea	Capsized	1994	852	137
M/V Al-Salam Boccaccio 98	Red Sea	Fire on board; sinking	2006	1,031	387
MS Herald of Free Enterprise (Ferry)	Port of Zeebrugge	Capsized	1987	188	351
Rabaul Queen (cargo-passenger)	Solomon Sea–Vitiaz Strait	Capsized; large wave	2012	165	246
Oriental star (Eastern Star or Dongfang zhi Xing)	Yangtze River	Capsized; thunderstorm	2015	442	12

2.3 ANA Security Threats

MARPART et al. (2016) analysed security threats associated with mid latitude regions such as terrorism and violent acts, highlighting that the limitations imposed by the extreme environments, vast distances and lack of infrastructure would likely pose a number of challenges for the planning and execution of such acts. As result of these challenges, the research suggests that any such actions would require significant support and infrastructure, characteristics associated with a limited number of organisations globally, diminishing the likelihood of any such acts taking place. Cottle, and Kern. (2020) lend support to these proposals suggesting that while the United States is focused on monitoring softer security threats such as human trafficking, piracy, and the transport of illegal goods, that the extreme environments of the Arctic limit the scope and opportunity for organised crime generally experienced within maritime law enforcement within mid-latitude regions. The research does however highlight the significant public exposure and interest in the Arctic, particularly in the context of climate change, suggesting a strong possibility of environmental activism and potential destruction of infrastructure. Such actions have the potential to pose a number of challenges for SAR practitioners, as scenarios such as this have the potential to escalate into emergency situations in which ANA practitioners may be required to engage in rescue operations, while containing potential damage to local eco-systems.

Beyond asymmetric threats such as terrorism or piracy, research suggests that the predominant security considerations within the Arctic are that of traditional geopolitical contexts. Research suggests that macro-economic drivers, and potential sovereignty opportunities within the ANA, are resulting in a somewhat re-emergence of *"military concerns"*. Lanteigne (2019) highlight an escalation in activity from numerous global superpowers such as Russia, the United States, Canada and China. Examples of these activities include the re-activation and upgrading of numerous Russian based cold war installations and infrastructure in an effort to support oil and gas exploration activities. Ongoing disputes between the United States and Canada in relation to the North West Passage continue to present friction between the nations in terms of Arctic focuses. China's multifaceted approach to the Arctic which includes influencing policy, investment in infrastructure, exploration, and power projection through military presence, adds further friction to this complex domain. Van der Togt. (2019) lends support to the proposed frictions between nations as result of increased global focuses towards the ANA. While (Van der Togt, 2019) suggests that increased military presences are a cause for concern, it is suggested that while tensions associated with these activities has escalated quickly, the likelihood of conflicts arising as a result of disputes associated with Arctic resources and territories are deemed to be low. This reduced likelihood is proposed to be as a result of the emergent and ever-evolving nature of claims to Arctic territories, and the fact that definitive boundaries associated with sovereignty such as the formalisation of EEZs (Exclusive Economic Zones), continue to be reviewed.

2.4 ANA Risk Analysis

In following on from SAR/emergency management practitioner priorities, this deliverable will provide a means to define and characterise potential seaborne disasters, catastrophic incidents, and security threats in the ANA region. The methodology applied in achieving this definition and categorisation will go beyond traditional work, in not only presenting categorisation, but also tools and mechanisms for practitioners to define and characterise potential future concerns beyond ARCSAR. This deliverable will therefore address the following risk analysis themed objectives:

- To provide tools for strategic decision making in risk assessment
- To provide root cause analysis techniques for operational learning from failures.
- To demonstrate the application of these techniques in the form of analysis of case studies related to the ANA region.
- To provide further information about related bodies of knowledge within the ANA region.

2.4.1 Risk assessment and root cause analysis

When one examines the literature related to risk assessment, an important observation is that risk assessment based on one dimension that relates to probability of occurrence is inadequate for providing a comprehensive view for evaluation (Heinmann, 2005). A two dimensional view that takes into consideration impact in addition to frequency offers a rich framework for selection of appropriate response strategies, necessary for the inclusion of both human and systems approaches. The second

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

observation is that experience gained from learning from failures can be a rich source of generic lessons in terms of longitudinal analysis within the same organization, and in terms of comparisons between similar events in different organizations.

There are five primary accident analysis types, as defined by Stellman (1998): (i) analysis and identification of where, and which types of, accidents occur;(ii) analysis with respect to monitoring developments in the incidence of accidents, which looks at factors that affect the process operation and could lead to accidents and drives the implementation of effective monitoring of preventive activities;(iii) analysis to prioritize initiatives that call for high degrees of risk measurement, which in turn involve calculating the frequency and seriousness of accidents;(iv) analysis to determine how accidents occurred and, especially, to establish both direct and underlying causes; and (v) analysis for elucidation of special areas which have otherwise attracted attention (a sort of rediscovery or control analysis).

The different approaches for treating the organizational dimension of accidents can be classified into three main types, as proposed by Le Coze (2008): research with theorizing purposes, commissions set up for investigating major accidents, and structured root cause analysis methods. Here, we will use the theoretical lens of such classification as a framework. Accordingly, it will be argued that techniques inspired by maintenance and reliability engineering, and decision sciences, can serve as a mental model for understanding the root causes of disaster and can support the decision-making process. A theory will then be built to address the dimensions of learning from failures and will argue that using mental models for the retention of knowledge, in the form of dynamic organizational routines, can contribute to preventing, or limiting, the 'unlearning' process.

Research indicates that organizations learn more effectively from failures than from successes (Madsen and Desai, 2010), that failures contain valuable information but organizations vary at learning from them (Desai, 2010), and that organizations vicariously learn from failures and near-failures of others (March, 1991;Kim and Miner, 2007; Madsen, 2009).

It is generally accepted, however, that learning from failures is a difficult process to assess. Few authors have attempted to define it. Organizational learning from failures has been defined by Madsen and Desai (2010) as any modification of an organization's knowledge occurring as a result of its experience. But again it is acknowledged that a change in organizational knowledge is itself difficult to observe. Subsequently, there has been a trend in research which argues that changes in observable organizational performance reflect changes in organizational knowledge (Baum and Dahlin, 2007; Argote, 1999). Another line of research has tried to explore ways of learning. For example, Carroll *et al.* (2002) proposed a four-stage model of organizational learning that reflected different approaches to control and learning.

Also, Chuang et *al.* (2007) developed a model of learning from failure of healthcare organizations that highlighted facilitating factors.

Organizations learn when individual knowledge is codified, synthesized and transformed into new technologies, training programs, policy, regulations, plans and organizational structure (Zolloa and Winter, 2002). Organizational learning can happen not only across hierarchical levels of the organization through transformation between tacit and explicit knowledge (Nonaka and Takeuchi, 1995), but can also occur within organizational routines (Feldman, 2000). Pentland *et al.* (2012) argue that routines have been theorized as a primary mechanism for organizational learning and, citing Levitt and March (1988), they argue that routines tend to improve over time, at least in the early stages of formation (Argote and Epple, 1990; Narduzzo *et al.*, 2000; Rerup and Feldman, 2011; Zollo and Winter, 2002).

Rare events have traditionally been on the margin of mainstream research in organizational learning, as they are often set aside as mere statistical outliers (Lampel *et al.,* 2009). However, a special issue of Organization Science in 2009 was dedicated to rare events and organizational learning. The editors (Lampel *et al.*, 2009) proposed a taxonomy of learning based on two categories: the impact of rare events on the organization, and their relevance to the organization. Based on those, they identified four classes of events: transformative, re-interpretative, focusing, and transitory. They then mapped the works of Beck and Plowman (2009), Christianson *et al.* (2009), Madsen (2009), Rerup (2009), Starbuck (2009) and Zollo (2009) into those classes. Using this theoretical lens, this report will examine disasters that have had high impact and hence may be regarded as either transforming or focusing depending on their degree of relevance to the specific ANA stakeholders organizations. However, there will also be a review of generic lessons that are applicable to a wide range of industries.

Lampel *et al.*, (2009) argued that further research is needed on how organizations can learn, and adapt their routines, following rare events in other organizations. They argued that the aviation industry is a good example, in which the lessons from accidents, near accidents, and the possibility of accidents are codified into rules and practices that change how airlines operate (Tamuz, 2000; Lampel, 2006).

2.4.2 Applying risk based perspectives to ANA contexts

Specifically for the Arctic, recent work has been done to provide a risk-based approach for determining the future of shipping on the Arctic (Christensen, et al, 2019), where they investigated associated with Arctic shipping along the Northern Sea Route (NSR) connecting European and Asian ports, and its alternative such as the southern sea route (SSR) through the Suez Canal. In this context, risk factors are defined as 'any external factors causing or contributing to an incident while at sea', including among others collision, and foundering that are not caused by human error or mechanical failure. Such factors

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

were prioritised (as percentage) in terms of both frequency and severity of cases, and the assessed risk where found to be comprising of wind speed (28%), wave height (28%), distance to ports (28%), icebergs (9%) shallow waters (7%). In addition, (Johannsdottir & Cook, 2019) investigated a systemic risk approach of maritime-related oil spills viewed from an Arctic and insurance perspective. They compared the economic and environmental impact of the two cases of oil spills of Exxon Valdez and BP Deepwater Horizon and proposed ecosystem-based management. Other work compiled the marine accidents/incidents which are recorded by Marine Accident Investigation Branch (MAIB) as occurring north of 66_330 in the years from 1993 to 2011 and attempted to apply root cause analysis (Kum, S & Sahin, 2015). In addition other work (Marchenko et al, 2018) investigated categories of risks and emergency in Arctic Shipping, and classified the Arctic shipping risks based on factors related to incident type, scale and location. This work is further discussed in the later sections of this report.
There is evidence of a lack of research into how the learning process can emerge or how to use models that can facilitate the process of learning from failures and extracting generic lessons. More specifically, there is a lack of research into how this learning can be dynamically fed back into organizational routines.

2.5 The Role of Search and Rescue (SAR)

2.5.1 The role of SAR services in responding to Arctic Accidents:

It has been acknowledged in the literature that research into the responsibilities for maritime emergency preparedness and rescue in the Arctic is limited (Kruke, and Auestad, 2021). The authors focus on JRCC in Norway and in particular on Svalbard which is situated in the High North of the Arctic. Hence it provides a good example in terms of SAR challenges within the Arctic where remoteness, in combination with low temperatures, wind and darkness, are the major factors affecting the ability to perform tasks correctly within allotted time. In addition, communication is difficult, and support may be far away. This is mainly due to the region's high latitude which affects navigation and communication systems as well as the quality of ice imagery information. Thus radio, satellite and data communication systems lack the necessary reliability in the Arctic. In addition, wildlife threats such as polar bears may also threaten humans and rescue operations.

Kruke, and Auestad (2021) study two cases that occurred in Svalbard (the Maxim Goriky in 1989, and the Northguider in 2018). They identified that the common denominator in these accidents is "*a swift mobilization and deployment of SAR-helicopters, or the presence of vessels of opportunity, as some sort of spontaneous volunteer*". The same authors were also involved in SARex exercises in 2016 and 2018. From these exercises they learned that preparedness kits are not suitable for the Arctic climate conditions, despite the fact that they mostly adhere to the IMO Polar Code. They also observed that requirements for rescue equipment for passenger ships are not adapted to the rapidly changing and severe Arctic climatic conditions.

They concluded that the limited rescue capacities in the Arctic and, even when adhering to the Polar Code, ship crew and passengers without the required equipment, competence and physical capacities for own rescue for a period of minimum five days, make survival challenging. To meet such challenges, they recommend the following: 1) Improvements in proper response by the crew and passengers on board the ship in distress. In Arctic waters, the nearest ships may be far away. Thus, much responsibility rests on the shoulders of the crew and passengers themselves. They therefore are the first responder. 2) Ensure availability of vessel of opportunity. 3) Ensure adequate professional response services. Thus, the preparedness to meet the special Arctic challenges following a ship accident is jointly formed by preparations conducted by the ship owners (relevant knowledge and equipment), the abilities of ship crew and passengers to handle the initial response, the prompt mobilization and deployment of professional response agencies, and, last but not least, of available vessels of opportunity.

According to Cruise traffic in Norwegian waters, 2022, "*In the event of a serious accident involving a larger cruise ship, there is reason to expect a large number of injured people who will need follow-up health care both in an emergency phase and in the somewhat longer term. Especially in the emergency phase, there is reason to believe that the health care system in many parts of the Arctic is not dimensioned to handle up to thousands of injured people"* pp, 22,23. The report highlights this as being most evident in areas such as Svalbard and northern Norway, where due to the long travel distance to official health resources, it may become necessary to create an emergency camp on shore or ice in the interim period of waiting for rescue resources. In a location such as Svalbard, the establishing of emergency camps is affected by numerous challenges such as low temperatures, expansive distances, and weather conditions, additionally the risk of polar bear attacks must be considered in these particularly vulnerable areas. According to the Polar Code, cruise operators are responsible in these situations to be prepared and ensure that they are suitably equipped to take care of passengers and crew until help arrives. (Cruise traffic in Norwegian waters, 2022).

2.5.2 SAR call-out data

2.5.2.1 Frequency of SAR Event: Nature of Event

Data from Norway indicated the most common (639) nature of event to be 'Assistance to Vessels' which accounted for 7.8% of all SAR operations in Norway in 2021, this was a decrease on the 2020 figure of 863 operations continuing a trend on 2020 and 2019 (HRS, 2022).

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

There were 317 incidents of Drifting recreational boat/minor object operations accounting for 3.9 % of total SAR operation in Norway in 2021 (HRS, 2022). Of more serious incidents Norway reported 98 'Fire onboard', 236 'Groundings' and 56 incidents with offshore installations. All of this out of a total of 2739 Maritime incidents.

2.5.2.2 *Frequency of SAR Event: Costs and Losses*

When asked to estimate the change in monetary cost of dealing with search and rescue events, from now to 2040 (at today's prices), respondents in a recent survey of coast guards from the Faroe Islands, Iceland, Canada and the UK gave responses as shown in Figure 6.

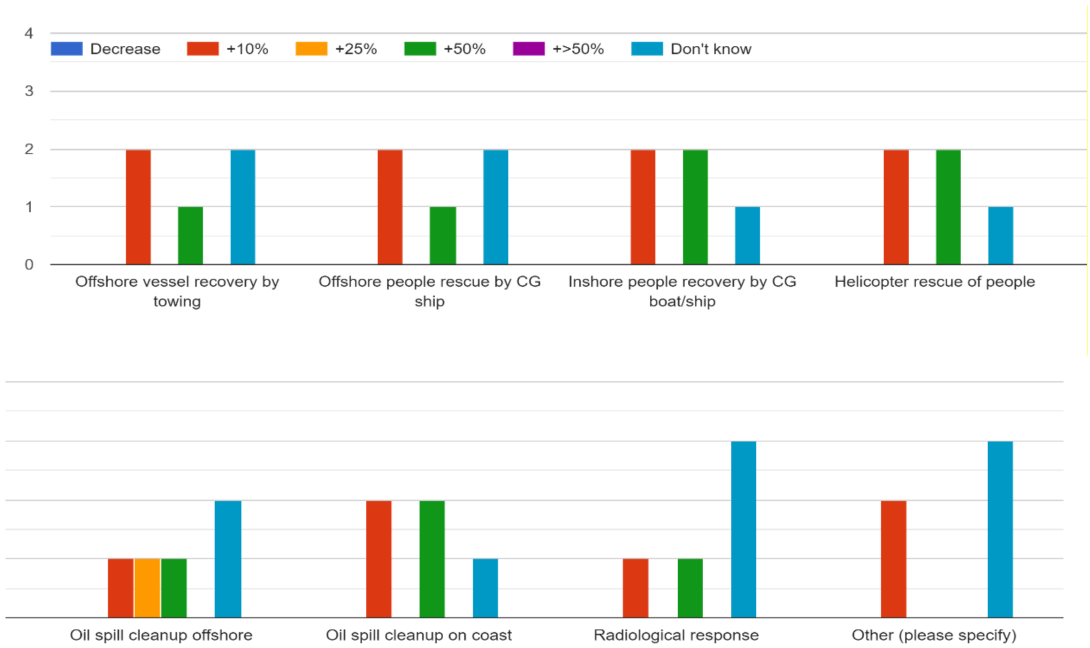
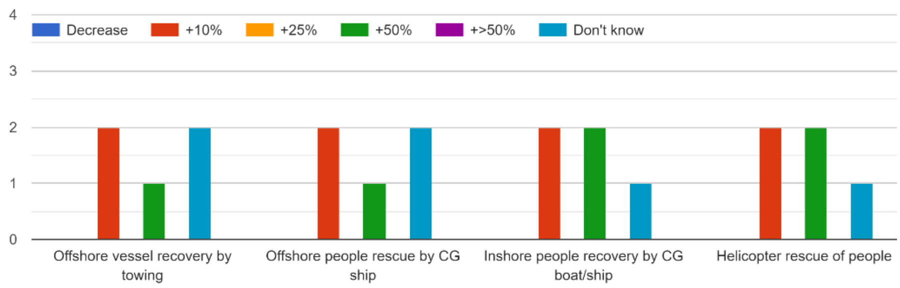


Figure 6: Estimated Change in Monetary Losses from SAR Events, from now to 2040 (at today's prices)

While the results of the survey hold much uncertainty about the change in the monetary cost of search and rescue operations over the coming decades, one thing is clear, there were no respondents who estimated that the monetary cost was going to decrease. See Figure 6 and Figure 7.

The high level of 'don't know' answers is reflective of the scant literature available on this area.



This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

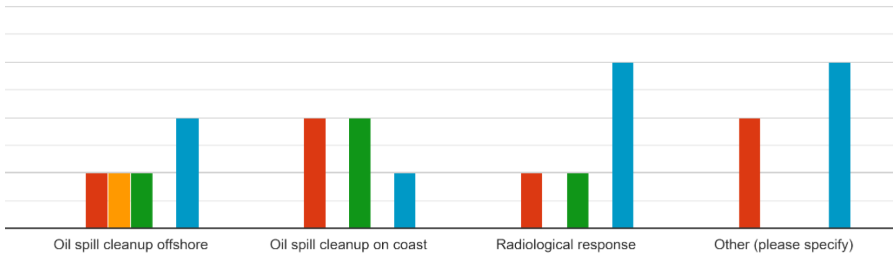
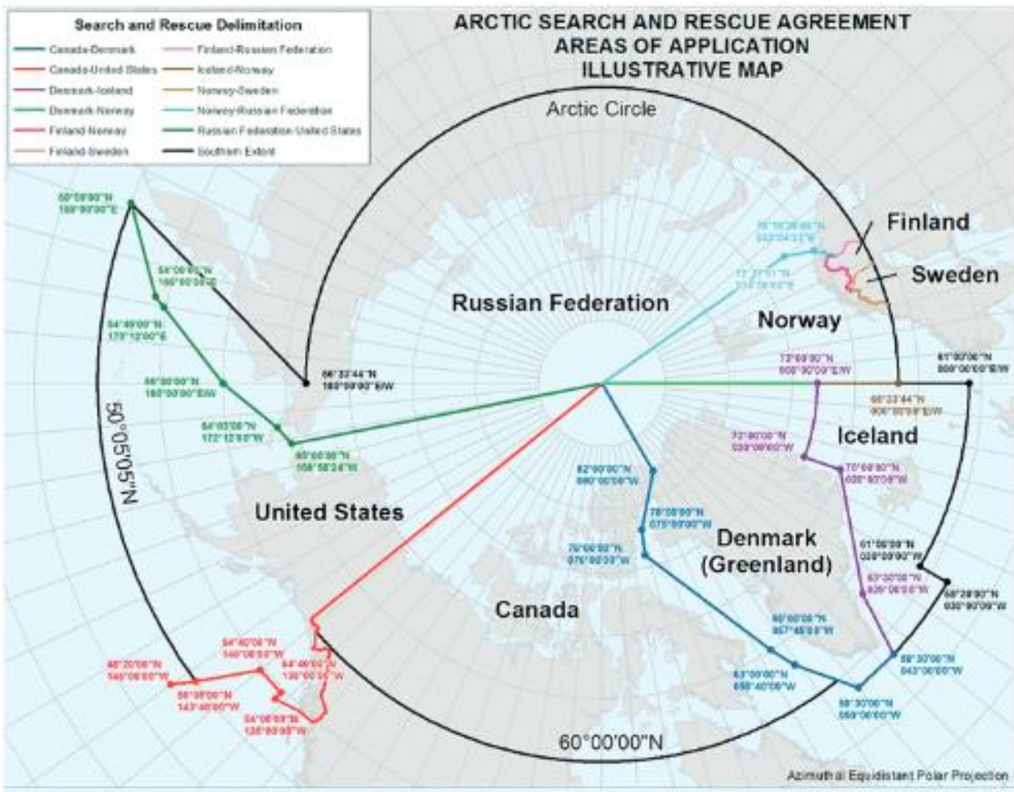


Figure 7: Estimated Change in Monetary Cost of dealing with Events, from now to 2040 (at today's prices).

2.5.3 Analysis of how SAR is expected to evolve in the coming decades

The commitments for Search and Rescue cooperation plans are established by the International Maritime Organization (IMO). The raison d'être for these, is to increase mutual understanding, in order increase the efficiency of response operation and minimize losses (Cruise traffic in Norwegian waters, 2022, pp, 19). The Arctic Search and Rescue Agreement is an international treaty concluded among the Arctic Council member states — Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States is one of the many active agreements. The treaty coordinates international search and rescue (SAR) coverage and response in the Arctic and establishes the area of SAR responsibility of each state party (Arctic Council, 2011).



This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Figure 8: Arctic Search and Rescue Agreement Areas of Application (Arctic Council, 2011)

The predicted increase in levels of activity in the Arctic region, there is also a higher risk of a major incident occurring.

In a recent survey, international coast guards were asked to estimate the change in Frequency of SAR Events, from now to 2040 in terms of nature of event and cost impact – see results in Figure 9. These show a general expectation among Coast Guards of increasing numbers of SAR callouts and higher costs, albeit that they do not report any research to quantify these data in any detail.

A Faroese Coast Guard Survey Participant referenced increased tourist activity, posing a higher risk of incidents that SAR operator will need to respond to *"Increasing number of tourist activity will create a bigger risk for SAR incidents*" - Faroese Coast Guard Survey Participant

Countries in the Arctic region are aware that if an incident should happen in the area, one country's SAR system would on many occasions not be sufficient to handle the incident in an appropriate manner (Arctic Council, 2011). Thus, with regards to how search and rescue operations are expected to evolve, it is expected that the need for collaboration will only be strengthened.

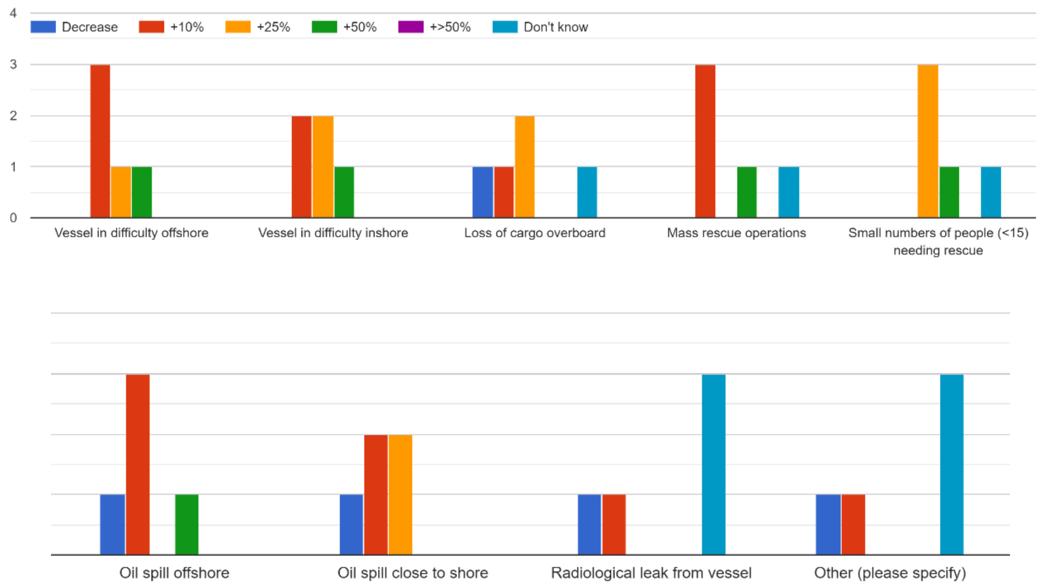


Figure 9: Estimated Change in Frequency of SAR Events, from now to 2040

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

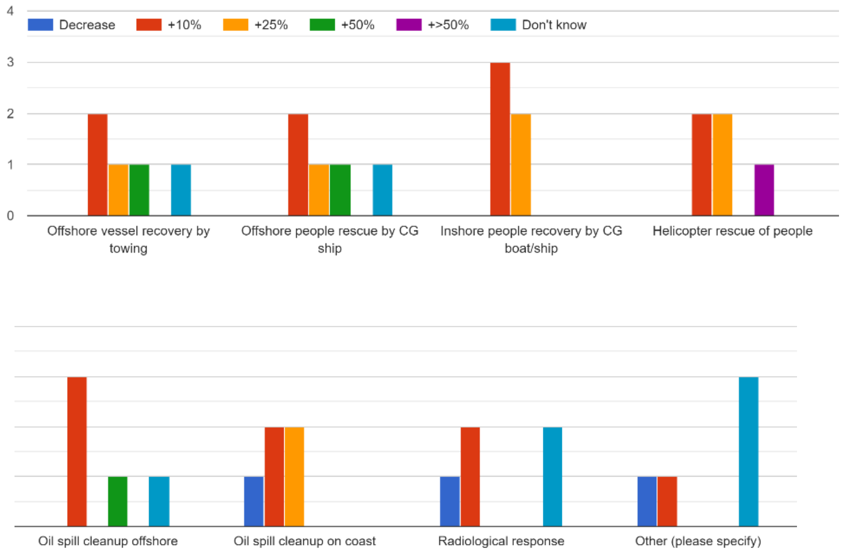


Figure 10 Estimated Change in Cost of SAR Callouts, from now to 2040

2.5.4 Analysis of the readiness of the existing SAR system

"Reliable and well-known intercommunication systems are important for safe navigation, search and rescue and emergency communication" - Cruise traffic in Norwegian waters, 2022, pp15. In response to the extensive development of satellite-based broadband solutions has been underway in the High North. An example of this is in Svalbard, where there are limited rescue and health resources over expansive distances. Further to this extreme weather and ice condition variance add unpredictability to the situation. *"A majority of the committee members therefore believe that a limit of 500–750 people on board cruise ships should be introduced in the territorial waters of Svalbard"* (Cruise traffic in Norwegian waters, 2022, pp, 14)

According to Cruise traffic in Norwegian waters, (2022) report, ships sailing in Norwegian waters have varying technical and safety standards for example many cruise ships do not have propulsion machinery with real redundancy, so in the event of an engine shut down, there is a risk of complete propulsion loss. This is due to fact that the requirements for technical safety on cruise ships have been developed over time, with structural engineering requirements not introduced with retroactive effect.

Any coordinated handling of serious incidents requires a commonly understood approach to situational awareness, communication and air coordination and can be decisive for the outcome of the response to the incident.

The report admits that there is challenge associated with establishing a joint understanding of what the situation is during major actions, and one of the reasons for this is the variance in communication

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

platforms. "*In the event of an incident with a larger cruise ship, it will often be necessary to use more helicopters".* Based on this the report suggests that effective air coordination is particularly important and that work on the concept of air coordination should be intensified further. (Cruise traffic in Norwegian waters, 2022).

3 Background of the Decision Making Grid

Safety and security domains are similar in that they deal with prevention and management of hazardous incidents or threats; the main difference relates to intent. It can be observed that the evolution of subsequent generations of research and development in safety and security disciplines can be summarised comprising four generations in terms of their increasing value. The First Generation is characterised as being '*descriptive*' in nature and aims to answer the question of '*What happened?*'. The Second Generation is characterised as '*diagnostic*' and aims to answer the question of '*Why did it happen?*'. The Third Generation is characterised as '*prognostic*' and aims to answer the question of '*When will it happen?*'. Finally the Fourth Generation is characterised as '*prescriptive*' and aims to answer the question of '*What must be done?*'. Hence the highest value in this classification is the prescriptive nature of models in order to strategically, and dynamically, inform the decision maker on what policies, strategies, or actions should be carried out. Hence, one of the approaches towards classifying different risks within the ARCSAR project can be achieved through a prescriptive grid with respect to the assessment of the users such as coast guards in terms of the challenges they face in both safety and security. This section will therefore provide a theoretical background, and case study application example in order to demonstrate and validate the proposed tools to be used for assessing risks within the ANA. These tools will facilitate ARCSAR efforts in defining and categorising potential seaborne disaster to be considered throughout ARCSAR research efforts, while also presenting tools and mechanism which can be applied by emergency management practitioners beyond the ARCSAR project. The basic idea of decision grids is that they aim to provide a visual representation based on two or more criteria, and hence the term 'multiple criteria', and they therefore directly address the prescriptive requirement in strategic decision-making. Examples of such grids are the Decision Making Grid (DMG) (Labib, 2004; 2014), and Jack-Knife Diagram (JKD) (Knights, 2001). For a review of both DMG (3x3 grid) and JKD (2x2 grid) see Seecharan et al (2018).

In our methodology we construct a revised structure of the DMG, The grid can be based on data related to perceived risks. It can be noticed that such grid is similar to a risk assessment of frequency x severity, or some would rather frame it instead as *risk = probability x consequence*. However, the main difference

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

is that here it is of a '*prescriptive*' nature. As in a classical risk assessment a score of high frequency low severity is equal to a score of high severity low frequency, whereas in a prescriptive approach both types of risk require different strategies.

3.1 Lessons learnt from the maintenance and reliability field

To help clarify the background of the DMG, we will examine its application in the maintenance management function. There are many similarities between maintenance and safety, both in general and with particular respect to routines. Maintenance deals with breakdowns of equipment, whereas safety may be dealing with disasters. Maintenance has preventive maintenance instructions which are in many ways similar to routines in safety. Maintenance has both reactive and proactive modes, whereas in safety we deal with response to disasters in a corrective mode, and enhance resilience in a proactive mode. So, maintenance in the form of models, and safety in the form of learning from failures can be combined to form a theory of dynamic adaptive routines in organization learning.

It is widely acknowledged that safety is created through proactive resilient processes, rather than through reactive barriers and defences (Wood and Hollnagel, 2006). The transformation from reactive to proactive modes in maintenance and reliability can be achieved, broadly speaking, via two schools of thought: human-oriented and system-oriented. In short, maintenance policies can be broadly categorized into the technology or systems-oriented (systems, or engineering) on the one hand, and the management of human factors oriented, and monitoring and inspection oriented on the other (Labib, 2008).

3.2 Human-oriented approach based on the TPM concept

Total productive maintenance (TPM) is a human factors-based concept in which maintainability is emphasized. It originated from the Japanese manufacturing systems (Nakajima, 1988; Hartmann, 1992; and Willmott, 1994), and is a tried and tested way of cutting waste, saving money, and making factories better places in which to work. It gives operators the knowledge and confidence to manage their own machines. Instead of waiting for a breakdown, and then calling the maintenance engineer, they deal directly with small problems, before they become big ones. Operators investigate and then eliminate the causes of minor and repetitive machine errors. Also, they work in small teams to achieve continuous improvements in the production lines.

One of the underpinning elements of TPM is the skill levels needed and the transformation of some of the basic maintenance skills from maintenance engineers to the front-line operators in production, and hence the term 'productive maintenance'. The designer of the machine is not usually the one who, on its failure, fixes it and, surprisingly, might not even have the ability to do so. For example, skills needed to restore equipment may include diagnostics, logical fault finding, disassembly, repair and assembly.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Depending on the level of complexity of the particular equipment, as well as on the level of complexity of the function that it carries out, the necessary skill level can be determined.

According to a survey conducted by McDonald (2006) of aircraft maintenance technicians, they reported that in approximately one third of the tasks they did not follow the routine procedure according to the maintenance manual. They felt that there were better, quicker, and even safer, ways of doing the task than following the manual to the letter. McDonald (2006) argued that manuals themselves are not an optimum guide to task performance as they have to fulfil other criteria, such as being comprehensive, and up-to-date. The question is: How to bring operator requirements to the forefront of the design process? Or how to feedback the knowledge, skills and experience of the operator who is, day in and day, out in front of the machine, to the designer? In a crisis, the skill levels and types needed constitute a major dilemma because disasters tend to be multi-disciplinary problems. They can span various fields such as information systems, maintenance, decision-making, and crisis and risk management, and hence there is a need for a synchronized multidisciplinary team approach.

3.3 Systems-oriented approach based on the RCM concept

Reliability Centred Maintenance (RCM), originated in the aviation industry, is a system and technologically-based concept in which the reliability of machines is emphasized. The name was originally coined by Nolan and Heap (1979).It is a method for determining the maintenance strategy in a coherent, systematic and logical manner (Moubray, 1991; Netherton, 2000). It offers a structured procedure for determining the maintenance requirements of any physical asset in its operational context, the primary objective being to preserve system function. The process consists of looking at the way equipment fails, assessing the consequences of each failure (for production, safety, etc), and choosing the correct maintenance action to ensure that the desired overall level of plant performance (i.e. availability, reliability) will be met.

One of the underpinning elements of RCM is the routine of root cause analysis. When performing reliability analysis investigation using tools such as FTA, the main aim is to identify the root-causes (i.e. at the bottom of the tree). These basic events are considered to be the ‘leaves’ of the tree, the initiators or ‘root causes’. Here the term ‘root cause’ needs to be treated with care and it is also important to differentiate between the concept of root cause for machines or equipment as compared with that for a disaster or an accident.

In an accident investigation, if root cause is perceived as, for example, someone’s behaviour then it may be likely, as argued by Rasmussen (1997), that the accident could occur by another cause at another

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

time. We agree that, in this example, such a root cause is superficial and should be regarded as still part of the symptom rather than the real root cause. A real root cause needs to be plan- and policy-related with respect to the current *status quo*. As such, ideally a root cause should lead to initiation or modification of a routine in the form of Standard Operating Procedures (SOPs). When digging deeper to find a real root-cause, the answer is the keyword phrase of 'lack of procedures' to do a certain task. We are looking for a *status quo* that is not acceptable, a lack of existing standard. Hence resolving this issue (through establishing a new routine that is currently missing) will lead to establishing a generic solution that will solve many similar problems.

3.4 The Decision-Making Grid

Here, we shall revise and extend the Decision-Making Grid (DMG) originated by the author (Labib, 1998 and 2004) and which has been tested by organisations for the selection of appropriate maintenance strategies for machines on the shop-floor of a manufacturing environment or process industry (Fernandez *et al.,*2003; Burhanuddin, 2007; Tahir *et al.,*2008; Zainudeen andLabib, 2011). The DMG acts as a map in which the the worst machines are represented according to multiple criteria of their performance. The objective is to identify appropriate actions that will lead to the movement of the machine location, on the grid, to positions indicating improved states with respect to the multiple criteria of performance in terms of frequency and downtime.

The revised model proposed here will be different from this in two ways: it will be applied to learning from disasters, and it will address the incorporation of organizational routines. The scale of the frequency axis will be based on the rate of failure, or on the incidence of chronic problems, whereas the significance axis will be based on a measure of the acuteness of the incident (i.e. of its severity, cost, etc).

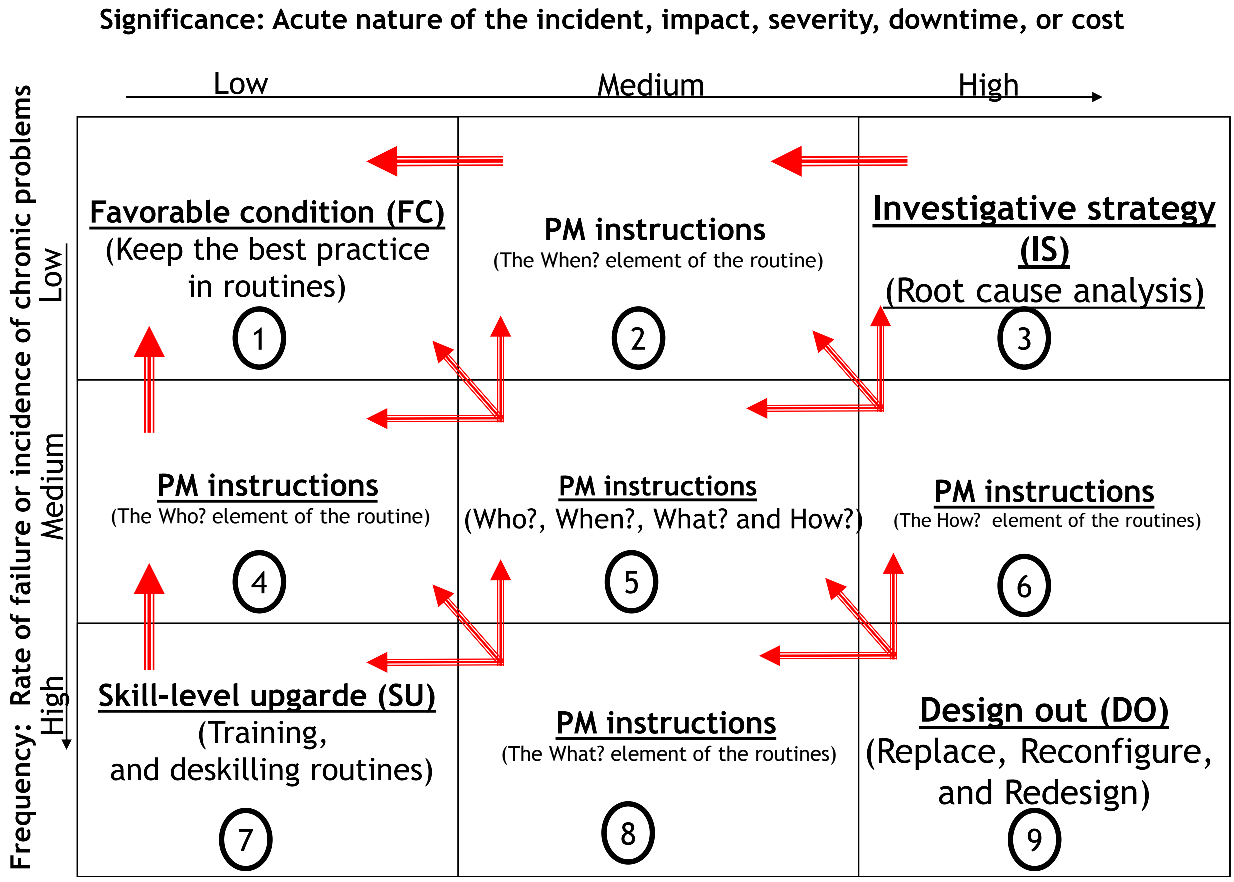


Figure 11: Frequency/Significance grid for deciding routines to meet threats of a given incident.

Events occurring on any asset (e.g. equipment or artefact) are plotted with respect to their relative performance, i.e. as regards their frequency and significance (see Figure 11). The objective is then to implement appropriate strategies that will lead the movement of the representation of each asset towards location on the grid indicating improved status.

The procedure is as follows:

(i) Criteria analysis: Establish Pareto analysis of the criteria, in terms of relative significance and frequency. For a disaster these would be expressed as 'acute-ness' and 'chronic-ness' as opposed to the 'downtime' and 'frequency' of the traditional DMG.

(ii) Decision mapping: Map the criteria on the matrix, i.e. plot each event for any asset on the grid.

(iii) Decision support: Identify an action, based on the suggested strategy, to be implemented.

The next section will explain the suggested safety measures in the case of learning from failures, and the impact of this on routines.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

3.5 Suggested strategies

Here, we will first address the 'extreme case' strategies, i.e. those indicated in Boxes 1, 3, 7 and 9 of Figure 11(i.e. at the corners of the grid), and then those indicated in Boxes 2, 4, 5, 6 and 8(the other less extreme cases).

1. **Favourable Condition (FC):** Box 1, low significance and frequency. Compared to others, the asset fails rarely, and failure is insignificant, i.e. only just noticeable. We would wish all events to fall in this category and the aim is to suggest appropriate strategies for the events indicated in the other boxes so that their indications would move towards this box. In the safety domain, this region is about sustaining current practice, i.e. business as usual, and hence keeping the *status quo* with respect to the routines for the assets concerned.
2. **Investigative Strategy (IS):** Box 3, breakdowns are infrequent but restoration of the asset takes a relatively long time. In the maintenance function the asset is perceived as problematic 'a killer' (Labib, 2004); in the safety field, a high significance event but a rare one, which can feature in a disaster. Whenever an airliner crash occurs, it is of extreme severity (incurring deaths and the loss of the plane). But nobody ever heard of the same airplane (asset) crashing twice: a case of extreme rarity. In such an eventuality, search teams look for the black-box flight recorder, which monitors, as much as possible, every detail of the flight prior to the crash. The strategy investigative, the focus being to find the root cause and make recommendations (new routines) in order to either eliminate the possibility of re-occurrence of such a crash or to mitigate the impact of such an event. The idea of using the black-box device - in many ways similar to condition-based maintenance (CBM), which relies on measuring vibration, acoustic emissions, etc - is to maximize access to data, in a situation which, due to the rarity of its occurrence, offers minimal opportunity for collecting information, and hence for an investigative approach.
3. **Skill-Level Upgrade (SU):** Box 7. In the maintenance field this could refer to a task on a machine that is visited many times (high frequency), but for limited periods because the task involved is easy to complete (low downtime). Upgrading the skill level of the operator is key, so that this relatively easy relatively easy task can be reliably assigned to the operators after upgrading their skill levels. Another variation of this strategy is to upgrade the machine so that its maintenance (the diagnosis or preventative measures required) is 'deskilled'. For example, in modern paper photocopier machines, one of the relatively frequent events, which is also relatively simple to fix, is the paper jamming inside the machine. Hence, we make it easier for a normal person (operator) to fix it, rather than calling a maintenance engineer, by installing a display that shows the structure of the photocopier and the location of the jammed paper.

Also, when the doors of the photocopier are opened we notice that the knobs and levers that can be accessed are coloured in an attractive green or blue, making it easier to identify which parts to touch or not. Then, when the job is finished the doors are designed in such a way that if a certain lever is left in the wrong position, the doors will not shut. Again, the idea is to 'deskill' the routines needed to respond to such frequent non-significant problems. In the safety domain, we are here addressing frequent incidents of low impact and the suggestion is to focus on training and on raising awareness of how to implement, in the most efficient way, safety measures and SOPs as routine, either by upgrading the skills of the operators involved or by deskilling the routines needed to respond to such incidents. In the safety domain a good example is the near-miss, a situation where a bad outcome could have occurred except for the fortunate intervention of chance (Dillon *et al*, 2012).

4. **Design Out (DO):** Box 9, the most crucial area in the grid. In maintenance, machines in this category are recommended for major design-out or overhaul projects. This is because they experience high downtime with high frequency. In the safety field we are dealing here with a disastrous situation that has been repeated e.g. NASA's Challenger and Columbia, and BP's Texas City and Deepwater Horizon events. The strategy is to examine a situation that is currently not fit for purpose and to re-configure or re-design it. Either terminate the *status quo* (e.g. stop the space shuttle program), or adopt a resilience approach, with a fundamental reconfiguration of organizational structure with the emphasis on preventing re-occurrence, minimizing its impact, and increasing ability to detect and monitor (A combination of strategies suggested in Boxes 3 and 7). Note here that both Boxes 3 and 9 indicate the same degree of significance, but the strategies suggested are very different, because they need two different mindsets for framing the problem. This aspect, of mindset, will be described in the section entitled Theoretical Framework and Discussion.

5. **PM instructions routines:** Boxes 2, 4, 5, 6 and 8. If one of the antecedent events is of medium significance or medium frequency, the suggestion is to focus on modifying the current preventive routines, and on their nature. Consider, for example, a simple PM routine with respect for a car. It might be as follows: *"Change the oil filter, the mechanic to use a certain spanner, every six months or every six thousand miles, whichever comes first"*. This simple instruction contains several features, i.e. *when* or how often it takes place (every six months or every six thousand miles), *who* will carry it out (the mechanic as opposed to the driver), *how* it will be done (using a certain spanner), and *what* is the nature of the instruction itself (change the oil filter), Hence it raises 'when?', 'who?', 'what?' and 'how?' types of questions.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

The adaptive feature of *ostensive* routines contains three issues: the need to generate new routines, the need to get rid of non-effective ones and the need to prioritize existing ones, whereas the adaptive feature of *performative* routines contains two main issues: regarding the relative 'easy' aspects of the PM instructions, such as who will perform the routine (a skill-related issue) and when it will be performed (a timing or schedule-related issue), and relatively 'difficult' aspects such as what is the nature or content of the instruction and how will the instruction be performed? In order to appreciate why the former issues are relatively easy, consider the case of giving a drug to a patient to prevent a disease as an analogy to applying a PM instruction/routine in maintaining certain equipment. The easy issues/questions concern who will administer the drug and the suggested dose, whereas the relatively difficult issues relate to questioning whether it is the right drug in the first place (a diagnostic expert skill is needed here) and how to perform the instruction in the right way (again a matter of high expertise). In the safety field, this is the region where we analyze our existing PM routines, basic checks of systems, safety barriers, and back-up systems. However, not all of the boxes that indicate a medium component are the same as we shall now see:

I. **Easy aspect of the PM routines:** This is concerned with the '*who*' and '*when*' type questions of the routine: There are some regions, such as those indicated by Boxes 2 and 4, that are near to the favorable top left corner of the grid (Box 1), which are concerned with the relatively "easy" aspects of preventive routines. Hence, they require re-addressing issues regarding '*who*' will perform the instruction or '*when*' the instruction will be implemented. For example, in some cases the issue may be about who will carry out the instruction - operator, maintenance engineer, or sub-contractor–which, would suggest that this applies to Box 4 situation, that box having a border with Box 7 that relates to the type of skills needed (a '*who*' question), and the aspect of the PM instruction is relatively 'easy' to implement, which normally denotes either a '*who?*' or a '*when?*' type of question. The '*when*' type question in the routine is also based on the same line of argument; if the event is located in Box 2 due to its relatively higher significance (or in maintenance words its higher 'downtime'),then the timing of instructions needs to be addressed which is a '*when?*' type of question with respect to the preventive routine.

II. **Difficult aspect of the PM routines:** Other preventive routines, such as the ones related to Boxes 6 and 8, need to be addressed in a different manner. Again, the' difficult' issues here are those related to the contents of the instruction itself. It might be the case that the wrong problem is being solved, or that the right one is not being

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

solved adequately. In other words, we are giving the patient a drug at the right time and in the right dose, but unfortunately it is not the right drug in the first place. In this case routines need to be investigated in terms of the content of their instructions, and expert advice is needed regarding the type of routines being implemented, the '*what?*' and '*how?*' types of question. These two types of 'difficult' question apply to Boxes 6 and 8 since they have borders with the 'worst' box Number 9. For a Box 6 routine the issue concerns the '*how*' aspects, as the time factor being the main problem in this case. As for a Box 8 routine, the issue is the '*what*' aspects, since the frequency of the event is high, which indicates that the routine in question is not fit for purpose. Figure 12 indicates the 'easy' and 'difficult' parts of the routines.

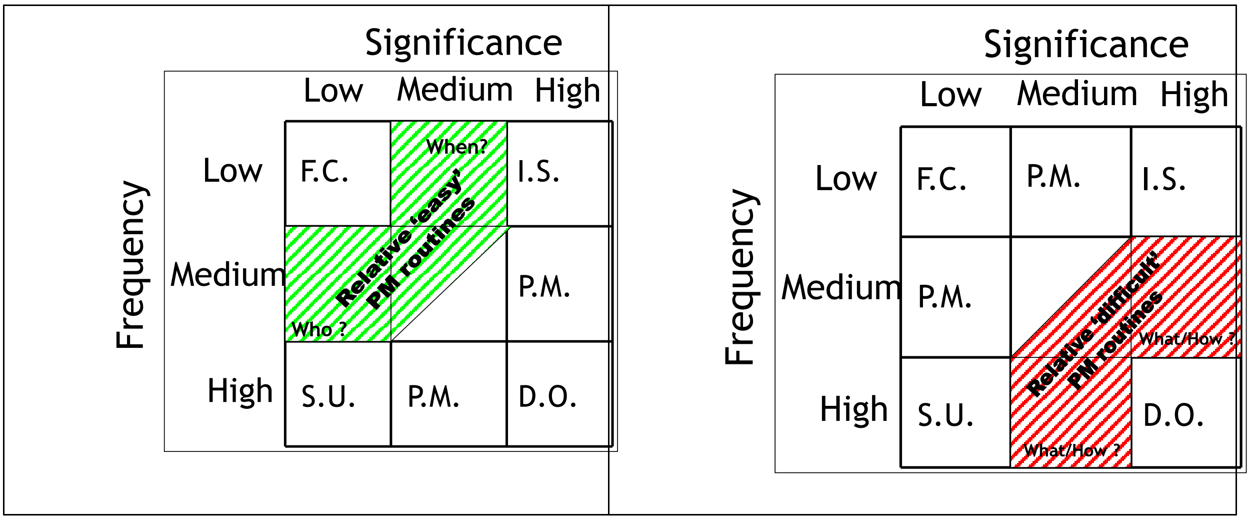


Figure 12. 'Easy' and 'Difficult' aspects of PM routines

Figure 1 also indicates that the human-oriented approach based on the TPM concept tends to occupy the bottom left triangle of the diagram, whereas the systems-oriented approach, based on the RCM concept, tends to occupy the top right triangle, as further illustrated in Figure 13.

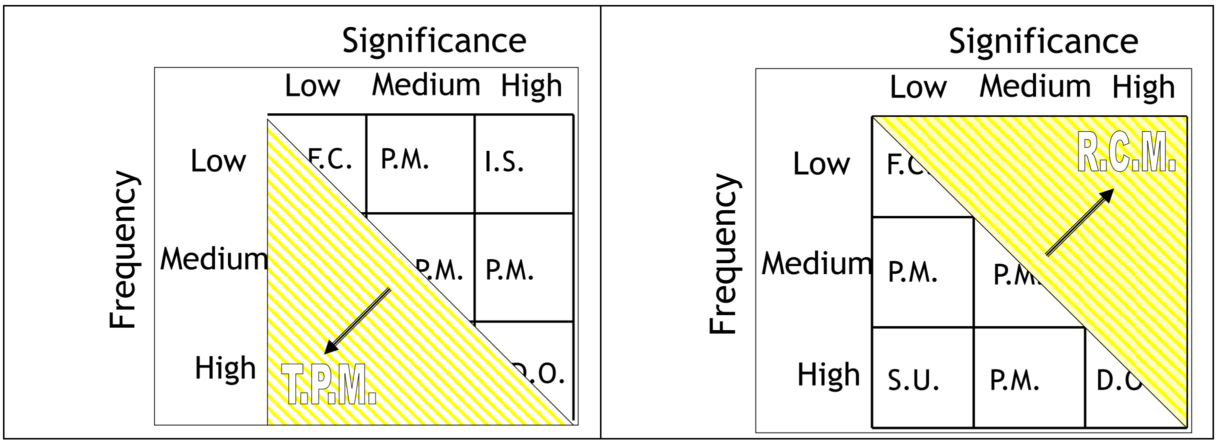


Figure 13. The TPM (human-factors-oriented) approach versus the RCM (systems-oriented) approach

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

The main contribution of the proposed Frequency/Significance grid is its provision of a classification of suggested strategies for different aspects of routines, depending on the relative performance of events as indicated by it. Thus, it represents a dynamic feedback approach to routines in a dynamic environment.

3.6 Case Study of Applying the Proposed Model to a Disaster Analysis

In one near-miss event, NASA's space shuttle, despite having undergone a Design-Out (DO) program, had to be repaired during a mission, on the discovery of a misplaced tile, by an astronaut with the help of a robotic arm. The damage could have resulted in a repeat of a catastrophic failure. The question is how can one use the proposed model to map the different stages through which the shuttle had gone, starting from the Design-Out Stage?

The basis of a possible solution is shown in Figure 14.

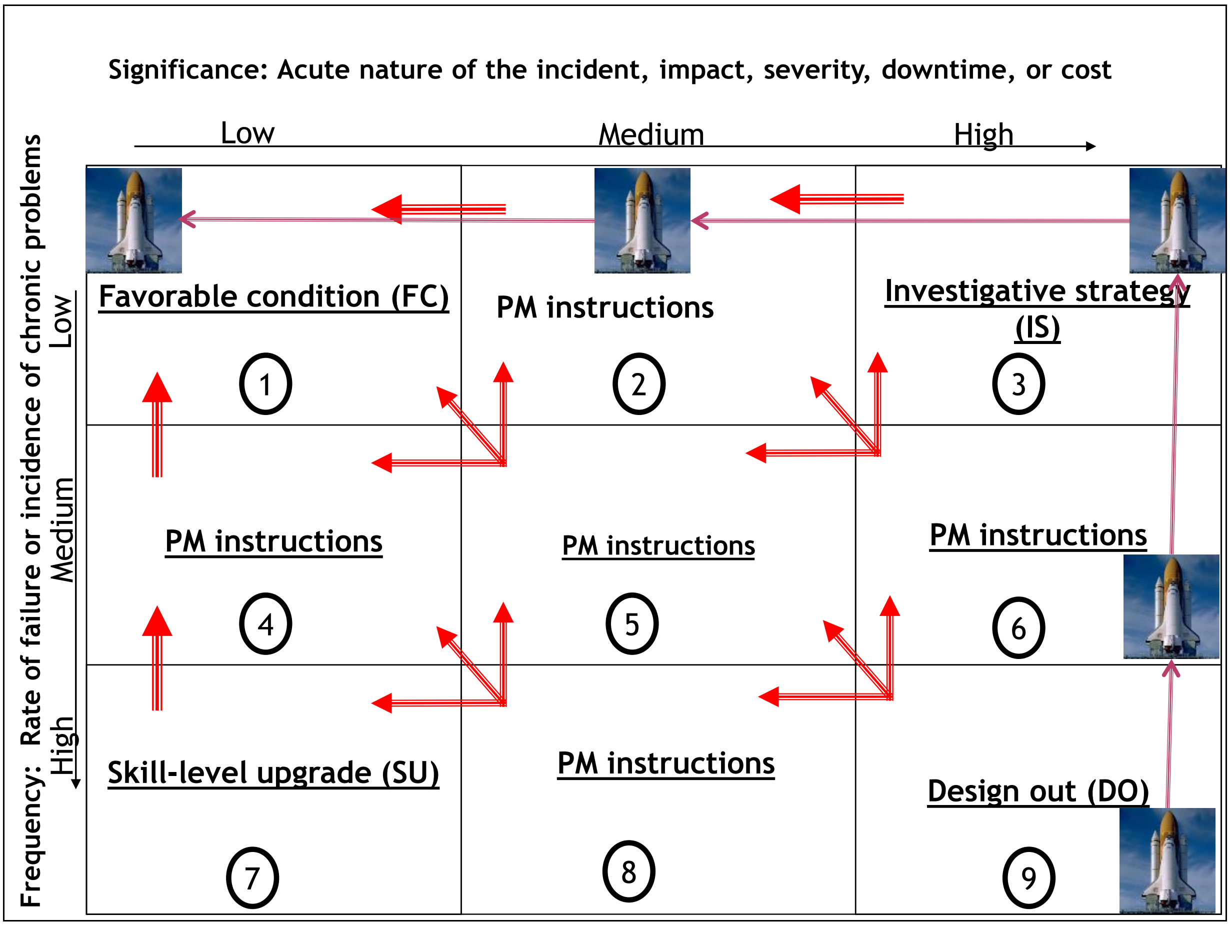


Figure 14. The Frequency/Significance routine-selection grid, applied to the NASA case

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

The shuttle was redesigned –a) Design-Out (DO) - after two disasters that had occurred in previous missions, firstly the Challenger and then Columbia. In particular, with respect to the Columbia disaster one of the root causes found was lack of imagery information for assessing the significance of damage on the wings after foam had hit tiles on it. The DO had resulted in the installation of cameras and remote monitoring devices (a condition based maintenance strategy or, in general terms an Investigative Strategy (IS)), that were able to capture the disoriented part. When the problem happened again, the reduction of significance, or severity, due to the CBM-prompted astronaut repair enabling the shuttle to land safely, put the event into Low Frequency Low Severity range, the situation having been returned to normal and a repeat disaster avoided. In summary, this study shows how the condition of the shuttle had been moved via DO from a Box 9state to a Box6 state (improving the routines) to a Box 3 state (implementing an IS), and then to a Box 2 state (enabling the routine of assessment and repair in real time), and ultimately to a Box1(FC) state. In other cases the outcome of the DO might lead to moving to an SU and, eventually, a favorable OTF state.

4 Risk Assessment in the ANA region and Towards an Application of the DMG

When examining categories of risks and emergency in Arctic Shipping, a set of risk matrices was compiled in MARPART analyses (Borch et al., 2016) and by the work of Marchenko et al (2018). In this work, they classified the Arctic shipping risks based on factors related to incident type, scale and location. In their research, they have decided to focus on five Arctic sea regions, Greenland, Iceland, Svalbard, coastal Norway, and Russian sector of the Barents Sea.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Figure 15. Considered Regions. Created on the base of Arctic Search and Rescue Agreement Map (Arctic Council 2011): 1-Greenland, 2-Iceland, 3-Svalbard, 4-Coastal Norway, 5- Russian sector of the Barents Sea (Ref: Marchenko et al, 2018).

They provided a taxonomy of ships related accidents in the Arctic depending on type of ship, and category of the event.

Table 1 Possible variations of accidents, depending on ship and event types

	Tourist	Cargo/tanker	Fishing
Grounding	T-G	C-G	F-G
Collision	T-C	C-C	F-C
Fire	T-F	C-F	F-F
Violent action	T-V	C-V	F-V
Other	T-O	C-O	F-O

Table 1. Categories of ships related accidents in the Arctic depending on type of ship, and category of the event (Ref: Marchenko et al, 2018).

They then performed risk assessment taking into consideration that 'risk' can be characterised by the product of the probability that an accident happens multiplied by the negative effects on health, environment and values that an accident may cause. Hence they proposed risk matrices to show 1) the frequency level of different types of incidents with different types of vessels and 2) the severity of consequences for human health and the environment, where they estimated the risk for people and environment separately. They reflect then on the risk patterns for different types of accidents and in

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

different regions of the Atlantic Arctic. Below is an example of a risk matrix for people in a specific type of incident in Greenlandic waters.

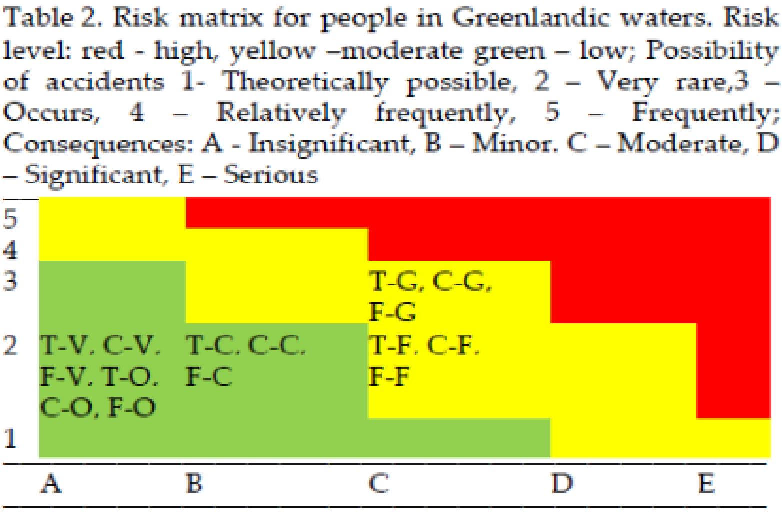


Table 2. A sample of Risk Matrices ((Ref: Marchenko et al, 2018).

Risk mapping further provide a basis for discussing the organising of preparedness capacities and response efforts. The MARPART analyses further provide reflections on the preparedness capacities demands and overview of the institutional arrangements and organizational structures that may influence effective strategies for risk mitigation and joint emergency response in the Arctic (Andreassen et al., 2018; 2019).

A lack of information is the key contributor to the unpredictability of the Arctic. Risk can be discussed in the various theoretical perspectives. An increase in the number of vessels might not necessarily lead to increased risk. The risk assessment techniques should include assessments focus then on the factors influencing the vulnerability of persons, nature, organizations, and society. Qualitative expert evaluations on specific risk areas or defined situations of hazard provide the basis for the matrices of Marchenko et al. (2018). The analyses are also based on the results from exercises showing the capabilities of mitigating the negative effects of accidents in the Arctic and knowledge on oil spill response (Marchenko, 2020).

While the risk matrices provided by Marchenko et al (2018) are useful for coding and mapping of risk, the important question is still how to deal with the activity level and the probabilities of accidents, and potential severity of the consequences. We need more knowledge and tools for an adequate estimation of risk and potential of seaborne disasters based on multiple criteria. The classical risk matrices do not

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

explicitly differentiate between cases of low frequency high severity versus high frequency low severity, as both scenarios are treated as yellow (as opposed to green and red). It is argued then that since the DMG model utilises the same 2-dimensions, of frequency severity, it can be utilised to risk assessment and hence provides a decision support for maritime incidents in the Arctic. Approaches that can address both the specific operation and type of consequence (people, environment, political), the specific type of vessel and type of disaster, as well as decision analyses from earlier accidents and learning from failures, including a root tree analysis of what went wrong can provide valuable insights even from major disasters in non-Arctic environments of high uncertainty (Labib, 2014).

In part 4, we focus on applying root cause analysis techniques which are considered as part of an Investigative Strategy in the DMG. In doing so, we will apply techniques related to Fault Tree Analysis (FTA), Reliability Block Diagrams (RBD), and Minimum Cut Sets (MCS). For those not familiar with this techniques please check Appendix 3.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

5 Application of Root Cause Analysis Techniques to Case Studies

In this part we cover 'classical' cases, of disasters as way of demonstration of methods for root cause analysis and learning from failures, through decision analysis of major disasters. Also, we have incorporated some analysis of recent cases, but due to lack of sufficient information about the causal factors, the analysis of these cases tend to be brief. Nevertheless, we followed a consistent approach in all he analysis. Moreover, the choice of the type of case studies was informed by the risk assessment of most likely scenarios of incidents in the ANA region performed by the report from USCGA/CASP (2020) already discussed in the earlier parts of this report. In completing this analysis of previous seaborne incidents, we can present a foresight analysis of potential seaborne disasters, catastrophic incidents and security threats based on real-world contexts and emergency management practitioner themed considerations.

The tools are incorporated as mental models and are considered as a key contribution of this report, having been constructed from the literature and reports related to each of the cases. Some of the chosen cases were also part of a workshop carried out as part of the ARCSAR project in Portsmouth, November 2018. The aim of the workshop was to demonstrate the applicability of the root-cause analysis techniques and risk assessment concepts in order to analyse scenarios of vulnerability in cold weather regions such as the Arctic and North Atlantic using real life case studies, and investigation reports from other regions for the sake of comparative analysis. In order to systematise the process of learning from failures we use a consistent framework proposed by Labib (2014) in analysing each case study comprising the answer to the following questions: What went wrong? What is the logical cause of the failure? What is the consequence of the failure? Were there any lessons learnt or recommendations from existing investigation reports? For some recent cases, available investigation reports are not available hence it was not clear what were the relationships between the different causal factors, and hence not possible to perform analysis using fault trees.

Case Study One: Exxon Valdez Disaster Oil Spill (March, 1989)

Case Study Two: BP Deep Water Horizon (April, 2010)

Case Study Three: Estonia Ferry Disaster (1994).

Case Study Four: Russian Arctic Oil Spill in Norlisk City (June, 2020).

Case Study Five: The Viking Sky (Near-miss Disaster) (March 2019).

Case Study 6: The Boreal (Near-miss Disaster) (2015).

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

5.1 Case Study One: Exxon Valdez Disaster

Case Study: Exxon Valdez disaster

What happened:

The tankers were entering and leaving the Valdez port through an area that included icebergs (Geistauts, 1992). Traffic lanes and a monitoring system were created by the US Coast Guard so as to control the traffic. In order to avoid the icebergs, the tankers decreased their speed or changed traffic lane (Geistauts, 1992). On 23 March 1989, the Exxon Valdez vessel was travelled from the Valdez to Los Angeles and it was loaded with 53 million gallons of oil (Skinner & Reilley, 1989). The captain with the permission of the Vessel Traffic System (VTS) changed traffic lane so as to avoid the ice (Skinner & Reilley, 1989; Slater, 2014). However, the course corrections were not conducted properly and the tanker ran aground the Bligh Reef on 24 March 1989, at 0004 (Gramling & Freudenburg, 1992). A large amount of oil poured into the Gulf of Prince William Sound (Harrald, Marcus, & Wallace, 1990).

Logic and technical of the failure:

The Exxon Valdez accident is an example of a number of failures of complicated man- machine systems in which attitudes, the design characteristics of the system, the inadequate management and the poor seamanship led to this disaster (Geistauts, 1992; Haycox, 2012). The basic cause of this incident is the human error (Haycox, 2012). The third mate and the captain failed to manoeuvre the ship and provide suitable navigation so as to pass through the Gulf safely (NTSB, 1990). Additionally, the design of the ship was poor and unsafe (Geistauts, 1992). The regulation required the operation of double-hulled vessels in the area (Slater, 2014). However, the vessel had single hull (Geistauts, 1992). The radar of the vessel did not work and there was absence of an effective and adequate VTS to oversight the area (NTSB, 1990; Slater, 2014). Moreover, the initial responses failed to contain the oil spill because the contingency plans in the area were inadequate for an amount of 250.000 barrels of oil (Harrald et al., 1990; Haycox, 2012).

The consequences:

The Exxon Valdez accident is one of the worst environmental disasters in the USA (Haycox, 2012). The collision of the tanker made 250.000 barrels of oil be poured into the Gulf (Kling, Phaneuf, & Zhao, 2012). The oil spill was spread 500 miles far from the reef and polluted 1000 miles of shoreline (Haycox, 2012). A great number of animals died (Kling et al., 2012). The oil spill caused economic and psychological problems on native people because they were depended on the water's resources (Geistauts, 1992). This incident harmed Exxon's image extensively despite the 2 billion of dollars spend on cleaning-up efforts (Small, 1991). Harrald et al. (1990) estimated that Exxon lost 5 million dollars because of the lost oil and needed 20 million dollars in order to repair and salvage the ship.

Fault tree analysis and reliability block diagram

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

The FTA analysis presented in Figure 16 shows that the two main factors that caused the environmental disaster were the collision of the ship that made the oil be poured and the inadequate response.

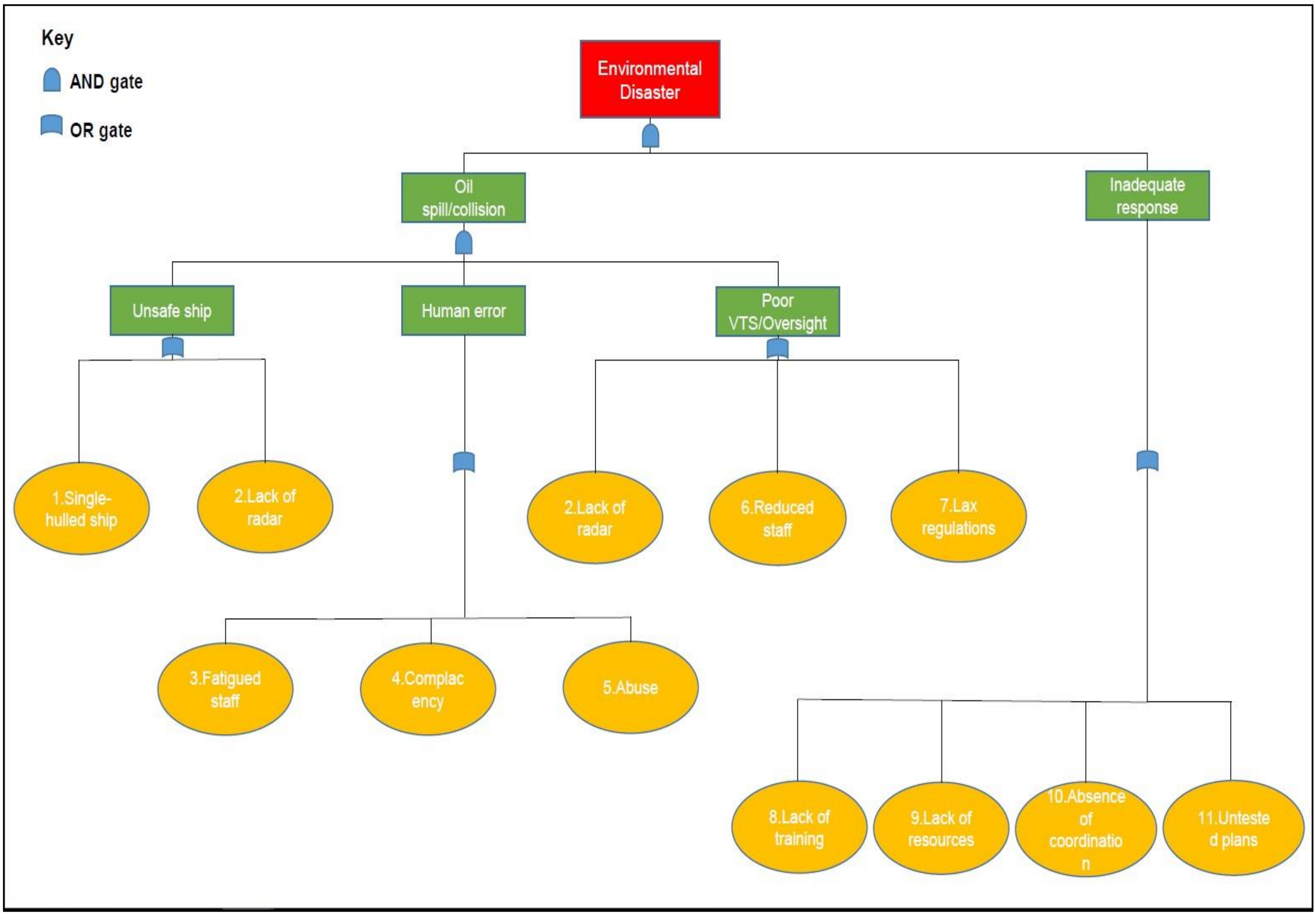


Figure 16. Fault tree analysis (FTA) of the Exxon Valdez disaster

The possible reasons that made the response being inadequate were:

- The absence of training that made the staff be poorly trained regarding the response techniques (Skinner & Reilly, 1989).
- The lack of resources to contain the oil spill because the planners had not pre- established the appropriate equipment (Harrald et al., 1990; Slater, 2014).
- The absence of coordination between authorities and industry organizations (Harrald et al., 1990). There was confusion in the structure ofdecision-making (Piper, 1993).

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

- The contingency plans that were not tested by making the deficiencies be unrevealed (Harrald et al.,1990).

According to the narrative of the case study, the factors that made the ship collide and oil be poured were the human error, the poor and unsafe ship design and the poor VTS which all of them are linked with an ANDgate.

The possible reasons that made the ship design be poor and unsafe were:

- The absence of an operational radar to detect potential hazards (Slater, 2014).
- The single-hulled ship design that increased the pour of the oil into the Gulf (Slater, 2014).

The possible factors that created the human errors were attributed to:

- The captain who was under the influence of alcohol (Gramling & Freudenburg, 1992).
- The absence of an accident in the past that made both the policy and operational levels feel complacency (Geistauts, 1992).
- The size of the crew which was decreased creating long shifts that made the third mate be fatigued (Slater,2014).

The possible reasons that made the VTS be poor were:

- The absence of adequate radar coverage operated by Coast Guard (Slater, 2014).
- The personnel reduction in the radar operations of the US Coast Guard (Marshall, 1989).
- The lax regulations regarding the traffic system and the movement of ships (AOSC, 1990).

The RBD in Figure 17 presents that the line of inadequate response which includes the boxes 8, 9, 10 and 11 are in a series structure whereas all the other lines are part of some parallel structure. According to Labib and Read (2013), the AND gates are more reliable than the OR gates and they mentioned that the more boxes are in a series structure the less reliable the system is. Hence, the series structure of the inadequate response line and the fact that it contains the greatest number of boxes from all lines in the RDB highlight its high vulnerability.

Furthermore, the RBD diagram shows that the lines of poor VTS and unsafe ship have the box 2 common. In a series structure, all the system fails if one of the parts included in it fails (Krasich, 2000). Thus, it is clear that the box 2 is one of the most vulnerable points because it can cause failure in both lines simultaneously.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

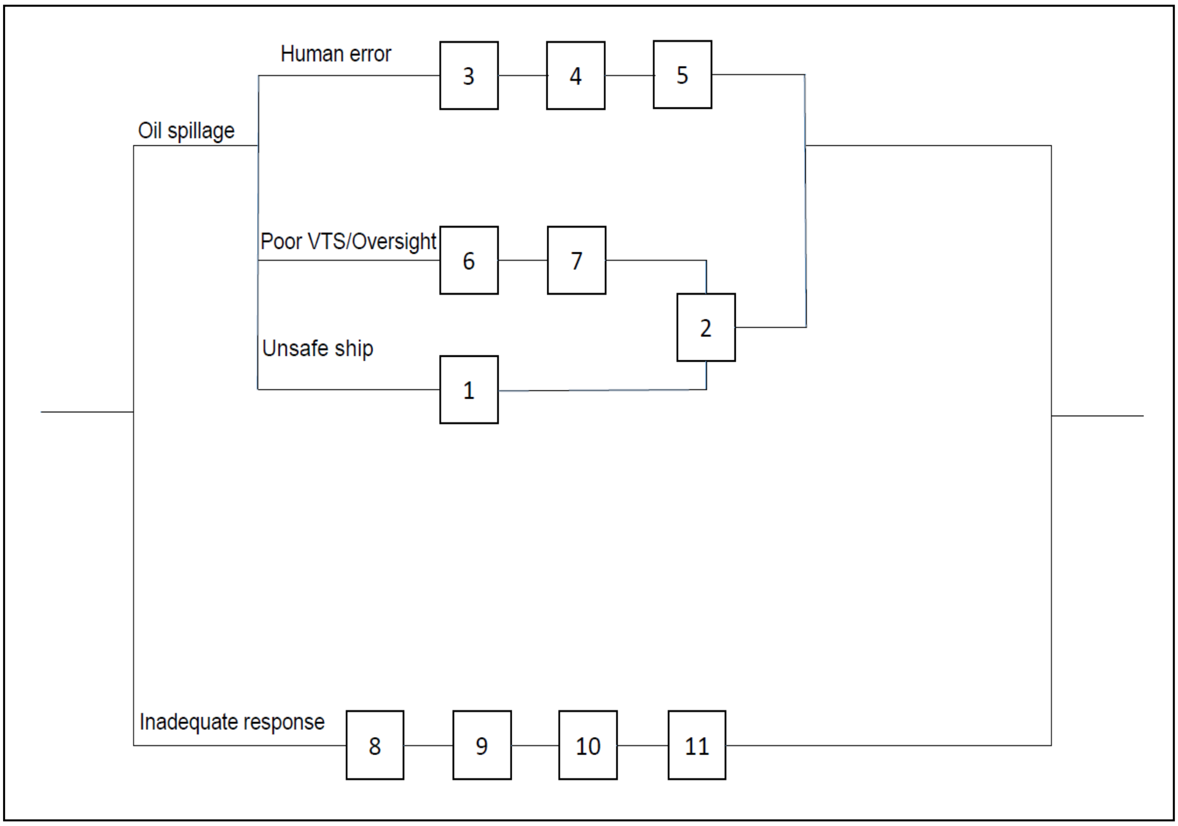


Figure 17. Reliability Block Diagram (RBD) for the Exxon Valdez disaster

Generic lessons and suggested improvements:

After the analysis of this incident, it is significant to discuss ways in which the system could become more reliable. The structure of command and control and the appropriate containment equipment should be determined prior to an accident so as to avoid potential confusions and resource deficiencies (Geistauts, 1992; Pearson & Mitroff, 1993). Furthermore, Skinner and Reilly (1989) mentioned that training in the clean-up methods should be conducted so as to obtain skilful staff. In order to test the plans realistically, live and table-top exercises could be developed (Skinner & Reilly, 1989). Moreover, appropriate position systems with analysis of the course using computer systems could have informed the bridge about the danger of grounding (Geistauts, 1992).

In order to increase the safety of the ships, it could be vital for them to be designed with double hulls. Additionally, the crew can be trained better and drug tests could be conducted (Harrald et al., 1990). Hence, the abusers could be removed from their duties (Geistauts, 1992). In the ship handling, the development of technology can improve the redundancy of the system (Geistauts,

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

1992). Appropriate equipment such as radar, fathometers and alarm systems to avoid collisions should be required by authorities (Harrald et al., 1990).

Over time, the complacency of individuals is increased because they obtain more faith in the safety systems. Thus, they stop being cautious creating failures (Geistauts, 1992). Safety programs and training should be created so as to impede the complacency and human errors (Skinner & Reilly, 1989).

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

5.2 Case Study Two: BP Deepwater Horizon disaster

Although this case study did not happen in the Arctic, it is an oil spill incident, which has been identified as a potential hazard that can occur in the Arctic Circle.

Case Study: BP Deepwater Horizon
What happened: In April 2010, BP started drilling into a rich of hydrocarbons formation in the Gulf of Mexico. The well was considered be financially worthwhile and the preparation for the production was started (Rose & Hunt, 2012). Cement techniques used to isolate the well from the hydrocarbons. Although several anomalous test readings and changes in the design occurred, the successful operation was declared on 20 April (Rose & Hunt, 2012). A blowout preventer (BoP) was established in order to prevent an uncontrollable release of gas. It is a safety system that is based on the hydraulic power so as to seal the well in an emergency (Rose & Hunt, 2012). However, on April 20, 2010, hydrocarbons were released in the floor of the rig leading to an ignition (Reader & O'Connor, 2013). The fire sunk the rig and a huge amount of oil was poured into the Gulf (Schultz, Walsh, Garfin, Wilson, & Neria, 2015).
Logic and technical of the failure: This accident was a combination of design failures, mechanical failures and incorrect human and governmental decisions (Blinder, 2010; Oun, 2015). According to Reader and O'Connor (2013) and Hopkins (2011), the experts did not communicate and assess the risks adequately. NOSC (2011) mentioned that a number of tests and actions relevant to the cement job were rejected. The barrier of cement utilized to isolate the annular space from the zone of hydrocarbon failed (NOSC, 2011). Additionally, the BoP that used to impede an uncontrolled gas flow did not operate (Bozeman, 2011). There was absence of situational awareness by the crew members (Reader & O'Connor, 2013). They did not recognize the warning signals (NOSC, 2011). Moreover, the fire and gas system failed to detect and prevent the releasing of hydrocarbons (BP investigation team, 2010). Hence, the gas was ignited damaging the rig (Oun, 2015). The US government and BP believed that a blowout would not have been significant (DHSG, 2011). As a result, the contingency plans of BP were not adequate to deal with an uncontrolled well making the initial response be inadequate (Mejri & Wolf, 2013).
The consequences: The uncontrolled well created the worst oil spill globally (Reader & O'Connor, 2013). Eleven workers died and seventeen of them were injured severely (Schultz et al., 2015). Almost five million barrels of oil were poured into the Gulf (Reader & O'Connor, 2013). Furthermore, a great number of animals died and the future sources of food in the area were in jeopardy (Rose & Hunt, 2012). The fishing and tourism industry were affected significantly in the area causing important economic loses (Parlett & Weaver, 2011; Rose & Hunt, 2012). Additionally, the reputation of BP collapsed especially in

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

U.S.A and a huge amount of lawsuits were made by the victims (Mejri & Wolf,2013). The BP's shares presented their lowest value and BP's market capitalization was reduced by 50% (Mejri & Wolf, 2013). The total financial cost for BP was estimated from 20 to 60 billions of dollars (Hiles, 2011).

Fault tree analysis and reliability block diagram:

The FTA analysis illustrated in Figure 18 presents that there were two main factors caused the environmental disaster, namely; (a) the explosion of the rig that made the oil be poured; and (b) the lack of an adequate response.

Beyond root cause analysis, appendix D outlines an example of the HRO framework being applied to this case study, illustrating the primary causative factors which were identified to have directly contributed to the Deepwater Horizon accident. This analysis also provides tools in which emergency management and SAR practitioner can make use of when analysing future seaborne incidents.

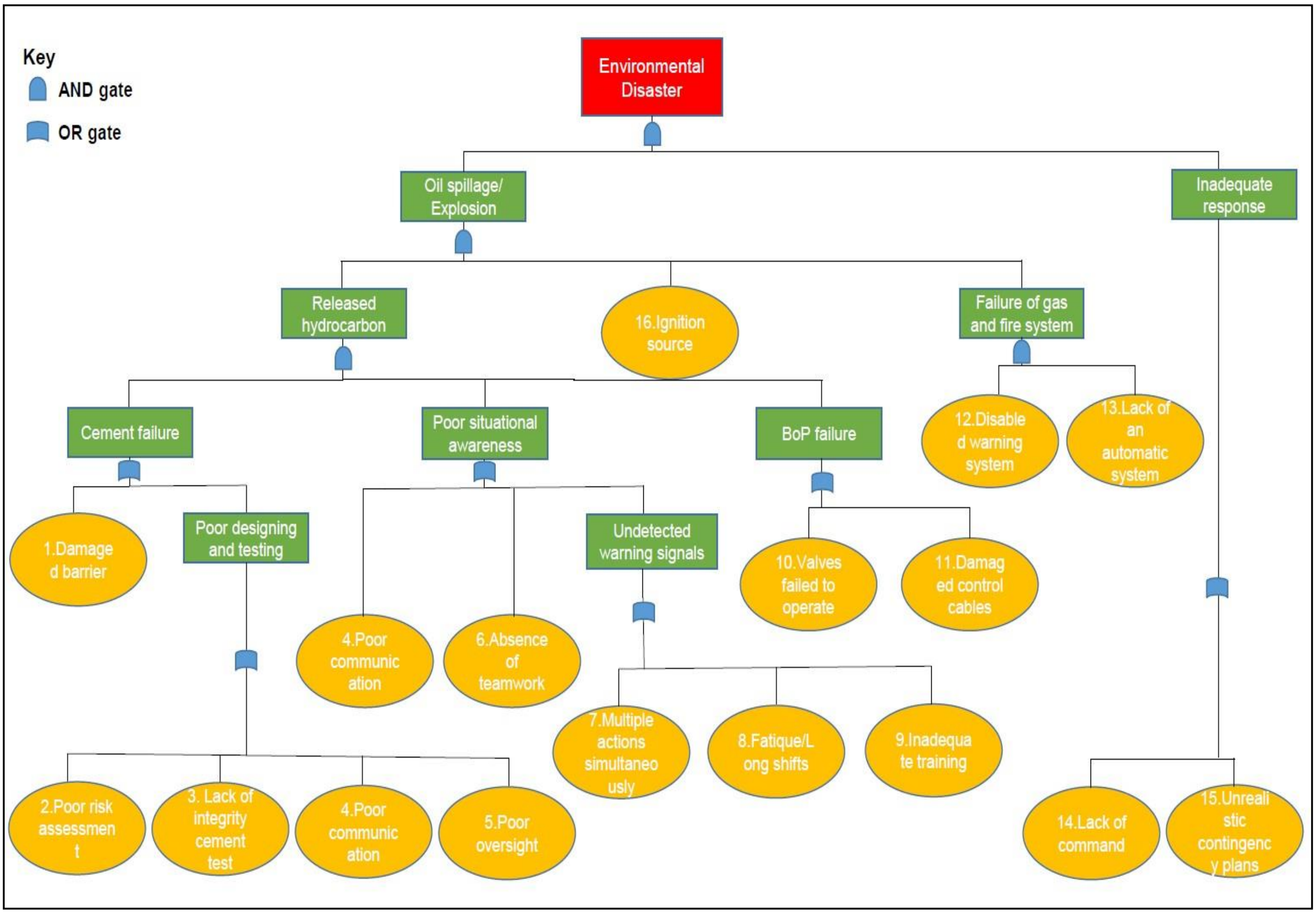


Figure 18. Fault tree analysis (FTA) of BP Deepwater Horizon disaster.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

The possible reasons that made the response be inadequate were:

- The untested and unrealistic contingency plans regarding a severe blowout (Hiles, 2011; Mejri & Wolf, 2013).
- The absence of an authority to command the response efforts, creating confusion (Blinder, 2010).

According to the narrative of the case study, the factors that created the explosion were the release of hydrocarbon, the ignition source and the failure of the fire and gas system all of which are linked with an ANDgate.

The possible causes of the failure of the gas and fire system were attributed to:

- The absence of an automatic gas and fire detection system (NOSC, 2011).
- The disabled warning system because of previous false alarms (Farell, 2011)

It is explicit that the hydrocarbon flew into the surface because of the failures of the cement and BoP and the absence of staff's situational awareness that all of themare linked with an ANDgate.

The possible reasons that cement failed to isolate the well were attributed to:

- The errors in the design of the process of cementing (NOSC, 2011).
- The lack of the test to estimate the integrity of the cement job (Oun, 2015)
- The high pressure of gas which damaged the barrier itself (Labib, 2014)
- The poor risk assessment implemented so as to save money and time and the poor regulation that supported the informal assessment of risk (Reader & O'Connor, 2013).
- The absence of adequate oversight on BP's operations by US government (Oun, 2015).
- The poor communication between BP and its contractors (NOSC, 2011).

Note that since the casual factors are identified as 'possible', then they are linked by an OR gate.

The possible reasons that BoP failed to seal the well were:

- The burnt cables of control that connected the BoP with the emergency disconnect system which failed to operate, and the pipe buckling (EDS) (NOSC, 2011; Oun, 2015).
- The poor maintenance of the BoP that created a problem in the system of batteries making the valves not operate (NOSC, 2011).

The lack of situational awareness and the non-detection of the warning signals were attributed to:

- The inadequate staff's training and the long shifts which made the workers be fatigued (NOSC, 2011; Oun,2015).
- The multiple actions which crew required to execute simultaneously, leading to the split of its attention (Reader & O'Connor,2013).

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

- The lack of communication and teamwork among the operators on the rig (Oun, 2015).

The RBD in Figure 19 illustrates that the boxes 14 and 15 are in a series structure in contrast with all the other lines that are included in some parallel system. Labib and Read (2013) mentioned that the OR gates are less reliable than the AND gates. Thus, the series structure of the inadequate response line illustrates its vulnerability.

Additionally, Labib and Read (2013) stated that the fewer boxes (causal factors) are in a series the more reliable the system is. In this way, the lines of cement failure and poor situational awareness are vulnerable significantly. They have the greatest number of boxes in a series structure in the RBD. Each one of them has five boxes in series structure and they have the box 4 common. Krasich (2000) stated that in a series structure if any of the parts fail then all the system fails. Hence, the box 4 is one of the most vulnerable points because it can cause failure in both lines simultaneously.

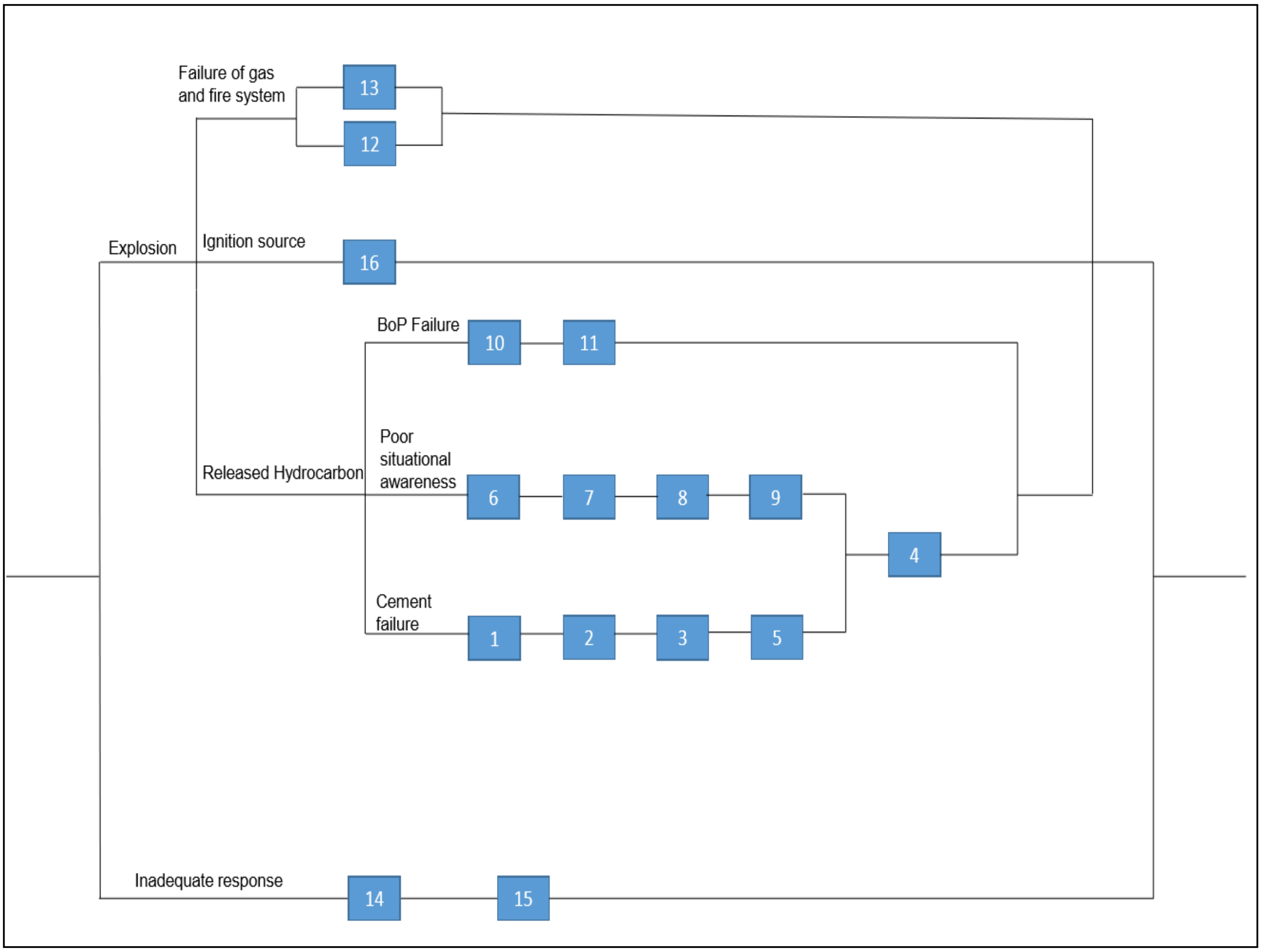


Figure 19. Reliability Block Diagram (RBD) for the BP Deepwater Horizon disaster.

This project has received funding from the EU Framework Programme for Research and Innovation HORIZON 2020 under the agreement 786571. Agency is not responsible of any use that may be made of the information it contains.

Generic lessons and suggested improvements:

After the analysis of the case study, it is vital to discuss how to make the system more reliable. It would be important for BP to improve the minimum requirements relevant to the BoP establishing appropriate redundancy minimum levels that contractors should follow (BP investigation team, 2010). Scheduled maintenances should be conducted on systems of BoP (BP investigation team, 2010). Moreover, an appropriate estimation of the cementing process through validation tests could have minimized the disaster (Oun, 2015). A gas and fire safety system that is capable to indicate and detect high concentrations of hydrocarbons should be implemented (Labib, 2014).

The crew resource management kind of training should be used so as to enhance the teamwork and decision-making skills in offshore teams (Crichton, 2009; Flin, 1995; Oconnor & Flin, 2003). The establishment of communication channels is vital in order to flow the information effectively (Pearson & Mitroff, 1993). Moreover, effective regulation is significant in order to shape the safety culture of offshores through rules on safety management (Cox, 2000; Taylor, 1979). In order to respond adequately to a crisis, it is vital for the contingency plans to be based on worst-case scenarios of different categories and probability so as to be realistic (Mitroff & Anagnow, 2001). Moreover, in order to improve the situational and risk awareness, it is significant to enhance the procedures of formal risk assessment and staff's training (Skogdalen, Utne, & Vinnem, 2011).

5.3 Case Study Three: Estonia Ferry Disaster

Case Study: Estonia Ferry Disaster

What happened:

The Estonia ferry disaster occurred on 28th September 1994 in the Baltic Sea near Uto Island, Finland en route to Stockholm, Sweden from Tallinn in Estonia. (Lancaster, 2005). Estonia was operated by Estline Marine Company Limited and departed Tallinn at 1915 on 27th with 989 people. Cruising at a high speed she encountered heavy waves at around 0100 on 28th that broke the bow visor door and the ramp pulled open. This caused rapid water ingress into the car deck leading to the capsize. Estonia disappeared from the radar at 0150. Only 137 people were rescued by other ferries and rescue helicopters (Dostal, Kim, & Ringstad, 2015).

Logic and technical of the failure:

After the disaster a Joint Accident Investigation Commission of Estonia, Finland and Sweden (JAIC) was set up to carry out an investigation and found the following as causes of the disaster (Lancaster, 2005; Klingbeil, 2014).

Design: The interconnected locking mechanism of the visor and the bow ramp did not meet the required wave load strength standard for the Baltic sea traffic. Consequently, the impact of the wave load tore off the visor from the vessel leading to the opening of the ramp and subsequent flooding of the car deck which accelerated the list. The bridge warning lamp failed to show the visor and ramp failure despite banging sounds in the bow area prior to the detachment. (JAIC 1997). An inner watertight door required to prevent water ingress was also forced open by water (Lancaster, 2005). Further, the company neglected maintenance to strengthen the mechanism and failed to learn from similar incidents prior to Estonia like *Diana II* in 1993 which led to the latter's closure of bow visor permanently (JAIC 1997).
Actions by the crew: Other vessels with similar doors reduced speed and sought shelter to avoid such failures (Lancaster, 2005). However, the Estonia bridge crew failed to reduce speed despite the banging sounds, to share information and consult their colleagues in the control room on the incident. They also delayed in transmitting the distress call (JAIC,1997).

Poor passenger evacuation: Estonia's list increased quickly (10-20 minutes) which made evacuation difficult. The crew delayed giving lifeboat warning hence passengers got trapped in the ferry due to narrow passages. Lifeboats could not be launched due to engine failure caused by the fast heel and lifejackets were insufficient. Though nearby ferries and rescue helicopters from Finland and Sweden rescued 34 and 103 people respectively, the former lacked sufficient rescue equipment while the latter arrived late (at 0305) due to poor distress communication between Turku and Helsinki Maritime Rescue Co-ordination Centers (MRCCs). Only one person was on duty at Turku MRCC who initially failed to comprehend the incident as a major one after receiving the distress call (JAIC,1997; Summerton & Berner 2002).

The consequences:

The disaster caused 852 deaths from 17 nationalities including 285 Estonians and 501 Swedes. Only 94 bodies were recovered, 758 were declared missing. The shipwreck could not be salvaged due to economic cost and it was declared a grave for the missing people, traumatizing the bereaved families (Bos, Ullberg & Hart, 2005).

Fault tree analysis and reliability block diagram:

The FTA in Figure 20 shows that structural failure, inaccurate bridge crews' action and insufficient passenger evacuation contributed to the disaster connected by an AND-gate. a) *Structural failure* was due to 1) weak visor locking mechanism because of inappropriate design or lack of maintenance 2) broken watertight door or 3) failed warning lamp connected by OR-gate; b) *inaccurate bridge crews' action* was attributed to over speeding and lack of coordination connected by AND-gate c) *insufficient passenger evacuation* because of narrow passages, improper distress communication, inadequate time or insufficient life boats connected by

OR-gate. OR-gates indicate that one cause was sufficient while AND-gates indicate that the causes needed to occur simultaneously.

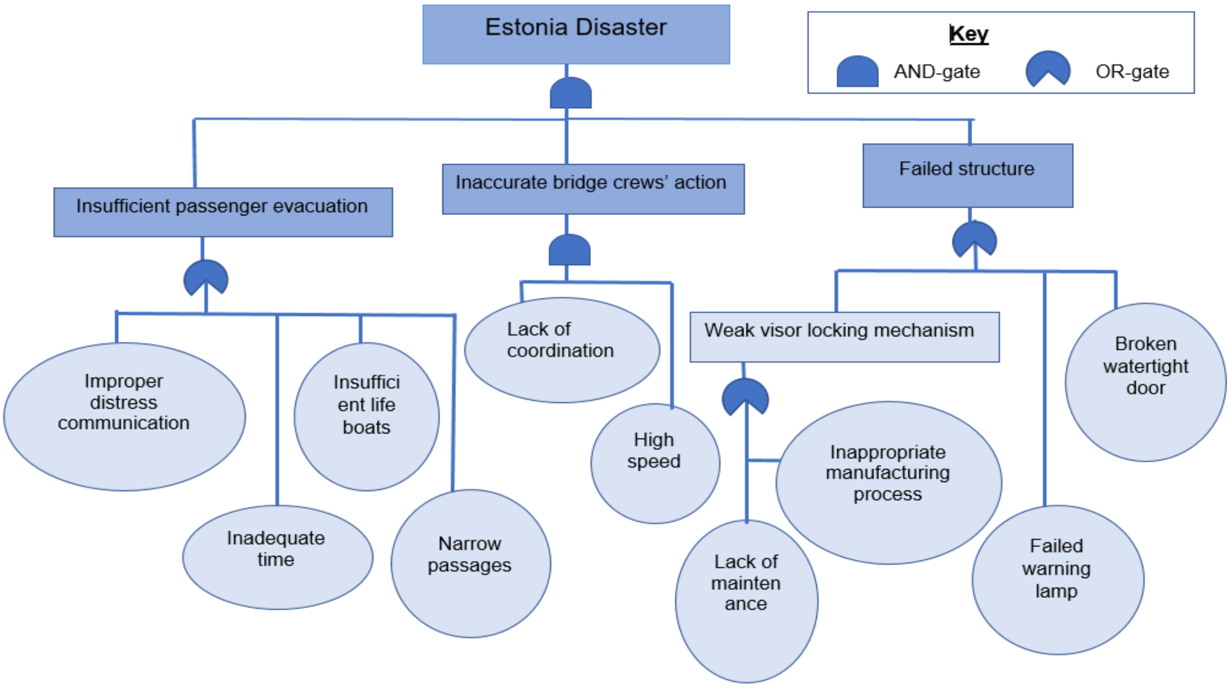


Figure 20. FTA of the Estonia disaster

The RBD in Figure 21 indicates that the three causation factors simultaneously led to the disaster as they are in parallel arrangement. Notice that the RBD in Figure 21 is constructed based on the structure of the FTA in Figure 20. So as indicated on the top right corner of Figure 20, each AND gate in the FTA is a parallel structure in the RBD, and each OR gate is a series structure. Hence, according to Figure 21, the system reliability should have been enhanced on design integrity and sufficient evacuation procedures and crew action to prevent such a disaster. Notably, the most vulnerable factors were the *insufficient passenger evacuation* and *failed structure* whose blocks are arranged in series. Thus, their contributing factors should be prioritised to avert similar accidents.

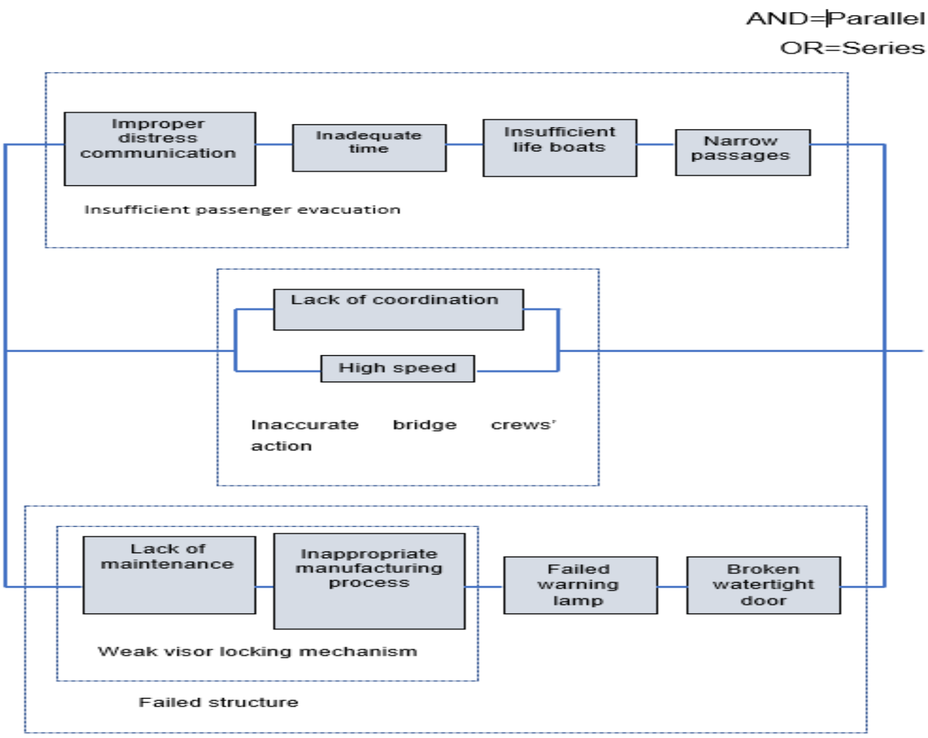


Figure 21. RBD for the Estonia Disaster

5.4 Case Study Four: Russian Arctic Oil Spill in Norlisk City

A very recent incident relevant for the ANA region occurred in June 2020 in the Arctic on Russian soil. As this incident is so recent there is no investigation reports yet that have been published. Hence, it is not possible to consider it as a full case study. However, we will try here to demonstrate the use of one of the techniques of FTA, given the limited knowledge we have about the incident. According to a report (Roth, 2020), briefly, environmental groups are said to have accused a Russian mining firm of emphasising the role of global climate change in a historic oil spill, which occurred in 3rd June 2020, in part to avoid punishment for its ageing infrastructure and potential negligence in the accident. The World Wildlife Fund and Greenpeace Russia said that although climate change likely played a role in the spillage of more than 20,000 tons of diesel fuel that turned two rivers crimson near the Arctic city of Norilsk, the risks of thawing permafrost to Arctic infrastructure were publicly known and could have been addressed months or years earlier. The accident is one of the largest in Russian history and had been compared by Greenpeace to the Exxon Valdez spill. In attempt to model causal factors, we developed an FTA model as shown in Figure 22.

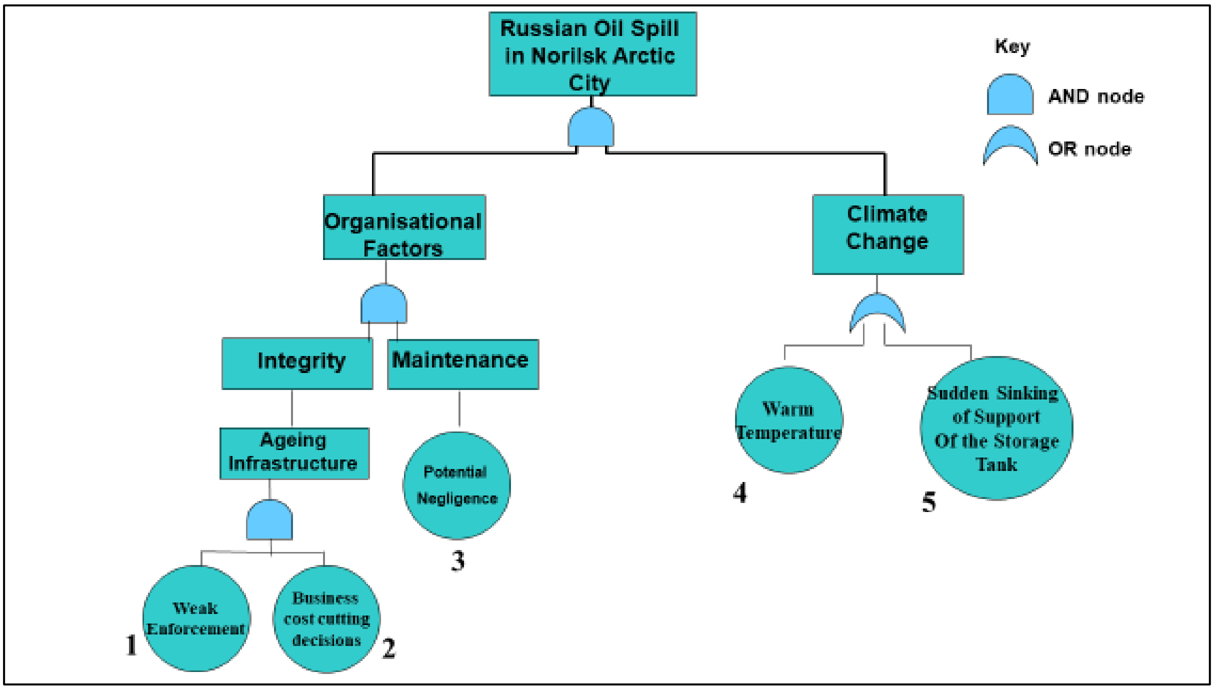


Figure 22. FTA preliminary model for the Russian Arctic Oil Spill in Norlisk City.

It is clear that there are currently two views on the causal factors of the incident, one attributed to Greenpeace and WWF which claims it as a man-made disaster caused by combination of bad integrity due to ageing infrastructure and bad maintenance due to potential negligence. On the other hand, the Russian Company is claiming climate change in the form of warm temperature as reasons for the failure. It can be claimed that both narratives could be simultaneously correct due to the top level AND gate, thus indicating that attention should be paid to both. It is hoped that as more evidence are being investigated and the ongoing event unfurls that the root cause analysis will be better understood and modelled.

5.5 Case Study Five: The Viking Sky

Case Study: The Viking Sky

What happened[1]:

On the afternoon of 23 March 2019, the cruise vessel *Viking Sky* experienced a black-out and loss of propulsion in gale to storm force conditions in the Hustadvika area of the Norwegian Coast. The master immediately sent out a mayday as the ship drifted towards shore. *Viking Sky* was owned by Viking Ocean Cruises with technical management provided by Wilhelmsen Ship Management. It was the third in the Viking Star class of cruise vessels, was classed by Lloyd's Register and was registered with the Norwegian International Ship registry (NIS). The vessel had been built at Fincantieri in Italy and was delivered in January 2017.
The electric power generation on board *Viking Sky* comprised four diesel generators (DG) manufactured by MAN Diesels & Turbo (MAN). The vessel was equipped with two types of DGs, the small generators (DG1 and DG4) were 5040 kW each, the large generators (DG2 and DG3) were 6720 kW each. *Viking Sky* had two separate engine rooms, and there were one large and one small DG in each engine room, DG1 and DG2 in the forward engine room and DG3 and DG4 in the aft engine room. Each engine room had its own switchboard which were usually connected by tie breakers to create a single switchboard for power distribution.

What went wrong?

Location and Conditions: The location of the accident was in Hustadvika, which is situated in the western part of the fairway between Bud and Kristiansund. **It is known according to the initial investgation report to be '*a notoriously dangerous area; the coast is completely exposed to the weather and extensive shoals lie offshore.*** *Strong winds from SW to NW raise a large steep swell with hollow breaking seas'. Also,* wind and sea conditions, on that day were forecasted to be *'strong gale to storm winds...total significant wave height1 over deep water of 9-10 meters from west (with a mean wave period of 12-13 seconds (s))'*.

Power and propulsion system failure: On 16 March 2019, diesel generator (DG) 3's turbocharger failed rendering the DG inoperable. The day of the blackout, a MAN technician was on board to dismantle the damaged turbocharger in preparation for a replacement to be fitted at the next port.

The blackout: On the morning of 23 March, between 0500 and 0904, 18 lubricating oil low level and low volume alarms were registered by the operational DGs. Each alarm, having been accepted, cleared within a few seconds. No more alarms were registered until 13:37:04 when DG4 registered an alarm indicating that the DG was shedding load as a result of low lubricating oil pressure. A few seconds later it registered a low lubricating oil pressure alarm. At 13:39:52, DG1 registered a low low lubricating oil sump level alarm. A little over five minutes later, at 13:45:26, DG4 shut down followed by DG2 eight seconds later. DG2 was restarted after approximately 11 minutes, but shut down again along with DG1 at 13:58:31, causing a complete black-out and loss of propulsion. The bridge team immediately called the engine control room but, at that early stage, the engineers were unsure of the cause, or causes, of the blackout and therefore could not estimate when it would be possible to restore power. The officer on watch called the master, who quickly made his way to the bridge. Having assessed the situation, the master broadcast a mayday at 1400. He then instructed the crew to drop both anchors. However, the anchors did not hold, and the ship continued to

[1] Viking Sky interim report from the Accident Investigation Board Norway: https://havarikommisjonen.no/Sjofart/Undersokelser/19-262

drift astern towards the shore at a speed of 6–7 knots. The General Alarm was activated at 1413 and the passengers and crew began to muster.

- On receipt of the mayday, Southern Norway Joint Rescue Coordination Centre (JRCC) launched a major rescue operation and started scrambling resources, including helicopters, on a large scale.
- According to the initial findings: The lubricating oil sump tanks of all the diesel generators were maintained at 28%–40% capacity. MAN's recommendation was to maintain them at 68%–75% capacity. The diesel generators shut down as a result of the loss of lubricating oil suction due to low sump tank levels, combined with pitching and rolling. All three operational diesel generators shut down within 19 minutes of each other, causing blackout and loss of propulsion.

The consequences:

Viking Sky was manned by 458 crew and was carrying 915 passengers. Most of the passengers were US (602) and UK (197) citizens, followed by Australians (69) and other nations (47). No reported casualities.

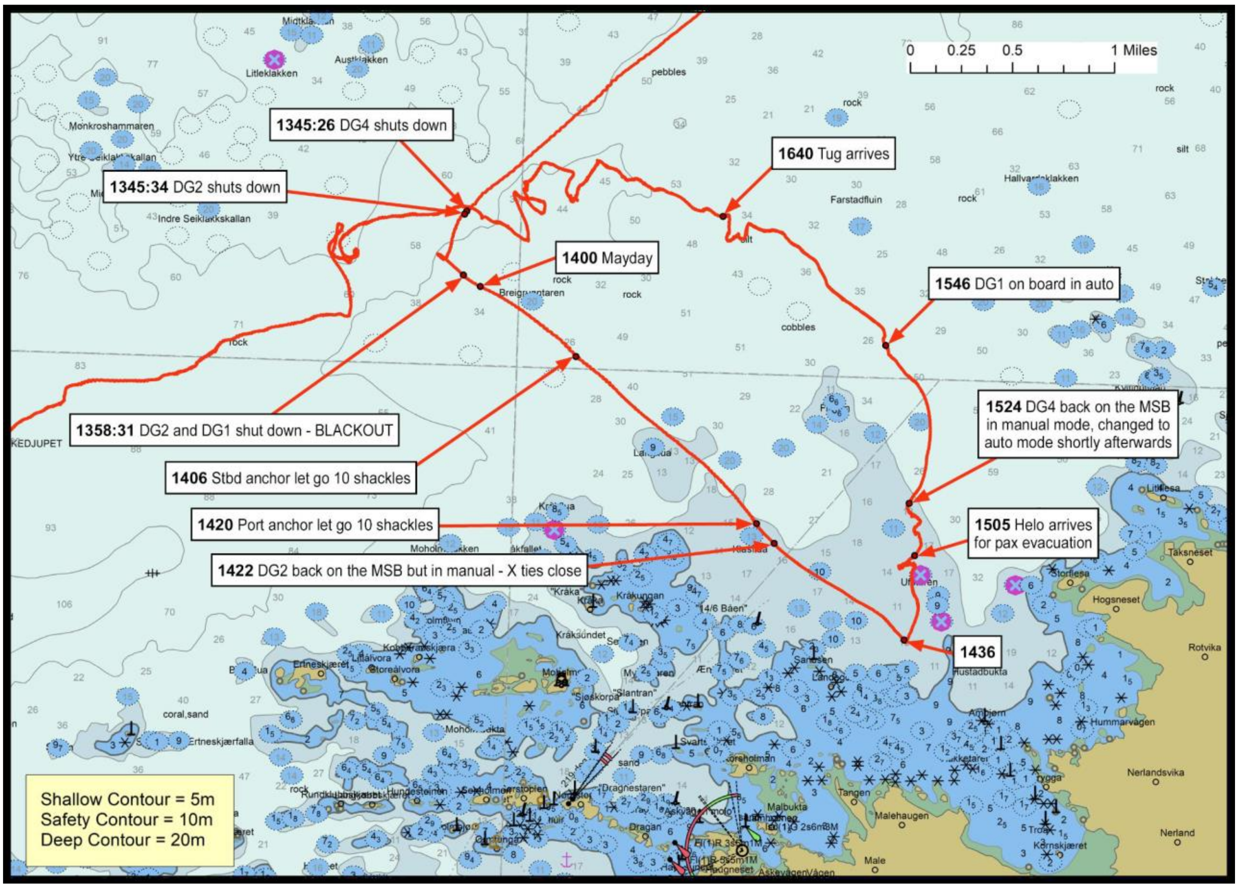


Figure 23. Sequence of events. Source: MAIB

Generic lessons and recommendations from investigation reports:

Shortly after the incident Wilhelmsen Ship Management distributed a Safety Bulletin including recommendations to all their vessels. The company has also identified several actions to be taken following their internal investigation of this incident. Specifically, they are reviewing the **management**

of appropriate lubricating oil levels in operational machinery, the preparations for heavy weather and the instructions regarding blackout recovery. Additionally, in cooperation with Class, they are establishing procedures for sailing with one engine (or other critical equipment) inoperative while maintaining compliance with the Safe Return to Port requirements. On 27 March 2019 the Norwegian Maritime Authority issued a Safety Message on risk assessment of critical systems which asked "*all shipping companies to take the necessary precautions to ensure the supply of lubricating oil to engines and other critical systems under expected weather conditions. This should be done in collaboration with the engine supplier and included as part of the ship's risk assessments in the safety management system*."

Main Recommendation: The safety advice issued by the Norwegian Maritime Authority is supported by the ongoing safety investigation, with the following recommendation: 'All vessel owners and operators are recommended to ensure that engine lubricating oil tank levels are maintained in accordance with engine manufacturer's instructions and topped up in the event of poor weather being forecast'.

Areas for Further Investigation (Medium/Long Term) include:

1) Engine room alarm management
2) Passage planning
3) Decision support
4) Lubricating oil management
5) Evacuation and LSA
6) Safety management
7) Local weather conditions and bathymetry
8) Safe Return to Port

5.6 Case Study Six: The Boreal

Case Study: Boreal
Background[2]: Cruise ship Le Boreal (IMO was built in 2010 operated by Compagnie du Ponant, a cruise ship operator, under French flag. The vessel is powered by 2 x 2300 kW electric motors; four 1600 kW diesel-generators (Wärtsilä 8L20) and one Caterpillar emergency generator rated at 800 kW. At the time of the incident, all four diesel generators (referred to as DG1, DG2, DG3, and DG4) were online and fed with heavy fuel oil (HFO 380).
What is the logical cause of the failure? - The HO had concerns about the quality of the Heavy Fuel Oil (HFO) being used, which contributed to the decision to replace the reserve filter without waiting for a mechanic rating to arrive in the morning. - The established practice was to replace the filter cartridges very frequently (2–3 times a day, versus the manufacturer's recommendation of every 1,000 h). This was understood to be due to switching from HFO to Marine Diesel Oil (MDO), which quickly clogged filters. - There was no coding system, no interlock mechanism to preclude the filter replacement when under pressure. - The HO was alone, therefore there was no benefit of a cross check. The understaffing was identified during the investigation: a rating had been needed to assist in the ER. - During the patrol (shortly before the incident), the HO did not notice any problem with the lagging cover of the turbo-blower exhaust elbow of DG3, which was likely dysfunctional already. No action was taken to rectify the hazard or adjust maintenance actions, as a result. The investigation concluded that "the engineer officer who carried out the replacement of a clogged fuel filter element had been presumably misled by a faulty visual memory and undertook the disassembly of an element under pressure" . That is, the investigators alluded to the human error. However, the initial explanation of the incident can be attributed to the following three types of causal factors: - Human error when replacing the fuel filter and inspecting thermal insulation; - Management error in providing inadequate manning in engine room on the night shift; - Design flaw in the fuel system segregation of heavy (HFO) and light fuels (MDO).
What is the consequence of the failure? There were no injuries to the passengers or crew. There were 347 people aboard Le Boréal when a fire in the engine room led to a complete loss of power, leaving the ship adrift in gale force conditions four miles offshore. Le Boréal's master decided on an evacuation of passengers and non-essential crew. 78 people were subsequently winched by helicopters from the ship's deck and her liferafts. Because of the high waves, there were problems with rescuing the passengers from the tenders/life boats onto the frigates. Thus, the frigates had to tow the life boats into calmer waters. This was a tough experience for the passengers on board. 258 more, aboard Le Boréal's two lifeboats, were recovered by a sister ship after the boats had been escorted to sheltered waters. The initial landing point was established at Cape Dolphin and the helicopters took some passengers there. Simultaneously, a reception center was being established at Mount Pleasant military base and L'Austral was boarding passengers to be taken to Port Stanley. This caused some confusion with accounting the passengers and identifying their whereabouts. (IMRF, 2016a; BEAmer, 2016). All were cared for in the islands until their repatriation could be arranged. The incident was subsequently investigated by the French marine casualty investigation board, Bureau d'Enquêtes sur les Événements de Mer (BEAmer), which published its findings in July 2016.

[2] Puisa, Williams, & Vassalos. (2019).

Generic lessons and recommendations from investigation reports:

One of the most important 'lessons learned' is the value of thinking through the challenges of mass rescue and discussing them with colleagues and subject-matter experts at such events. Other lessons learnt related to evacuation include:

- Identification and establishment of tactical on-scene coordinators should occur at the earliest opportunity. The OSC is the primary point of contact in establishing the 'truth on the ground'.
- Aircraft have an advantageous position for command and control as well as situational awareness. This worked well during the Le Boréal rescue with one fixed-wing unit responsible for coordinating all air and surface assets at sea and another covering all aviation over land.
- The use of aircraft also gave improved VHF radio coverage.
- Aircraft cannot stay airborne indefinitely and may have to hand over responsibility to another unit (including a sea vessel or UAV). If multiple air assets are available consideration should be given to sequencing tasks, or splitting responsibilities in order to maintain control and understanding.
- Whilst information sharing between strategic authorities was accurate and timely, the correct identification and utilisation of liaison officers from all organisations involved was the main area identified for improvement.
- Regarding the managerial roles, there was some obscurity with the roles of the officers and crew onboard the ship and the life boats during the evacuation. In addition, the rescue operation was very demanding and called for improvisation by the rescue units. This in turn caused some confusion about the whereabouts of the passengers that were brought ashore. This is normally a task for the on-scene coordinator to control. The Commander of British Forces in the South Atlantic Islands characterized the emergency evacuation as *"an extremely complex and hazardous rescue operation in difficult conditions.*" (Andreassen, Borch and Ikonen, 2018)

5.7 Root Cause Analysis Conclusion

This section about different case studies is helpful in several ways summarised as follows:

1. The generic lessons for each major incident case study, through the analysis of existing report, help to generate needs for revising the status quo. This may include need for new standards, policies, or routines.

2. The specific lessons learned from each case study can tell us something on how we can use them in the emergency preparedness planning for the ANA region.
3. The use of root cause analysis techniques can help us to focus our attention on analysing different vulnerabilities in the system, and can provide ideas for future critical safety barriers.
4. The scenarios and the analysis of each case study can be used to design future simulation exercises, where resilience and lessons learnt can be assessed.
5. Being aware about these disasters and the tools used for analysing their root causes promotes resilience, and identify gaps in capacity, against potential seaborne disasters, catastrophic incidents and security threats in the ANA region.

6 ARCSAR Stakeholder Engagement

The workshops completed throughout T3.1 and WP2 were a critical component in capturing key stakeholder knowledge when defining a categorising potential seaborne disasters, catastrophic incidents, and security threats in the ANA region.

6.1 Workshop: Organisation Learning from Failures – Towards Operational Resilience and Excellence

Location: University of Portsmouth,

Date: 27th and 28th November, 2018:

The workshop took place in Portsmouth, UK in November 2018 and concentrated on the capabilities gaps and priorities with respect to disaster management (maritime, shipping, oil spillage and radiological incident), as well as methodologies for their mitigation and preparedness. This workshop had some tutorial aspects in order to train delegates in the necessary root cause analysis techniques to identify and analyse needs, gaps and threats. Several well-known maritime, pollution incident and radiological catastrophe scenarios (Labib, 2014) were used to illustrate the techniques. Delegates then worked in self-selecting groups, each developing maritime, pollution and radiological disaster scenarios and using the taught techniques to identify root cause capability and procedural gaps and needs for enhancement. The conclusions of each group for each scenario were recorded and presented on flipcharts.

The workshop synopsis:

1. Theory with Photos and Presentations of Small Groups.
    a) Risk Matrix and FMEA.

   b) Resilience & High Reliability Organisations (HRO).
   c) Fault Tree Analysis (FTA) and Reliability Block Diagrams (RBD).
   d) Contents of Recommendations.
2. Case Studies from the Arctic (Actual & Hypothetical):
   a) Oil Spills.
   b) Fire.
   c) Grounding.
   d) Nuclear.

   The real life case studies reviewed were as follows:

   a) Le Boreal Incident (2015, South Atlantic).
   b) Costa Concordia Incident (2012, Italy).
   c) Vessel Grounding in ANA region (General).
   d) Elgin Oil Platform Incident (2012, Scotland).
   e) MS Estonia Incident (1994, Baltic Sea).
   f) Nuclear Incident in ANA region such as potential hazard from nuclear powered icebreakers, or mobile nuclear power stations (general).

1. The workshop examined learning from failures and techniques for decision analysis with emphasis on the use of advanced operational research techniques and applying it to cases of major failures and disasters.
2. The framework can then be extended to other failures and near misses. It is participatory in nature and will involve sharing expertise with respect to relevant investigation reports of previous incidents or situations.
3. The idea of the workshop is to look at Learning from Failures and develop capabilities for root cause analysis as well as operationalizing the decision making process. This will be through examining known and topical cases, as well as cases related to the particular own experience of the delegates.

   ARCSAR hosted its second practitioner workshop at the University of Portsmouth, UK on the 27th and 28th November 2018.

   A range of search and rescue, coastguard, industrial and academic organisations were represented from a diverse set of countries including Norway, Iceland, Faroe Islands, Italy, New Zealand, Russia, Ireland and the United Kingdom.

   Number of attendees: 23 (For images refer to appendix E)

The focus of the workshop was techniques for mitigation of and preparedness for incidents leading to disasters in the Arctic and North Atlantic. The workshop was facilitated by Prof Ashraf Labib of the

University of Portsmouth, an expert in disaster management and learning through failures. Sharing case studies from his textbook and his industrial expertise, he guided delegates through a series of advanced decision analysis techniques and disaster case studies, demonstrating the root causes of each disaster and the actions that could have been taken to avoid it.

The case studies included maritime disasters, natural catastrophes such as the Exxon Valdez oil spillage and radiological incidents such as the Fukushima nuclear disaster. Smaller scale incidents were also studied and methodologies for assessing severity of incidents and risks discussed. They also covered features of High Reliability Organisations (HRO), and how this can be incorporated in SAR activities. The workshop attendees were then asked to work in roundtable groups comprised of different nationalities and types of organisation in order to describe a number of occurred or potential incident scenarios and develop their root causes and mitigation scenarios. Key to the ARCSAR project is understanding the failure and what technological advance, innovation research or collaboration needs to be put in place to mitigate or prevent it in future. Attendees developed and analysed a number of scenarios relating to maritime, environmental and radiological hazards in the ARCSAR zone. Further theories used during the workshop can be found from Appendix D. Pictures from the workshop can be founds from Appendix E.

7 Potential seaborne disasters, catastrophic incidents and security threats in the ANA region

This section will provide a brief summary overview of the categorisation of seaborne disasters, catastrophic incidents and security threats identified throughout the extensive review of literature, risk assessment application and primary research efforts via workshops.

Order of priority	Incident/threat	Category	Likelihood of occurrence	Severity of potential outcome
1	Cruise ship accident	Seaborne disaster/catastrophic incident	Low	High

2	Oil spill and environmental accident	Seaborne disaster/catastrophic incident	Low	High
3	Collisions	Seaborne disaster/catastrophic incident	Low	Medium - High
4	Groundings	Seaborne disaster/catastrophic incident	Medium	Medium - High
5	Danger from small vessels	Seaborne disaster/catastrophic incident	Medium	Medium - High
6	Waste dumping at sea	Seaborne disaster/catastrophic incident	Medium	Medium
7	Icebreaker breakdown	Seaborne disaster/catastrophic incident	Low	Medium - High
8	Asymmetric threats	Security threat	Low	Low
9	Emergence of military concerns	Security threat	Low	High

Table 3. Summary of Seaborne disasters, catastrophic incidents and security threats

7.1 Cruise Ship Accidents

While the cruise and passenger ship sectors have experienced extensive developments in terms of regulatory components and technology solutions, the findings presented throughout the literature review, risk analysis and work shop efforts suggest that accidents or incidents associated with these vessels continue to dominate the focuses of SAR and emergency management practitioners within the ANA. Although the likelihood of incidents occurring were deemed to be low throughout all sections, the extreme severity associated with the consequences as a result of the complex and multi-faceted nature of cruise ship incidents suggests that this is a potential seaborne disaster or catastrophic incident which is of major concern to ANA stakeholders.

As we can see from the case studies examined in this report, accidents with cruise ships and passenger ferries do occur, although seldom. Often large-scale incidents with cruise ships are so called mass-rescue operations (MRO) and may overwhelm the national and regional SAR capacities. As demonstrated with the Viking Sky incident, this was a so-called near miss incident however major efforts were required from the national SAR response organizations, local community, industry and the international community as well. Due to the realities of the ANA region, such as scarce rescue assets, long distances, harsh weather conditions, lack of resources at the local communities, response efforts as big and fast as they were during the Viking Sky might not have been possible in parts of the ANA region. Mass evacuation from large cruise ships often take a lot of time, as was seen during this incident, and the long distances in the ANA region would make evacuation to nearest villages, if any, challenging. This is why live-exercises and table top exercises on MRO situations as well as establishing rescue camps on shore to wait for evacuation are examined in the ARCSAR project.

The Antarctic region has many of the same challenges as the Arctic region when it comes to emergency response. Distances are often vast, resources are scarce, water is cold, sea is rough, capacities to host and accommodate passengers are limited, and communication lines and networks might not be available. When it comes to the Le Boreal incident, luckily the incident happened near the British naval base at the Falkland Islands. As the island is remote and sparsely inhabited, the response required full-scale marine, air and land response assets from the Falkland Island government, military and private sector. The Le Boreal incident shows that large-scale incidents such as this require seamless cooperation from various agencies, and this is also what ARCSAR is trying to concentrate on and exercise during the planned live exercise in 2021.

The third passenger vessel incident examined in this report, MS Estonia, has catastrophic consequences from human life. In this case as well, the incident happened relatively close to land and available assets from all over the Baltic Sea but other factor contributed to the high consequences such as inefficient passenger evacuation, inefficient bridge crew action and structure failure of the ship itself. Although many operational and vessel structural procedures were implemented after the incident, these kinds of catastrophic incidents are still called “the worst-case” scenario for many of the SAR agencies since they are unexpected but difficult to deal with, can cause massive consequences for both human life and for the environment in case of an oil spill or a chemical explosion, and therefore high on the list of concern and potential threats for the ANA region.

The root cause analysis from this report provides a tool for the emergency response agencies to increase their preparedness methods and take the lessons learned into consideration when conducting risk assessments and prevention reviews.

7.2 Oil spills and environmental accidents

The ANA region, particularly the Artic, is a highly vulnerable eco-system. Here you also find significant stocks of living marine resources that makes it one of the most productive areas in the world and fishing represents the biggest source of income for some Arctic states. There has been numerous cases of acute pollution in the Arctic in the past, and in the context of the increased activity in both shipping and oil exploitation, there is still high probability that this will happen again. Three large cases of oil spill were examined in this report, two that happened in the ANA region.

As stated in the case study, the Exxon Valdez accident is one of the worst environmental disasters in the USA. A great number of animals died and the oil spill did not only harmed the environment and the fragile ecosystem in Alaska, but also caused economic and psychological problems to the Indigenous people because they were depended on the resources from the sea such as fishing and hunting. This is another important point for the ARCSAR project to consider, especially as the ARCSAR project aims to facilitate concerns and knowledge from the Indigenous communities in the ANA region to emergency preparedness and response.

The most recent accident happened in the Russian Arctic and is one of the largest in Russian history and had been compared by Greenpeace to the Exxon Valdez spill. As investigation from this incident is not ready, the full impact to the environment and the Norilsk community is not known yet. This could be something that ARCSAR could look into.

The BP Deepwater Horizon disaster had major consequences for both human life and the environment. The uncontrolled well created the worst oil spill globally and eleven workers died and seventeen of them were injured severely. Furthermore, similarly to the Exxon Valdez disaster, a great number of animals died and the future sources of food in the area were in jeopardy. The fishing and tourism industry were affected significantly in the area causing important economic loses. These kind of multi-sectoral disasters are also high on the list for the emergency response agencies as “worst-case scenarios” where both the SAR and oil spill capacities of one country are overwhelmed.

Similar to SAR response, long distances between the existing infrastructure, polar night with low visibility, poor satellite communication, low temperatures that makes the equipment malfunctioning and ice infected waters are some of the ANA characteristics that makes an oil spill response operation in this area extremely challenging. Because of oil's unique behaviour in cold water, this also influences how it can be cleaned, and at present, there is insufficient knowledge as to how to clean up oil in ice. Thus oil spills and other acute pollution cases are far more complicated to combat in the Arctic compared to other parts of the world Oceans – making the consequences of a possible large oil spill to be severe.

7.3 Collisions

The literature, risk analysis and primary research efforts support that as a result of improvements in navigation technology that the likelihood of collision related incidents continues to diminish throughout the ANA, similar to that experience throughout mid-latitude regions. However, as shipping activity increases, particularly as mainstream cargo attempts to make transits via northern routes as a result of short transit times the probability of collision related incidents occurring will more than likely increase. Furthermore, similar to the cruise ship contexts, while the likelihood of an incident occurring is at present quite low, the severity has the potential to be high, particularly if a vessel is severely damaged with the potential to result in loss of life or pollution to the marine environment.

7.4 Groundings

Groundings discussed in the context of all vessels (major risk from cruise ships, tankers and cargo ships), have the potential to reach increased likelihoods of occurrence, particularly in areas with limited valid navigation data. As outlined throughout the report, significant variations exist between the standard of valid and up to date hydrographic survey data of the ANA. For examples, areas such as the NSR which has received extensive survey efforts from Russian hydrographic survey sources experiences a limited quantity of groundings as these regions have been the focus of significant trade and exploration efforts. However, areas external to regularly used shipping routes such as the NSR have throughout the globe have been subject to limited survey efforts. These incidents can be particularly prevalent within the Cruise Ship sector, as these vessels can at times deviate from commonly used shipping routes in an effort to provide unique and novel tourism experiences. Similar to the consequences associated with collisions, these seaborne disasters or catastrophic incidents have the potential to result in loss of life or damage to sensitive marine eco-systems.

7.5 Danger from small vessels/ships including fishing vessels, yachts, or aircrafts

While the consequences associated with incidents or accidents on board smaller vessels are similar to those experienced on larger the primary differences are the rate in which these incidents can increase in severity. Incidents such as groundings or collisions can be catastrophic on any vessel, however the likelihood of a vessel being able to maintain structural integrity significantly increases relative to the size. For example, the Viking Sky incident discussed throughout this deliverable, while this was a serious incident which required a large scale rescue coordination effort, as the vessel was large enough to withstand the sea conditions and remain upright and afloat, there was no loss of life or pollution. However in the event of similar incident occurring on a smaller vessel, the likelihood of such an incident escalating to a catastrophic scale increases significantly, particularly on board yachts or leisure craft. A recent example of this is the Northguider incident, where a shrimp trawler grounded in Svalbard in the winter of 2019. This incident was not taken as one of the large case studies in this report, but significant and complicated efforts were initiated to prevent large environmental incident from happening in difficult and harsh Arctic winter conditions after the SAR efforts had been completed. The Northguider incident highlighted also the challenges with poor radio and satellite coverage, darkness and freezing cold temperatures in the ANA region. The Northguider incident was presented at the second ARCSAR workshop in Rome. For aircraft not designed to float or operate in extreme environments, the likelihood of escalation increases significantly.

7.6 Waste dumping at sea

Marine litter from various sources has become an increased threat in the recent years. Although waste dumping is strictly regulated after MSPAR (EPA) and the London convention / London Protocol (IMO), there is evidence that waste dumping occurs and have increased in the arctic due to the reduction in sea ice. Both litter from traditional fisheries (fishing nets etc.) and from other anthropogenic activities as tourism, is thought to have its origin both from waste dumping in the ANA-region or being transported to the Arctic Ocean by ice and/or ocean currents.

7.7 Danger from ice breakers breakdown

Ice breaker breakdown incidents have the potential to escalate into major seaborne disasters. If engaged in icebreaker escort duties, particularly convoy operations, the potential for multiple vessels reliant on the icebreaker escort to become beset in ice has the scope to become a catastrophic incident. As a scenario, which could result in a multi-ship rescue operation, such an incident has the potential to pose a number of challenges for emergency management practitioners. Beyond beset in ice considerations, the increased prevalence of nuclear powered icebreakers has the potential to escalate into a major seaborne incident of a radiological nature. There has also been increasing maritime activity in the Arctic sea areas involving nuclear-powered vessels, ships transporting nuclear fuel and high-level radioactive waste as well as the world’s first floating nuclear power plant. The presence of radiological and nuclear material in the Arctic poses a risk for serious incidents or accidents.

The organization of emergency response in case of a radiological accident at sea differs considerably from country to country. Response to such scenarios may be very complex and challenging, and require close cooperation between several authorities. Exercises and training for these kinds of incidents have been very limited, as training scenarios often concentrate on nuclear power plants or vessels at port. Furthermore, the SAR personnel may not have suitable equipment, protective gear and knowledge of SAR incidents with radiological or nuclear substance involved. This will cause a high threat for the SAR responders and volunteers involved in this kind of an incident. There is a risk that emergency response may be compromised due to lack of knowledge and a heightened perceived risk among emergency workers and emergency helpers. The potential consequences have been deemed to be so severe, that the Arctic Council's EPPR have in Dec 2019 established a radiation expert group dedicated to addressing radiological and nuclear emergency management considerations within the Arctic[3].

7.8 Asymmetric security threats

Although discussed in the context of the literature review and stakeholder engagement, the research suggests that the likelihood of asymmetric threats or criminal activity occurring within the Arctic is relatively low as a result of the challenges associated with operating within these extreme environments, vast distances, and technology limitations. One area discussed within the literature was that of acts of violence/protest against infrastructure as a result of increased public interest within the Arctic and High North. These scenarios pose a number of challenges as a result of the complexity associated with monitoring such behaviour, and the asymmetric manner by which they manifest themselves.

7.9 Emergence of military concerns

While not a focal point of the stakeholder engagement of this deliverable, the review of geopolitical research suggests an escalation in focus from major global superpowers towards the Arctic and high north. While military focuses are beyond the scope of the ARCSAR project, as a major international relations contextual variable, it is critical that SAR and emergency management stakeholders be mindful of geopolitical considerations.

[3] See EPPR RAD EG Mandate: https://oaarchive.arctic-council.org/bitstream/handle/11374/2443/EPPR_RAD-EG-Mandate-Final-Signed.pdf?sequence=1&isAllowed=y

List of References:

1. Alaska Oil Spill Commission (AOSC). (1990). Spill : the wreck of the Exxon Valdez : final report. Alaska: The commission. Retrieved from http://www.arlis.org/docs/vol1/B/33339870.pdf
2. Andreassen, N., Borch, O.J. & Ikonen, E. (Eds.) (2019) Organizing emergency response in the European Arctic: a comparative study of Norway, Russia, Iceland and Greenland, MARPART 5, FOU-rapport, Issue 46, Nord University.
3. 2. Andreassen, N., Borch, O.J. & Ikonen, E. (Eds.) (2018) Managerial Roles and Structuring Mechanisms within Arctic Maritime Emergency Response. Arctic Yearbook 2018.
4. Andreassen, N., Borch, O.J. & Schmied, J. (Eds.) (2018) Maritime emergency preparedness resources in the Arctic - capacity challenges and the benefits of cross-border cooperation between Norway, Russia, Iceland and Greenland. MARPART Report 4, FOU-rapport, Issue 33, Nord University.
5. Arctic Council (2011). Agreement on cooperation on aeronautical and maritime search and rescue in the Arctic. Nuuk, Greenland, Arctic Council.
6. Arctic Council 10 MAY 2021: https://www.arctic-council.org/news/navigating-the-future-of-arctic-shipping/
7. Binder, D. (2010). Lessons From the BP Emergency Action Plan in Action. *Environmental Law Reporter News And Analysis, (11),* 11115. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=edsbl&AN=RN283116530&site=eds-live
8. Borch, O.J., Andreassen, N., Marchenko, N., Ingimundarson, V., Gunnarsdottir, Jakobsen, U., Kern, B., Iudin, I., Petrov, S., Markov, S. & Kuznetsova, S. (2016) Maritime Activity and Risk Patterns in The High North. MARPART Report 2, FOU rapport, Issue 4, Nord University.
9. Brandvik, P. J., Sørheim, K. R., Singsaas I., Reed, M. (2006) Short State-of-the-art report on oil spills in ice-infested waters. SINTEF Marine Environmental Technology. A016148 SINTEF Report.
10. Christensen, M., Georgati, M., & Arsanjani, J. J. (2019). A risk-based approach for determining the future potential of commercial shipping in the Arctic. *Journal of Marine Engineering & Technology*, 1-18.
11. *Cruise traffic in Norwegian waters and adjacent sea areas*, summary of the Government-appointed committee (the Cruise Committee) report submitted to the Ministry of Justice and Public Security, 02/2022
12. Labib, A. (2014). *Learning from failures: decision analysis of major disasters*. Elsevier.
13. Bozeman, B. (2011). The 2010 BP Gulf of Mexico oil spill: Implications for

theory of organizational disaster. *Technology in Society, 33*(3-4),244-252.

14. BP Investigation team. (2010). *Deepwater Horizon investigation report.* Retrieved from https://www.bp.com/content/dam/bp/pdf/sustainability/issue-reports/Deepwater_Horizon_Accident_Investigation_Report.pdf
15. Chen, J., Zhang, W., Li, S., Zhang, F., Zhu, Y., & Huang, X. (2018). Identifying critical factors of oil spill in the tanker shipping industry worldwide. *Journal of Cleaner Production*, *180*, 1-10.
16. Chuang, Y., Ginsburg, L., & Berta, W. B. (2007). Learning from preventable adverse events in health care organizations. *Health Care Management Review, 32*(4), 330-340.
17. Cottle, J.L., and Kern, J., The Future of Shipping in the Arctic: New Perspectives on the Next Frontier, Watson Institute International & Public Affairs, Brown University, 2020
18. Cox, S., & Cheyne, A. (2000). Assessing safety culture in offshore environments. *Safety Science, 34*(1-3), 111-129.
19. Deepwater Horizon Study Group (DHSG). (2011). *Final report on the investigation of the Macondo Well Blowout.* Retrieved from http://ccrm.berkeley.edu/pdfs_papers/bea_pdfs/DHSGFinalReport-March2011-tag.pdf
20. Desai, V. (2010). Do organizations have to change to learn? Examining the effects of technological change and learning from failures in the natural gas distribution industry. *Industrial and Corporate Change, 19*(3), 713-739.
21. Ekaette, E., Lee, R. C., Cooke, D. L., Iftody, S., & Craighead, P. (2007). Probabilistic Fault Tree Analysis of a Radiation Treatment System. *Risk Analysis, 27*(6), 1395-1410.
22. Farrell, C. (2011). *Gulf of Mexico Oil Spill.* USA: ABDO
23. Flin, R. H. (1995). Crew resource management for teams in the offshore oil industry. *Journal of European Industrial Training, 19*(9), 23-27.
24. Geistauts, G. A. (1992). Strategic management of oil spills: Some lessons from the Exxon Valdez disaster. *OPEC Review, 16*(S4), 243-255. http://dx.doi.org/10.1111/j.1468-0076.1992.tb00460.x
25. Gramling, R., & Freudenburg, W. R. (1992). The Exxon Valdez oil spill in the

context of US petroleum politics. *Industrial Crisis Quarterly, 6*(3), 175-196.

26. Greening, D. W., & Gray, B. (1994). Testing A Model Of Organizational Response To Social And Political Issues. *Academy of Management Journal, 37*(3), 467-498.
27. Groso, A., Ouedraogo, A., & Meyer, T. (2012). Risk analysis in research environment. *Journal of Risk Research*, *15*(2), 187-208.
28. Gul, M., & Ak, M. F. (2018). A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. *Journal of Cleaner Production*.
29. Gunnarsson, B. (2021). Recent ship traffic and developing shipping trends on the Northern Sea Route—Policy implications f
30. Harrald, J. R., Marcus, H. S., & Wallace, W. A. (1990). The EXXON Valdez: An Assessment of Crisis Prevention and Management Systems. *Interfaces, 20(5),* 14-30.
31. Haunschild, P. R., & Rhee, M. (2004). The Role of Volition in Organizational Learning: The Case of Automotive Product Recalls. *Management Science, 50*(11), 1545-1560.
32. Haycox, S. (2012). "Fetched Up": Unlearned Lessons from the Exxon Valdez. *Journal of American History, 99*(1), 219-228.
33. Hiles, A. (2011). *The definitive handbook of business continuity management.* Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=cat01619a&AN=up.1001254&site=eds-live
34. Hopkins, A. (2011). Management walk-arounds: Lessons from the Gulf of Mexico oil well blowout. *Safety Science, 49*(10), 1421-1425.
35. HRS. (2022) Statistics 2021
36. Incardona, J. P., Swarts, T. L., Edmunds, R. C., Linbo, T. L., Aquilina-Beck, A., Sloan, C. A., ... & Scholz, N. L. (2013). Exxon Valdez to Deepwater Horizon: Comparable toxicity of both crude oils to fish early life stages. *Aquatic toxicology*, *142*, 303-316.
37. Johannsdottir, L., & Cook, D. (2019). Systemic risk of maritime-related oil spills viewed from an Arctic and insurance perspective. *Ocean & Coastal Management*, *179*, 104853.
38. Johannsdottir, L., Cook, D., & Arruda, G. M. (2021). Systemic risk of cruise ship incidents from an Arctic and insurance perspective. *Elem Sci Anth*, *9*(1), 00009.
39. Khan, R. A., Anand, A., & Wani, M. F. (2018). A holistic framework for environment conscious based product risk modeling and assessment using multi criteria decision

making. *Journal of Cleaner Production*, *174*, 954-965.

40. Kim, J., & Miner, A. S. (2007). Vicarious Learning From The Failures And Near-Failures Of Others: Evidence From The U.s. Commercial Banking Industry. *Academy of Management Journal, 50*(3), 687-714.
41. Kling, C. L., Phaneuf, D. J., & Zhao, J. (2012). From Exxon to BP: Has Some Number Become Better than No Number? *Journal of Economic Perspectives, 26*(4), 3-26.
42. Krasich, M. (2000). Use of fault tree analysis for evaluation of system- reliability improvements in design phase. *Annual Reliability and Maintainability Symposium, 2000 Proceedings.* http://dx.doi.org/10.1109/rams.2000.816275
43. Kruke, B. I., & Auestad, A. C. (2021). Emergency preparedness and rescue in Arctic waters. *Safety science*, *136*, 105163.
44. Kum, S., & Sahin, B. (2015). A root cause analysis for Arctic Marine accidents from 1993 to 2011. *Safety science*, *74*, 206-220.
45. Labib, A. (2014). *Learning from Failures: Decision Analysis of Major Disasters.* Retrieved from https://ebookcentral.proquest.com/lib/portsmouth-ebooks/detail.action?docID=1718625
46. Labib, A., & Read, M. (2013). Not just rearranging the deckchairs on the Titanic: Learning from failures through Risk and Reliability Analysis. *Safety Science*, *51*(1), 397-413.
47. Labuschagne, C., Brent, A. C., & Van Erck, R. P. (2005). Assessing the sustainability performances of industries. *Journal of cleaner production*, *13*(4), 373-385.
48. Lanteigne, Marc. 2019. *The Changing Shape of Arctic Security*. NATO Review. Online: https://www.nato.int/docu/review/2019/Also-in-2019/the-changing-shape-of-arctic-security/EN/index.htm.
49. Lynch, R. and Griew, M. (2019) SEDNA Deliverable D3.6 – Arctic Navigation and Communications Solutions, Roadmaps and Mitigation Strategies.
50. Lynch, R. (2020) SEDNA Deliverable 3.7 – Arctic Bridge Operational Procedures
51. Makajic-Nikolic, D., Petrovic, N., Belic, A., Rokvic, M., Radakovic, J. A., & Tubic, V. (2016). The fault tree analysis of infectious medical waste management. *Journal of Cleaner Production*, *113*, 365-373.
52. Madsen, P. M., & Desai, V. (2010). Failing to Learn? The Effects of Failure and Success on Organizational Learning in the Global Orbital Launch Vehicle Industry. *Academy of Management Journal, 53*(3), 451-476.

53. Marchenko, N. Andreassen, O.J. Borch, S. Yu, V. Ingimundarson, U. Jakobsen,Arctic shipping and risks: emergency categories and response capacities, TransNav12 (1) (2018) 107–114.
54. Marchenko, N. (2020). Maritime Activity and Risk, in Andreassen, N. & Borch, O.J. (Eds.) Crisis and Emergency Management in the Arctic. Navigating Complex Environments, Routledge.
55. Marshall, E. (1989). Valdez: The Predicted Oil Spill. *Science, 244(4900),* 20- 21. http://dx.doi.org/10.1126/science.244.4900.20
56. MARPART (2016) Maritime activity and risk patterns in the High North, MARPART Project Report 2.
57. Mcgrath, R. G. (1999). Falling Forward: Real Options Reasoning and Entrepreneurial Failure. *The Academy of Management Review, 24*(1), 13.
58. Mejri, M., & Wolf, D. D. (2013). Crisis Management: Lessons Learnt from the BP Deepwater Horizon Spill Oil. *Business Management and Strategy, 4(2),* 67.
59. Mitroff, I. I., & Anagnos, G. (2001). *Managing crises before they happen : what every executive and manager needs to know about crisis management*. New York : AMACOM
60. Morris, M. W., & Moore, P. C. (2000). The Lessons We (Dont) Learn: Counterfactual Thinking and Organizational Accountability after a Close Call. *Administrative Science Quarterly, 45*(4), 737.
61. National Oil Spill Commission (NOSC). (2011). *Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling.* Retrieved from http://www.iadc.org/archived-2014-osc-
61.2 report/documents/DEEPWATER_ReporttothePresident_FINAL.pdf
62. National Transportation Safety Board (NTSB). (1990). *Marine Accident Report-Grounding of the U.S. Tankship EXXON VALDEZ on Bligh Reef, Prince William Sound, near Valdez, Alaska.* Retrieved from https://www.hsdl.org/?view&did=746707
63. Necci, A., Tarantola, S., Vamanu, B., Krausmann, E., & Ponte, L. (2019). Lessons learned from offshore oil and gas incidents in the Arctic and other ice-prone seas. *Ocean Engineering*, *185*, 12-26.

64. Oconnor, P., & Flin, R. (2003). Crew Resource Management training for offshore oil production teams. *Safety Science, 41*(7), 591-609.
65. Oun, H. (2015). Was it management-technical failure or safety ignorance? root cause analysis of the BP Oil Spill in the Gulf of Mexico. *International Conference on Industrial Engineering and Operations Management (IEOM)*. http://dx.doi.org/10.1109/ieom.2015.7093724
66. PAME - Arctic Shipping: https://pame.is/arctic-shipping (acceded, 13/6/2022).
67. Partlett, D. F., & Weaver, R. L. (2011). BP Oil Spill: Compensation, Agency Costs, and Restitution. *Washington & Lee Law Review*, *68*(3), 1341-1375. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=70200558&site=eds-live
68. Pearson, C. M., & Mitroff, I. I. (1993). From crisis prone to crisis prepared: A framework for crisis management. *Academy of Management Perspectives, 7(1),* 48-59.
69. Piadeh, F., Ahmadi, M., & Behzadian, K. (2018). Reliability Assessment for Hybrid Systems of Advanced Treatment Units of Industrial Wastewater Reuse Using Combined Event Tree and Fuzzy Fault Tree Analyses. *Journal of Cleaner Production*.
70. Piper, E. (1993). *The Exxon Valdez oil spill: Final report, state of Alaska response*. Anchorage, AK: Alaska Dept. of Environmental Conservation.
71. Prendergast, D. P., & Gschwend, P. M. (2014). Assessing the performance and cost of oil spill remediation technologies. *Journal of cleaner production*, *78*, 233-242.
72. Puisa, R., Williams, S., & Vassalos, D. (2019). Towards an explanation of why onboard fires happen: The case of an engine room fire on the cruise ship “Le Boreal”. *Applied Ocean Research*, *88*, 223-232.
73. Reader, T. W., & O’Connor, P. (2013). The Deepwater Horizon explosion: Non-technical skills, safety culture, and system complexity. *Journal of Risk Research, 17*(3), 405-424.
74. Rose, M. A., & Hunt, B. (2012). Learning from Engineering Failures: A Case Study of the Deepwater Horizon. *Technology And Engineering Teacher*, *71*(5), 5-11.
75. Sharratt, P. N., & Choong, P. M. (2002). A life-cycle framework to analyse business risk in process industry projects. *Journal of Cleaner Production*, *10*(5), 479-493.

76. Sheehan, R., Dalaklis, D., Christodoulou, A., Drewniak, M., Raneri, P., & Dalaklis, A. (2021). The Northwest Passage in the Arctic: A brief assessment of the relevant marine transportation system and current availability of search and rescue services. *Logistics*, *5*(2), 23.
77. Shultz, J., Walsh, L., Garfin, D., Wilson, F., & Neria, Y. (2015). The 2010 Deepwater Horizon Oil Spill: The Trauma Signature of an Ecological Disaster. *Journal Of Behavioral Health Services & Research*, *42*(1), 58-76.
78. Silber, G. K., & Adams, J. D. (2019). Vessel operations in the Arctic, 2015–2017. *Frontiers in Marine Science*, 573.
79. Silvestre, B. S., & Gimenes, F. A. P. (2017). A sustainability paradox? Sustainable operations in the offshore oil and gas industry: The case of Petrobras. *Journal of Cleaner Production*, *142*, 360-370.
80. Skinner, S. K. & Reilly, W. K. (1989). *The Exxon Valdez oil spill: a report to the president.* Retrieved from https://www.bookdepository.com/EXXON- Valdez-Oil-Spill-Report-President-Samuel-K-Skinner/9781608880492
81. Skogdalen, J. E., Utne, I. B., & Vinnem, J. E. (2011). Developing safety indicators for preventing offshore oil and gas deepwater drilling blowouts. *Safety Science, 49*(8-9), 1187-1199.
82. Slater, D. (2014). Exxon Valdez: safety on the rocks? *TCE: The Chemical Engineer*, (873), 36-38.
83. Small, W. J. (1991). Exxon Valdez: How to spend billions and still get a black eye. *Public Relations Review, 17*(1), 9-25.
84. Stagonas, D., Thomas, G. and Ryan, C. (2018) SEDNA D1.2 Arctic Shipping Future Trends
85. Statista: https://www.statista.com/statistics/1278604/unique-ship-traffic-arctic-ocean-by-ship-type/ (acceded, 13/6/2022).
86. Taylor, S. E. (1979). Hospital Patient Behavior: Reactance, Helplessness, or Control? *Journal of Social Issues, 35*(1), 156-184. Sylves, R. T., & Comfort, L. K. (2012). The Exxon Valdez and BP Deepwater Horizon oil spills: reducing risk in socio-technical systems. *American Behavioral Scientist*, *56*(1), 76-103.
87. Tekman, M. B., Krumpen, T., Bergmann, M. (2017). Marine litter on deep Arctic seafloor continues to increase and spreads to the North at the HAUSGARTEN observatory. *Deep Sea Research Part I: Oceanographic Research Papers.* Volume 120,

88-99.

88. Van der Togt, Tony. 2019. *Conflict Prevention and Regional Cooperation in the Arctic*. Clingendael Magazine. Online: https://www.clingendael.org/publication/conflict-prevention-and-regional-cooperation-arctic

89. Wang, H., Jiang, Z., Zhang, X., Wang, Y., & Wang, Y. (2017). A fault feature characterization based method for remanufacturing process planning optimization. *Journal of Cleaner Production*, *161*, 708-719.

90. Yang, Z., Shah, K., Laforest, S., Hollebone, B. P., Lambert, P., Brown, C. E. & Goldthorp, M. (2018). A study of the 46-year-old Arrow oil spill: Persistence of oil residues and variability in oil contamination along Chedabucto Bay, Nova Scotia, Canada. *Journal of Cleaner Production*, *198*, 1459-1473.

Appendix A: Fault Tree Analysis (FTA), Reliability Block Diagram (RBD) and Minimum Cut Sets (MCS) (Labib and Read, 2013[4]; Labib, 2014[5]; Labib et al., 2019[6]):

A1: Fault Tree Analysis (FTA):

A fault tree is a logical diagram that is in the shape of a Christmas tree where the top of the tree depicts the undesirable event. Fault tree analysis (FTA) helps in understanding the causal relation between system failure, i.e. a specific undesirable event in the system, and failures of the components of the system. The undesirable event constitutes the top event of the tree and the different component failures constitute the basic event of the tree. The causes of the TOP event are 'connected' through logic gates; we only consider AND gates and OR gates. Although there are other types of gates, their use in modelling tends to be limited and is hence not considered in our analysis as the majority of problems can be modelled by either AND or OR gates. Basic events are those associated with human errors, equipment failure and environmental interference. FTA provides a logical representation of the relation between the top event and those basic events. From a design perspective, this technique could give indications of how a system could fail, which is equally important as how a system will operate successfully. There are two important types of logic gate in an FTA, i.e. the AND gate (symbolized by an inverted arc with a horizontal line at the bottom) and the OR gate (symbolized by an inverted arc with a curve at the bottom), as shown in Figure A1.

[4] Labib, A., & Read, M. (2013). Not just rearranging the deckchairs on the Titanic: Learning from failures through Risk and Reliability Analysis. *Safety science*, *51*(1), 397-413.

[5] Labib, A. 2014. Learning from Failures: Decision Analysis of Major Disasters. Oxford: Butterworth-Heinemann.

[6] Labib, A., Hadleigh-Dunn, S., Mahfouz, A., & Gentile, M. (2019). Operationalizing learning from rare events: Framework for middle humanitarian operations managers. *Production and Operations Management*, *28*(9), 2323-2337.

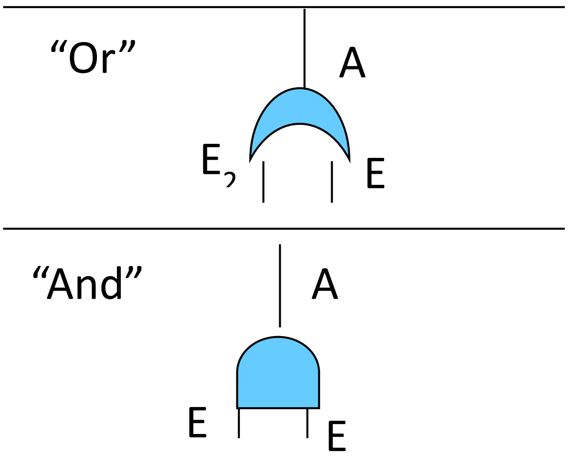


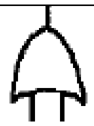
Figure A1: The Main Logic Gates in FTA (OR and AND Gates).

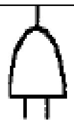
An OR gate indicates that the output event (top vertical line A) occurs only if one or more of the input events occur (bottom vertical lines E1 or E2). There may be any number of input events to an OR gate. The implication is that the system involved is vulnerable to any one of the inputs, i.e. each one is sufficient to cause the disaster.

An AND gate, on the other hand, indicates that the output event (top vertical line A) occurs only if all the input events ((bottom vertical lines E1 and E2) occur at the same time. There may be any number of input events to an AND gate. When modelling a disaster, if the fault tree involved has one gate at the top that is an AND gate the implication is that there exists a set of barriers that were all insufficient to prevent the disaster.

Symbols for OR and AND gates are shown in Table A1.

Table A1: OR and AND logic gates:

Symbol	Symbol name	Description	Reliability Model	Inputs
	OR gate	The output event occurs if any of its input events occur	Failure occurs if any of the parts of the system fail – series system	≥ 2

	AND gate	The output event occurs if all input events occur	Parallel redundancy, one out of n equal or different branches	≥ 2

For an OR gate, the following logic applies as shown in Table A2.

Table A2: Logic table for OR gate

$P_{input\ 1}$	$P_{input\ 2}$	P_{output}
0	0	0
1	0	1
0	1	1
1	1	1

For an AND gate, the following logic applies as shown in Table A3.

Table A3: Logic table for aND Gate

$P_{input\ 1}$	$P_{input\ 2}$	P_{output}
0	0	0
1	0	0
0	1	0
1	1	1

For OR and AND gates the probabilities are calculated as follows:

$$P_{(OR\_Gate)} = 1 - \prod(1 - P_{(input\_i)})$$

$$P_{(AND\_Gate)} = \prod P_{(input\_i)}$$

The steps in constructing an FTA are a top-down approach as shown in Figure A.2.

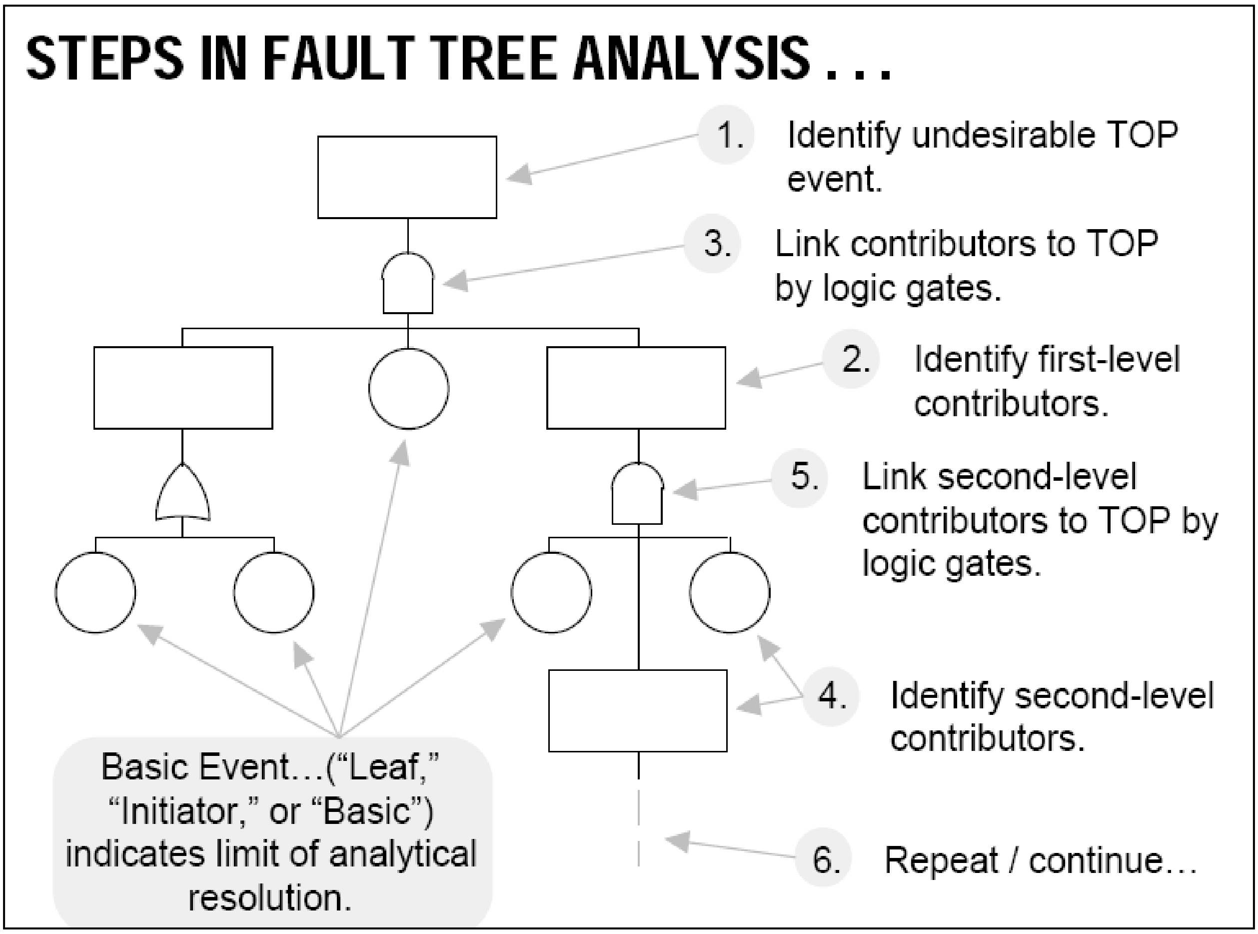


Figure A2: Steps in Constructing a Top-Down FTA.

The basic events (shown as the bottom circles in Figure A.2) are considered to be the 'leaves' of the tree, the 'initiators' or 'root causes'.

A2: Reliability Block Diagram (RBD):

The FTA described in Appendix A1 can then be mapped into a reliability block diagram (RBD). Therefore an RBD is a natural outcome of FTA. The RBD is a logic diagram intended to highlight the overall relationship among different causal factors. Each block in the RBD represents an actual functioning component. Any failure is represented by removing the block from the diagram. If the connection between input and output is interrupted the system fails; however, if only one path remains active from input to output the system is functional. So the RBD helps us to assess the vulnerability of the whole system. Blocks can be arranged in two formats either in parallel or series. These different sections and connections can all be summarized in a single block and its reliability can be calculated using series and parallel equations.

The mapping from FTA into RBDs is carried out based on the following 'golden rules':

Golden Rule No. 1: Every OR gate in an FTA is equivalent to a series structure in an RBD.

Golden Rule No. 2: Every AND gate in an FTA is equivalent to a parallel structure in an RBD.

Golden Rule No. 3: The number of basic events (circles) in an FTA is equal to the number of boxes (squares) in an RBD.

Golden Rule No. 4: Order (sequence) does not matter.

Figure A3 shows how to map an FTA into an RBD.

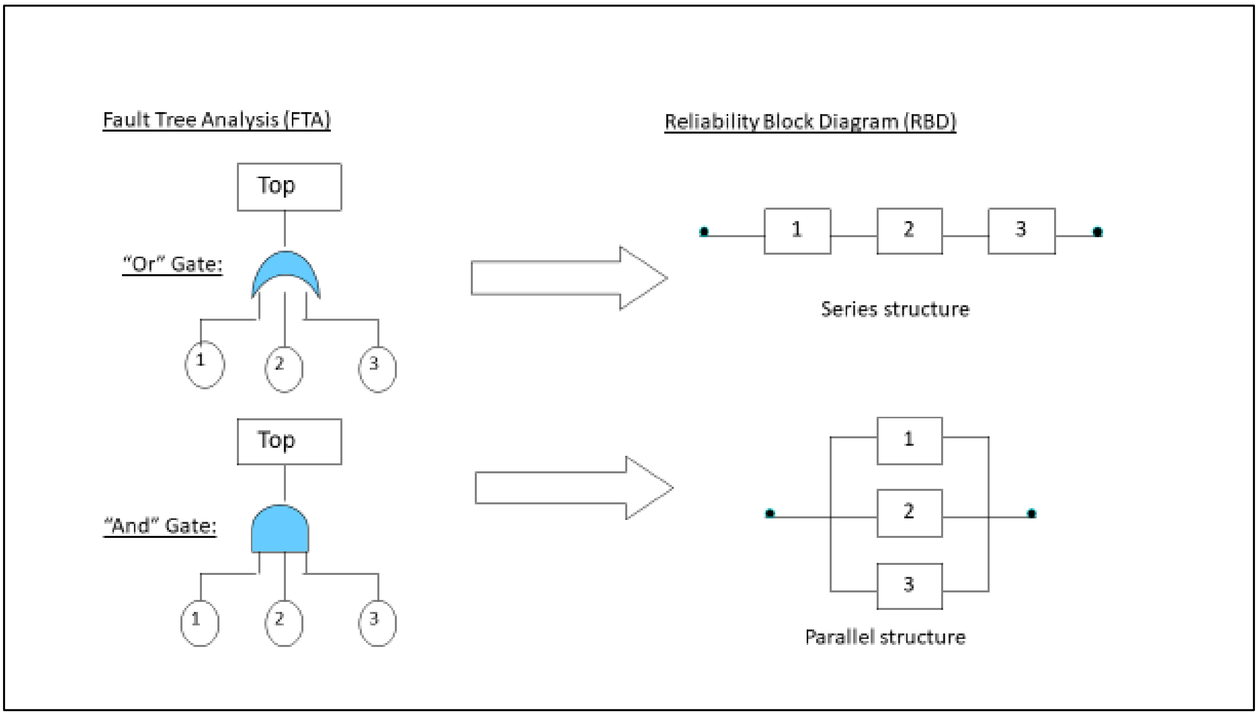


Figure A3: Mapping of FTA into the Equivalent RBD.

When trying to calculate the reliability Rs of the whole system, given that we know the reliabilities Ri of each component, then the following equations apply. The basic idea is that: R+F=1, as a system has a probability of being either in a reliable (success) or a fault state. So, in the equation of a series structure (the outcome of an OR gate) we have:

$R_{sys} = R_1 x R_2 .. R_n$

On the other hand, redundancy means adding more components, which reduces the probability F of failure and hence enhances the reliability R, so for a parallel structure all redundant components need to fail for the system to fail and hence

$F_{sys} = F_1 x F_2..F_n$.

Therefore, reliability increases geometrically with the number of redundant (parallel) parts while cost increases linearly. So when reliability is important, redundant designs become cost-effective.

Therefore for the series (OR gate) and parallel (AND gate) structures the system reliability in the RBD is modelled using the equations shown below.

$$R_s = \prod_{i=1}^{n} R_i$$

$$R_P = 1 - \prod_{i=1}^{m} R_i$$

A3: Minimum Cut Sets (MCS):

A cut set is any group of basic events in the FTA (or squares in the RBD) that, if all occur, will cause the top event to occur. Hence, a minimum cut set (MCS) is a minimum group of basic events that, if they all occur, will cause the top event to occur. So it is arranged to indicate which combinations of component failures result in the failure of the system or which combination of properly working components keep the system functioning. Here MCS analysis helps us to deal with different possible scenarios of combinations of causal factors.

In order to derive cut sets, we need first to revise Boolean algebra rules:

Axioms of Boolean algebra in cut sets:

[A1] xy = yx (Commutative Law)

[A2] x+y = y+x (Commutative Law)

[A3] (x+y)+z = x+(y+z) = x+y+z (Associate Law)

[A4] (xy)z = x(yz) = xyz (Associate Law)

[A5] x(y+z) = xy + xz (Distributive Law)

Theorems of Boolean algebra

[T1] x + 0 = x

[T2} x + 1 = 1

[T3] x . 0 = 0

[T4] x . 1 = x

[T5] x . x = x (Idempotent Law)

[T6] x **+** x = x (Idempotent Law)

[T7] x **+** **x**y = x (Law of Absorption)

[T8] x (x + y) = x (Law of Absorption)

In Boolean: Plus "+" represents an "OR" gate, whereas multiplication "**.**" represents an "AND" gate.

The figure below will be used to illustrate how cut set analysis can be performed from an FTA.

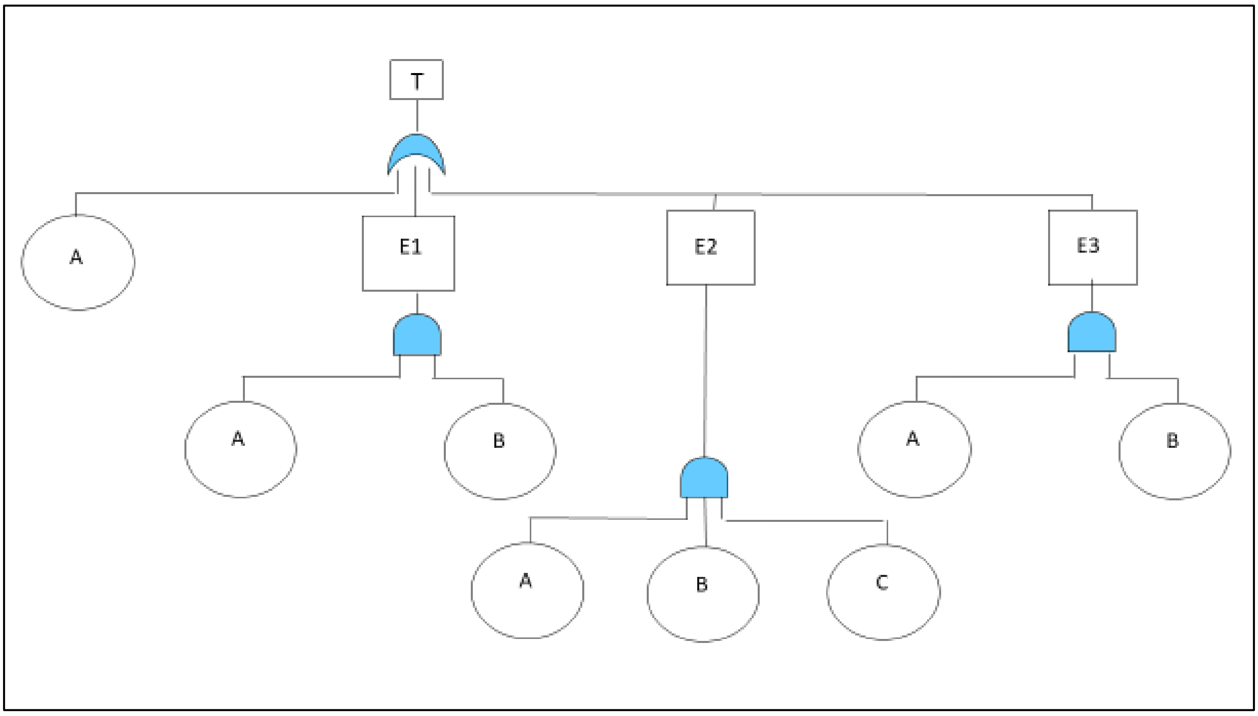


Figure A4: FTA Example for Illustration.

Top event (T) is given by:

TE = A + E1 +E2 +E3

Substituting for E1, E2, E3:

TE = A + (A.B) +(A.B.C) + (A.B)

The cut sets are: A, A.B, A.B.C

Minimizing the top event using Boolean gives the minimal cut set:

TE = A + (A.B) + (A.B.C) + (A.B)

TE = A + (A.B) +(A.B.C) [Applying T6]

TE = A + (A.B) [Applying T9]

TE = A [Applying T9]

Thus the minimal cut set is “A”. This means that if event “A” occurs the top event will occur. We can also see this directly in the fault tree.

Note that cut sets can also be performed visually from the RBD as shown in Figure A5. This is done by imagining the RBD as an electrical circuit. And this circuit can be ‘cut’, i.e. a top event occurs if scissors can cut through a combination of boxes, or a minimum number of boxes in the case of MCS.

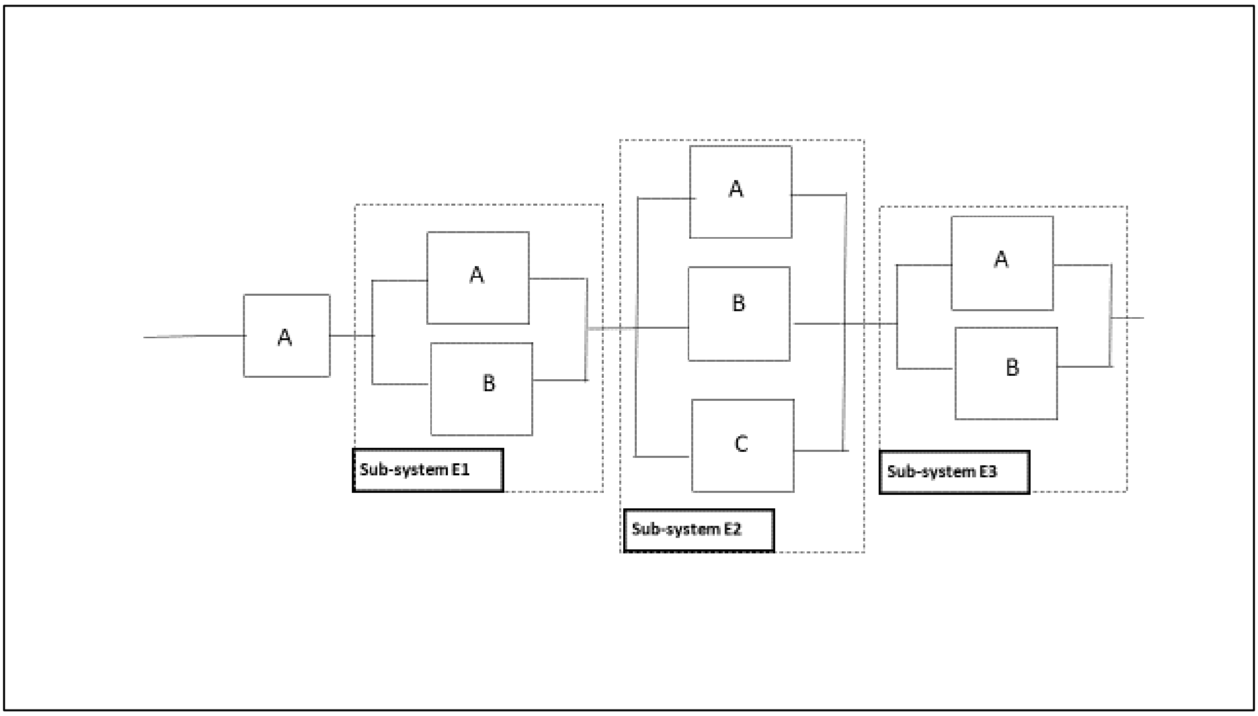


Figure A5: The Equivalent RBD.

Appendix B: Relation to the ARCSAR project plan

This report contains a description of the organisational and scientific activities necessary for the completion of Task 3.1 of Work Package 3 of the ARCSAR project:

"T3.1. Foresight analysis. Define and characterise potential seaborne disasters, catastrophic incidents, and security threats in the ANA region. This will be carried out through analysis of existing reports, real life case studies and investigation reports, and through the working groups established in WP1. Targeted meetings with groups of practitioners and stakeholders will be held in order to fine-tune the characterisation of potential major crises. Identify known critical barriers and gaps in capacity, competence and infrastructure of professional security and emergency response practitioners. Information generated in WP2 (T1.2) will also be accessed. [Task Leader: UP]. M12 – M24]" (ARCSAR, 2017).

The output of this deliverable (D3.1) will be utilised in Task3.3. "T3.3 Needs and Barriers analysis. Based on outputs of Tasks 3.1 and 3.2, conduct a comprehensive assessment of the critical gaps and needs in capacity, competence and infrastructure of practitioners working in the ANA region. This will be facilitated by two large stakeholder events, held under different themes. The focus areas will be determined by the outcomes of the previous Tasks. [Task Leader: UP]. M31 – M50" (ARCSAR, 2017).

This deliverable's results will also be utilised in Task 3.2: " T3.2. Catastrophic incident simulations and live exercises. Based on the most likely major seaborne disasters, catastrophic incidents, and security threats (T3.1), conduct live exercises and simulated table-top exercises as part of the network actions. Infrastructure, and geographic specificities of particular relevance to the ANA region will be taken in to account, for example: challenges in radio and satellite communication in the polar region; cold and harsh polar and Atlantic climatic conditions; operations in sea ice; sparsely or non-populated areas; highly populated areas; functioning of equipment in cold climate; challenging topography on coasts, including cliffs, mountains, and fjords; islands; and, other marine infrastructure and traffic operating in the region on defined routes. Local, regional, national and international SAR and Emergency operations will be considered. Situational awareness between emergency management agencies and other emergency actors, cross sector and cross border, will be assessed as well approaches to risk assessment and decision-making. Analysis of vulnerability, and selection of appropriate response policies and decision-making as applied to retrospective and prospective scenarios in the Arctic and North Atlantic region will be used" (ARCSAR, 2017).

It will also inform "Table-top exercises: It will also be possible to simulate other catastrophic incidences through well-structured table-top exercises. These exercises will be extensive and multi-actor, led by groups of practitioners that need to cooperate across the ANA region. The scenarios to be built in to the live exercise will be informed from T3.1. 3). Examples could include:

1) 'Collision in North Atlantic' based on a collision between a freight ship and an oil rig in the North Atlantic. Such an incident would involve Search and Rescue services, and other emergency services, as well as practitioners involved in environmental catastrophes;

2) 'Violent Attack' based on an unexpected violent attack on marine infrastructure (oil rigs, renewable energy platforms, shipping), or passenger ferry in the ANA region, during extreme weather events;

3) 'Marine Hazardous Incident' based on a human and environmental threat due to a radiological or nuclear incident, or collision at sea of shipping carrying hazardous goods. Specific technology and equipment would be required, where there is a risk of radiological or chemical exposure, and the incident would have human as well as environmental consequences. Both Arctic and North Atlantic scenarios will be tested. Geospatial satellite information, SAR in particular, properly suited and customized for the exercises, leveraging the optimal coverage for the region will be an integral part of the monitoring" (ARCSAR, 2017).

The relevant deliverable descriptions are:

This deliverable

D3.1. “Report on definition and characterization of potential seaborne disasters, catastrophic incidents, and security threats in the ANA region” - WP3 16 – CIT , due M24, changed from M18 (ARCSAR, 2017).

Future deliverables informed by this deliverable

D3.2: “Report on critical gaps and needs in capacity, competence and infrastructure of practitioners working in the ANA region” - WP3 13 – UP due M54 (ARCSAR, 2017).

D3.3: “Policy paper on future needs for innovations and knowledge” WP3 5 – USCG, due M56 (ARCSAR, 2017).

D3.4: “Practitioner-led guidelines for interfaces between emergency and security practitioners in ANA region WP3 12 – NORD, due M60 (ARCSAR, 2017).

Also critical barriers and gaps in capacity, competence and infrastructure of professional security and emergency response practitioners, have already been identified in Deliverable 2.1.Work is simultaneously being undertaken in Work Package 2 to identify promising innovations, technologies, knowledge, research and collaborations to fill these gaps (Task 2.3) and to monitor their subsequent update (Task 2.4). Broadly speaking, the competence related gaps fill into the “Education and Training” topic of the Deliverable 2.1 classification, whereas capacity and infrastructure related gaps span the remaining five topics. Readers are referred to the Deliverable 2.1 and Task 2.3 reports for further details.

Appendix C: Information Related Bodies of Knowledge:

This section summarises the content of related four recent reports from the Arctic Council's Emergency Prevention, Preparedness and Response (EPPR) working group. The four sources are:

1. Source No 1: Arctic Council Emergency Prevention, Preparedness and Response (EPPR) Working Group,
2. 2019, EPPR ARCSAFE: Summary Status Report. 16 pp.
3. Source No 2: EPPR, 2019, Arctic Council status on implementation of the "Framework Plan for Cooperation on Prevention of Oil Pollution from Petroleum and maritime Activities in the Marine Areas of the Arctic". Emergency Prevention, Preparedness and Response (EPPR). 30 pp.
4. Source No 3: EPPR, 2019, Agreement on Cooperation on Marine Oil Pollution Preparedness And Response In the Arctic (MOSPA) - 2018 Table-top exercise After Action Report. Emergency Prevention Preparedness and Response (EPPR). 42 pp.
5. Source 4: EPPR, 2017, Final Report: Standardization as a tool for prevention of oil spills in the Arctic. 129 pp.

Source No 1: Arctic Council Emergency Prevention, Preparedness and Response (EPPR) Working Group, 2019, EPPR ARCSAFE: Summary Status Report. 16 pp.

The document highlights the challenges in the Arctic ship traffic. Ship traffic in the Arctic includes nuclear-powered vessels, ships transporting spent nuclear fuel and high-level radioactive waste, and the prospect of a floating nuclear power plant. The report also argues the need for generating electric power to support growing Arctic industry activities at remote locations, which may also include new technologies, such as small modular nuclear reactors for surface or submerged use. Hence it is argues that the presence of radiological and nuclear material in the Arctic poses a risk for serious incidents or accidents that may affect Arctic inhabitants and their communities, the Arctic environment, and Arctic industries, including traditional livelihoods such as fisheries and local food sources.

The report then describes the ARCSAFE project where its goal is to 'to promote cooperation among the Arctic Council States to strengthen cross-border prevention, preparedness and handling of maritime incidents or accidents which may involve a potential release of radioactive substances to the Arctic environment'. It describes the project in terms of its mandate, expected outcome, partners, format, activities,

The Key findings are summarised as follows:

• The organization of emergency response in case of a radiological accident at sea differs considerably from country to country. Response to such scenarios may be very complex and challenging, and require close cooperation between several authorities.
• Depending on type of response unit, there may be a lack of training and necessary protective gear and radiological measuring equipment. Deployment of special response units that normally operate on land may require special arrangements, for example, transport and communications that need to be exercised.
• There is a risk that emergency response may be compromised due to lack of knowledge and a heightened perceived risk among emergency workers and emergency helpers.
• There is a need for joint exercises and trust building between RN experts and emergency workers / emergency helpers.
• Regarding the transport and deployment of floating nuclear power plants in the Arctic, there is a need for detailed technical information, hazard assessment(s) and development of detailed technical guidance for proper emergency prevention and response, including security and specific features of the area.

Source No 2: EPPR, 2019, Arctic Council status on implementation of the "Framework Plan for Cooperation on Prevention of Oil Pollution from Petroleum and maritime Activities in the Marine Areas of the Arctic". Emergency Prevention, Preparedness and Response (EPPR). 30 pp.

In 2015, the Arctic Council Ministers approved the “Framework Plan for Cooperation on Prevention of Oil Pollution from Petroleum and Maritime Activities in the Marine Areas of the Arctic” (Framework Plan).

The objective of the Framework Plan is to strengthen cooperation, including exchange of information, among the Participants in the field of prevention of marine oil pollution in order to protect the Arctic marine environment. The Framework Plan applies to petroleum and maritime activities in the marine areas of the Arctic that entail a risk of oil pollution to the Arctic marine environment.

In May 2017, Arctic Council Ministers approved the first status report on the implementation of the Framework Plan. This report provides an update on the status of implementation by outlining activities undertaken by Arctic States, working groups of the Arctic Council and other relevant stakeholders in the period of May 2017 – May 2019.

2. Status of progress on initiatives related to prevention of oil pollution from Arctic petroleum activity:

2.1 Develop an overview of measures for improved safety.

The Participants intent to: Cooperate to develop an overview of the existing and potential technical and operational safety measures specifically designed to prevent oil pollution in the Arctic marine environment from offshore petroleum activity.

The EPPR Working Group continues to explore opportunities to advance the prevention and preparedness aspects of oil pollution mitigation in the Arctic. To date, several projects have been completed or are in progress that will advance prevention and preparedness measures, including:

- Development of a Compendium of Arctic Shipping Accidents (CASA) in cooperation with PAME detailing incident and location specific data for all Arctic states that can better define potential problem corridors in the Arctic,
- Pan-Arctic Pollution Response Equipment database detailing pollution response equipment type and locations in the Arctic, and
- Increased risk assessments detailing emerging risks as human activity increases in the Arctic.

2.2 Promote standardization activities

The Participants intent to:

a) promote the development of standards and/or best practices relevant to the prevention of oil pollution in the Arctic, e.g., well design, source control, capping, containment and other technical and operational measures;
b) assess whether existing and proposed standards for petroleum activity are sufficient to meet Arctic challenges; and
c) support participation of technical experts in the efforts referred to in this section.

Key Reference Documents reported on in the 2017 Status Report
International standards for petroleum, offshore-oil and maritime industries
https://oaarchive.arctic-council.org/handle/11374/1951
Standardization as a Tool for Prevention of Oil Spills in the Arctic

2.3 Strengthen cooperation of national regulators.

The Participants intent to:

a) promote cooperation between competent national authorities on issues concerning the prevention of Arctic marine oil pollution from petroleum activities.

With the establishment of Arctic Offshore Regulators Forum (2015), national regulators have a forum to exchange information, collaborate, and promote cooperation in the area of prevention. The terms of reference for AORF are available at the following site: https://www.bsee.gov/sites/bsee.gov/files/meeting-minutes/ safety/aorf-terms-of-reference-final-may-2015.pdf

3.Status of progress on initiatives related to measures for prevention of oil pollution from Arctic maritime activity

3.1 Strengthen traffic monitoring and management

3.1.1 Remote and aerial surveillance

The Participants intent to:

a) share lessons learned and best practices from responding to/monitoring pollution incidents and operating in harsh Arctic environments;
b) develop operational procedures for pollution patrol, ice patrol, etc. in the Arctic;
c) explore possible exchange of personnel for familiarization tours as part of the crew;
d) explore the possibility of coordination of earth observation satellites to acquire/share imagery over contiguous waters.

1. The eight Arctic nations formally established the Arctic Coast Guard Forum which is a venue for operational practitioners to share information and best practices, conduct joint Arctic operations and exercises, and collaborate on tactical Arctic issues.

3.1.2 Enhancing cooperation on maritime risk assessments.

The Participants intent to:

a) exchange experience and best practices of data collection and analysis for maritime risk assessments;
b) exchange maritime traffic and environmental sensitivity data and associated methodologies; and

c) explore the possibility of developing a common and publicly accessible database of Arctic maritime traffic and environmental sensitivity data.

3.2 Improve maritime services

3.2.1 Navigational charts

The Participants intent to:

a) explore coordination of hydrography and mapping surveys to improve the safety of Arctic shipping; and
b) exchange experiences and best practices on hydrography and nautical charting in the Arctic.

3.2.2 Improve meteorological and oceanographic forecasts

The Participants intent to:

a) exchange experience and best practices in the field of forecasting meteorological, oceanographic and ice related conditions and hazards as well as regarding climatological ice and metocean information; and
b) improve methods, standards and systems for detecting and monitoring metocean and ice related conditions, and distributing this information, when appropriate, in a timely manner between Participants and communities throughout the Arctic.

3.2.3 Broadband and satellite communications

The Participants intent to:

Exchange information on relevant systems of broadband and satellite communication to improve safety of navigation in the Arctic.

3.2.4 Prevention of marine incidents that could result in oil pollution

The Participants intent to:

a) develop a catalogue of existing resources (tug boats, tow packages, ship arrestors, mooring buoys, etc.) that may play a role in minimizing the potential for, and the environmental impact of, a marine incident that could result in oil pollution, and to assess the adequacy of such resources.

Pan-Arctic Database of Arctic Response Assets - The database is located on the National Oceanic and Atmospheric Administration's (NOAA) Arctic Environmental Response Management Application (Arctic ERMA)

3.2.5 Navigation in ice conditions

The Participants intent to:

exchange best practices and any other relevant information on national requirements and, when appropriate, industry standards for navigating in marine areas of the Arctic in ice conditions.

3.2.6 Icebreaking and ice-management services

The Participants intent to:

a) exchange best practices and information on existing icebreaking and ice-management services.

Source No 3: EPPR, 2019, Agreement on Cooperation on Marine Oil Pollution Preparedness And Response In the Arctic (MOSPA) - 2018 Table-top exercise After Action Report. Emergency Prevention Preparedness and Response (EPPR). 42 pp.

The report is related to the 2018 EPPR MOSPA TTX. The purpose of this exercise was to further validate and update, as appropriate, the Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic (MOSPA Agreement) and the associated Operational Guidelines. This exercise built upon the lessons learned from the 2016 MOSPA exercise while also evaluating the Notification and Request for Assistance protocols for each EPPR member state in order to enhance collaboration in the event of a real-world incident.

Scope: This exercise engaged EPPR member state representatives whose countries may be impacted by an oil spill that is large enough to require the implementation of the multi-lateral MOSPA Agreement and Operational Guidelines. By exercising the Operational Guidelines and Notification and Request (and Offer) for Assistance protocols, EPPR member states, Permanent Participants, and Observers can benefit from enhanced preparedness throughout the Arctic marine environment.

Several observations / recommendations included:

- Comparison of Communication & Notification Protocols under the Copenhagen and MOSPA Agreements.
- Maximizing Use of EPPR Website, SharePoint, and Social Media Channels.
- Coordination between EPPR and the Arctic Coast Guard Forum.
- Request for Assistance Process and Utilizing the Pan-Arctic Response Equipment Database.
- Liaisons.
- Circumpolar Oil Spill Response Viability Analysis.

2018 MOSPA Exercise Objectives: The main goal of the MOSPA is to strengthen cooperation, coordination and mutual assistance among the Parties on oil pollution, preparedness and response in the Arctic. Therefore, the following objectives, approved at EPPR II 2017, focus on strengthening mutual assistance and building upon the lessons learned from the 2016 MOSPA exercise:

1. Analyzing Agreements: Both the Copenhagen Agreement and the MOSPA Agreement (and associated Operational Guidelines) are multi-lateral agreements. An analysis between the two Agreements under the framework of an actual exercise could provide a great opportunity to review both Agreements in order to examine similarities and differences, with a focus on: a. Initial incident reporting;

b. Intergovernmental communications (situation reports); and

c. Communications with the public (social media, etc).

Objective: Review the notification, communication, and situational reporting protocols of both the MOSPA and Copenhagen Agreements to identify potential synergies, mitigate gaps and reduce duplicities when conducting an oil spill response under the Copenhagen Agreement that escalates into the broader MOSPA Agreement.

2. Request for Assistance: Previous *MOSPA* exercises executed an actual request for assistance utilizing procedures and forms contained within the *Operational Guidelines*. The 2018 *MOSPA* exercise should also utilize this process with the additional incorporation of the Pan-Arctic Response Equipment Database in order to select the specific resources for this exercise.

Objective: Demonstrate the capability to utilize the Pan-Arctic Response Equipment Database while managing an unsolicited Offer of Assistance from another Party of the MOSPA Agreement.

3. *Cross-border Coordination / Liaison:* The 2016 *MOSPA* exercise identified a lesson learned highlighting issues associated with coordinating the offer / request for assistance process from one EPPR member state to another in order to mitigate logistical issues associated with cross-border movement of resources, i.e. staging a liaison or coordinating officer from the offering state within the requesting state's command structure to help facilitate the movement and direction of resources.
Objective: Demonstrate the capacity to identify and assign a liaison or authority (within a specified timeframe) entitled to act on behalf of the Offering Party in order to render appropriate assistance to the Requesting Party.

4. Circumpolar Oil Spill Response Viability Analysis (COSRVA): The purpose of the COSRVA is to better understand the ability of existing spill response systems to operate in the Arctic marine environment. Based upon the timeframe of the 2018 *MOSPA* exercise, utilization of the COSRVA for the specific region could aid in risk mitigation efforts in addition to spill response planning.

Objective: During the 2018 MOSPA exercise, demonstrate the capability to utilize the Circumpolar Oil Spill Response Viability Analysis (COSRVA) to facilitate decision-making on OSR planning and tactics during a response in the Arctic marine environment.

Lessons Learned, Best Practices, and Recommendations :

1. Comparison of Communication & Notification Protocols under the Copenhagen and MOSPA Agreements:

The Connectivity Test:

Recommendation: Capture all updates (from the 2018 Connectivity Test) to contact information in the Operational Guidelines and finalize by EPPR I 2018.

Recommendation: The state currently responsible for the Arctic Council Chair (during an exercise year) or the MER Experts Group Chair (during a non-exercise year) continue to lead the Connectivity Test.

Recommendation: Each test has been conducted with some general awareness of when it will occur. A future test should consider not giving advanced notice to truly exercise the “surprise factor” of receiving this notification.

Internal communication protocols :

Recommendation: Creation of a flow chart or one page checklist describing the notification protocols of the CPH and MOSPA Agreements in order to create alignment with EPPR member states. Future consideration should be made to an update in the MOSPA Operational Guidelines that would include a section detailing how the MOSPA Operational Guidelines interact in situations where the CPH Agreement (or other applicable agreements) is, or has the potential to be, activated.

Recommendation: At a future EPPR meeting, discuss the benefits of creating alignment between the CPH’s POLREP and the MOSPA forms (Section 11 Operational Guidelines). Notification procedures vary greatly between the CPH and MOSPA, TTX participants recommended finding alignment or adopting common procedures. It was noted that much of the incident information being shared is the same, the difference lies within the process (CPH vs MOSPA) in which the information is shared.

Recommendation: Develop Roles and Responsibilities section of the MOSPA Operational Guidelines to include those positions that would be involved in the communication and notification portion of a MOSPA activation in order to detail expectations for EPPR member states. This could include amplification of the “Liaisons” role as detailed in Section 2.4 of the Operational Guidelines. Creating alignment with this section between the CPH and MOSPA Agreements is preferred.

External communication protocols:

Recommendation: The ACS creates a brief paper detailing the roles and functions of the ACS during a MOSPA activation and the resources that are available to all member states and potentially the member state leading the response. Share this paper (and/or receive a briefing from the ACS) at EPPR I 2018.

For a member state requesting assistance:

Recommendation: Explore ways to expedite the notification and Request for Assistance process for duty officers by creating more seamless notification procedures. This can be accomplished by (possibly thru the EPPR Executive Secretariat) creating one email address for duty officers to use that will go to a broader “bang” list of contacts listed in the MOSPA Operational Guidelines.

2 Maximizing Use of EPPR Website, SharePoint, and Social Media Channels

The ACS and EPPR Secretariat have proven to be a vital resource of the EPPR

Recommendation: Under the direction of the EPPR Executive Secretariat and MER EG Chair/Co- Chair, continue to utilize the new EPPR website (www.EPPR.org) and SharePoint (EPPR and MER EG) to share both external and internal information, which includes (but not limited to): EPPR and MER EG Meeting information (agendas, documents, etc.);

Lessons Learned / After-action Report library;

Review of documents and proposals slated for EPPR approval (either during EPPR meeting or intersessionary); and

Sharing of other guidance (Liaisons) and agreements (multi/bi-lateral).

Recommendation: Under the direction of the EPPR Executive Secretariat, expand EPPR's social media presence via all relevant platforms (Twitter, Instagram, etc.) in order to increase awareness and success of EPPR activities. It is also recommended that EPPR member states, Permanent Participants, and Observers who are active on social media link (follow) their accounts to the EPPR.

3. Coordination between EPPR and the Arctic Coast Guard Forum

Representatives within the EPPR and the Arctic Coast Guard Forum (ACGF)

Recommendation: Maximize opportunities to share EPPR activities/updates during ACGF meetings and offer similar opportunities for ACGF presence at EPPR meetings/exercises.

4. Request for Assistance Process and Utilizing the Pan-Arctic Response Equipment Database

Recommendation: The forms (Notification, Request & Offers for Assistance, etc.) listed in the Operational Guidelines clearly address many of the questions and information gathering for a MOSPA Request for Assistance. However, the forms are not easy to utilize across various mobile and computing platforms. Recommend creating forms/ process that can be: Easily populated (type in forms, drop-down menus) and shared; and

Noted as being used during an "EXERCISE" without having to manually alter the form or handwrite on the forms.

Recommendation: Explore moving the forms to an online location and the ability to populate the forms online and send the information via that site or portal. Recommend a solution that will be easy for the end user (member states) to utilize.

• Observation: During the Request for Assistance process, the Requesting Party corresponds directly with the Offering Parties. Under this scenario, the Offering Parties do not have visibility on what other member states may offer. Recommendation: Create a process during the Request for Assistance that ensures visibility across all member states, Permanent Participants, and Observers so that Offers of Assistance can be coordinated with more visibility of what is being offered across all parties.

• Observation: During this and previous MOSPA exercises, the Request for Assistance process was exercised. Each member state was asked to review their internal protocols for offering assistance (for example, what does it take to secure authority to offer up resources or expertise); however, it is not apparent that was actually completed. Recommendation: During every MOSPA exercise, member states should review their internal protocols for Requests (and Offers) of Assistance and come prepared to share those lessons learned from their internal review. This process should be added to the MOSPA Exercise Planning Guidance currently under development by EPPR.

• Observation: During this MOSPA TTX, we were asked to "Demonstrate the capability to utilize the Pan-Arctic Response Equipment Database while managing an unsolicited Offer of Assistance from another Party of the MOSPA." The database was developed as a stand-alone system and also integrated in to NOAA's Arctic ERMA application. During the 2018 TTX, several recommendations were made on the potential next phase of the database. The proposal (being developed by EPPR) should consider the following recommendations:
Recommendation: The database is not all-inclusive and member states should ensure that all appropriate response equipment (and personnel) are included in the next phase of the database.

Recommendation: The database is not interactive, only the data entered prior to its final development (2017) is reflected and also displayed via NOAA's Arctic ERMA application. The next phase of the database should allow updating of database information, ensuring equipment is flagged as available or not available, location of equipment (since equipment is routinely relocated).

Recommendation: The database does not factor expertise and other types of emerging technology, instead it only references equipment. The next phase of the database should include specific personnel subject matter expertise and technology that can be offered by a member state, Permanent Participant, or Observer. For example:

- Oiled wildlife response and rehabilitation.
- Metocean data collection for remote areas to precise weather forecasting and to assist in fate and behavior analyses.
- Drones, other emerging technology.

◦Recommendation: The database is currently stored as a "zip" file on the EPPR website that can be utilized as a standalone database and integrated into other member states' plat-forms/systems. Converting the next phase of the database to an interactive (possibly cloud based) system in one location would: Place management/control under one entity (potentially EPPR Secretariat);
Allow member states the opportunity to link their national systems to the database so that when states update their national databases, the information could automatically update the Arctic database. If states do not link national systems to the database hosted by EPPR, states could still manually update their information via the EPPR hosted system;

Provide one location for requesting/offering equipment (and potentially personnel);
Allow mobile computing possibilities if system was compatible/viewable from mobile phones/tablets; and
Allow usage of the database across multiple operating Systems (Android, Windows, iOS, etc.).

5 Liaisons

Member states highlighted the importance on designating a liaison and highlighted lessons learned from previous exercise and incidents when using liaisons.

Recommendation: Continue to share protocols, guidance, and policy for utilizing liaisons during cross-border offers of assistance.

Recommendation: Establish a library of existing policy and guidance on usage of "Liaisons" during transboundary resource requests/offers.

Recommendation: Determine if additional updates are required for the Operational Guidelines.

6. Circumpolar Oil Spill Response Viability Analysis

Recommendation: Participants were asked to discuss the benefits and the challenges of utilizing the COSRVA and possibilities to overcome (or work around) those challenges. TTX participants determined that the COSRVA provided a great amount of detail in the static report as presented; however, could benefit for a more interactive solution. Recommend developing a proposal for the next phase of the COSRVA (Norway to lead).

Questions Considered during the 2018 MOSPA TTX

The following questions were considered during the 2018 MOSPA TTX and should be reviewed for future exercises.

- Based on the given scenario, explain the process for making initial notifications.
- What type of information should be included in the initial incident notification?
- Do the updated forms (Notification, Request for Assistance, etc.) capture all of the pertinent/ required information? If not, elaborate.
- Are you aware of any incorrect or missing contact information that you would like included in the Operational Guidelines?
- Does the overall Notification process work for your country? If not, what modifications to the process would you recommend?
- Do you have an internal notification best practice that you utilize for your agencies (federal, state and local) and commercial entities that you would like to share?
- What is your country's process to respond once notified (actions taken)?

- What does the Host nation or Requesting Party see as key or critical components of information which they would want reported to them? Frequency of reports? Any other data requirements?
- What new procedures, if any, will be established regarding internal Requestor communications resulting from an incident enacting the MOSPA Agreement?
- What new procedures, if any, will be established regarding bi-lateral communications between the neighboring countries?
- Discuss the ability to effectively balance communications between internal, national, bi-lateral, and multi-lateral components.
- Discuss how information was shared during this exercise; what worked and what did not work.
- Discuss the process for accountability of the notifications made and acknowledgements received.
- Discuss the personnel requirements for maintaining an effective communication team in order to conduct internal, national, bi-lateral, and multi-lateral notifications.
- Discuss your protocols for removing response resources / personnel from your national response system to support another country's response.
- Do you have mutual aid agreements in place for other countries to offer support in this type of circumstance?
- Discuss customs requirements for allowing equipment and personnel to enter your country when an emergency occurs (land and maritime), and determine who from your country will ensure safe and secure personnel and equipment movement.
- As resources are offered and eventually deployed, how do you incorporate those resources, and personnel, into your response framework and command system? Do they interact at the national level or do you incorporate them at lower levels; i.e. regional and local.
- How do you overcome language barriers and individual country differences during a response? Do you have
- Do you stand up roles or positions to function as liaisons for external resources and personnel?
- What role do your embassies or State entities play during a response?
- What types of Indigenous community assistance would you require in your country and do the Operational Guidelines address this effectively?
- How do you effectively collect consistent data (statistics for oil recovery, wildlife, modeling, weather, etc.) when mitigating multiple international response protocols and potential differences in data capture? How do you share this data?
- Discuss your internal procedures/ approval process for accepting assistance for applying alternative response technologies (i.e., dispersants, in-situ burn, bioremediation).
- Discuss the approval process in place for the use of, and presence of another county's vessels/aircraft/personnel in the waters or air space of the other country and who needs to be aware of, and "approve" of the operation prior to it commencing.
- Are there vessel manning/ safety/ licensing requirements that must be adhered to?

- Are there aircraft manning/ safety/ licensing requirements that must be adhered to?
- What is the process for “over flight” and low altitude assessments and cross boundary reconnaissance?
- What is the process for non-resident personnel/ responders working in Norway (i.e., is a visa required)?
- What Norwegian agencies govern the movement of personnel and equipment across the border into their respective countries?
- Do the MOSPA Agreement and Operational Guidelines address the movement of resources internationally adequately?
- What authorizations do the EPPR member states (Government, a contractor, and Vessels of Opportunity) need to obtain to conduct operations in Norwegian waters?
- What are the protocols/ restrictions for moving, storing, cleaning, and returning contaminated response equipment (e.g. boom, skimmers, etc.)?
- Discuss customs requirements for allowing equipment and personnel to enter your country when an emergency occurs (land and maritime), and determine who from your country will ensure safe and secure personnel and equipment movement.
- Discuss border requirements when the response shifts from one nation’s water to another due to marine environmental conditions.
- Discuss process in place for the disposal of oil originating in one country and recovered on the other, both offshore and onshore.

Source 4: EPPR, 2017, Final Report: Standardization as a tool for prevention of oil spills in the Arctic. 129 pp.

The report on "Standards for the Prevention of Oil Spills from Offshore Oil and Maritime Industry in the Arctic" has been prepared for the Arctic Council - Emergency, Prevention, Preparedness and Response (EPPR) Working Group as a response to the Task Force on Pollution Prevention (TFOPP) Framework Plan recommendation "Promotion of standardization activities". The work has been financed by the Norwegian Ministry of Foreign Affairs and administered by the Norwegian Coastal Administration (NCA).

The purpose of the work is to describe how necessary engineering and technical standards are identified, developed, established, and maintained. Furthermore the work done by various international trade groups and standards organizations are described, and participants in the various phases of the work have been identified.

The work relates to offshore petroleum and maritime activities. Petroleum activities (oil and gas) include exploration; drilling and production; subsea and topside installations; internal and external transportation pipelines, and offshore storage and offloading facilities. Drilling or stationary petroleum activities performed by mobile offshore drilling units (MODUs) are included in petroleum activities.

Maritime activities include all kinds of shipping; including cruise traffic, fisheries in international waters, national and international transportation of products, transportation of crude oil and petroleum products and petroleum service vessels. MODU's under transit are Maritime activities.

The roles and functions of a total of 47 organizations in the Arctic states, dealing with standardization in one form or another, both nationally and internationally in the maritime and petroleum sectors, are presented. In the maritime industry, the equivalent to standards is Codes and Class Rules.

Both the petroleum industry and the maritime industry apply a wide range of standards both for construction and design and for their daily operations. Many standards contribute to preventing oil spills and are generally applicable. Therefore, while the number of "Arctic-specific" standards is relatively limited, there are in fact many standards that contribute to preventing incidents in the Arctic.

Standards which are specifically focusing on prevention of oil spills in the Arctic has not been identified. It is however recognized that a wide range of safety related industrial standards are relevant for prevention of oil pollution in general and thus are also applicable in the Arctic.

One standard, the ISO 19906:2010 - Arctic offshore structures, has been published and is currently under revision. This is an important standard for design and construction of Arctic petroleum installations. National variations of this standard also exist.

The work done by the Barents 2020 project has formed an important basis for the development of Arctic
Petroleum Operation standards within the International standards Organization (ISO) in ISO/TC 67/SC 8,
where six new ISO standards are under development. These are:

- ISO 35101 - Working environment
- ISO 35102 - Escape, evacuation and rescue from offshore installations
- ISO 35103 - Environmental monitoring
- ISO 35104 - Ice management standard
- ISO TS 35105 - Material requirements for Arctic operations
- ISO 35106 - Arctic metocean, ice and seabed data

The ISO 35103 Environmental monitoring standard addresses the monitoring of both regular discharges and acute spills, but does not specifically address the prevention of oil pollution.

In the petroleum sector, regulators often utilise standards as recognised best practices. In some countries the standards are made mandatory when included in the regulations, while in other countries standards are included as guidelines or as examples of a way to comply with the regulations.

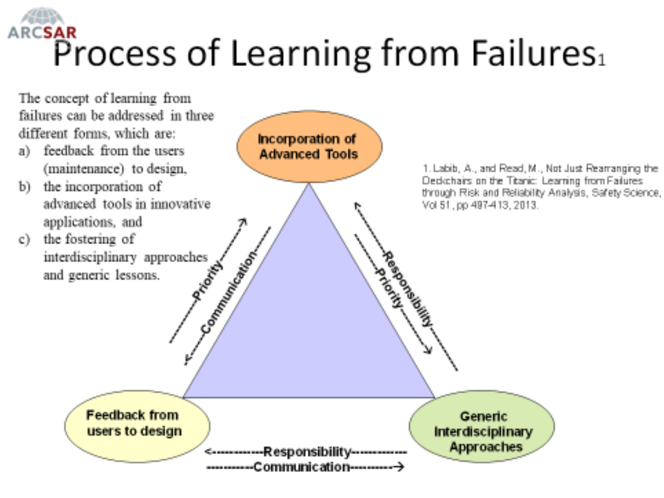
For the Maritime sector, the Polar Code developed by the International Maritime Organization (IMO) form the central document for Prevention of Oils Spills in the Arctic from maritime activities and will, in practice, function as a combination of a standard and an international regulation. Internationally adopted Conventions, Codes and Class Rules are mandatory for vessels in international waters, while within the harbour states national waters, the harbour state include a set of Codes and Class rules into their regulations and define which to include. Conventions are binding for ratifying nations.

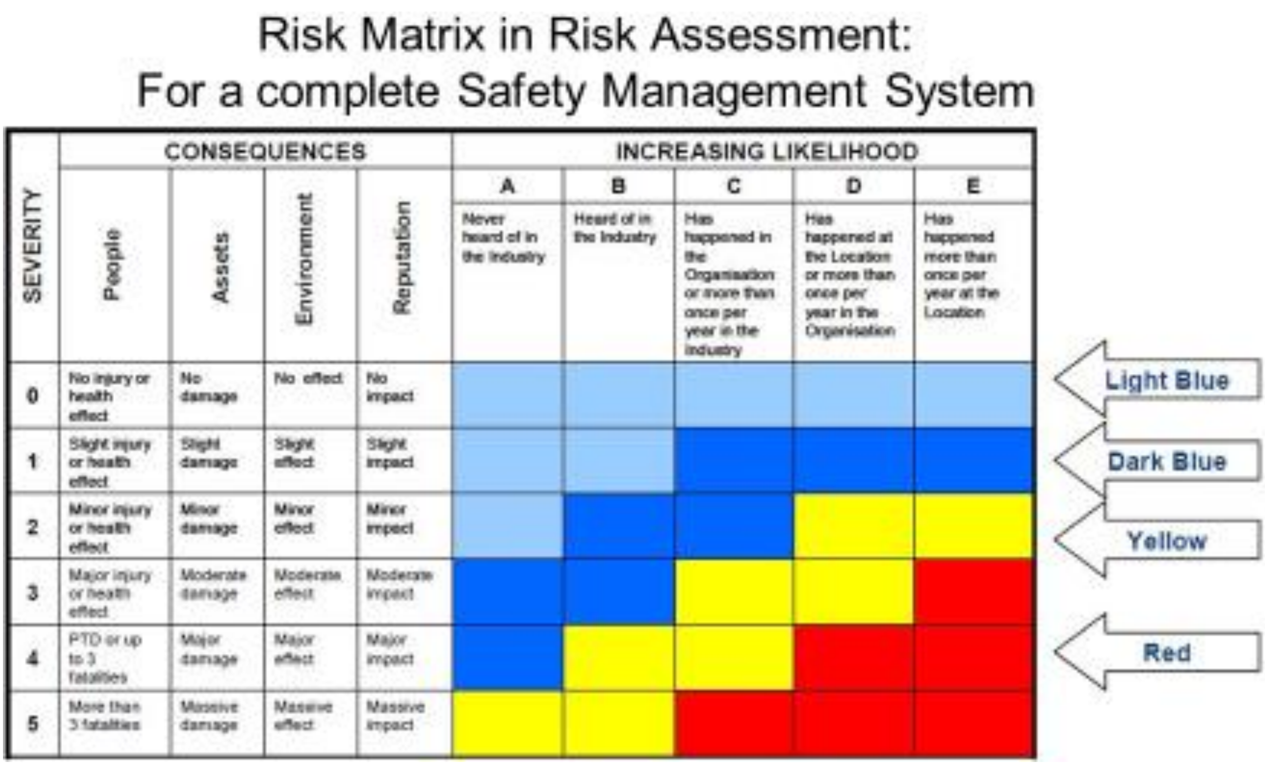
IMO has adopted the International Code for Ships Operating in Polar Waters (Polar Code) and related amendments to make it mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL).

The Polar Code and SOLAS amendments were adopted during the 94th session of IMO’s Maritime Safety Committee (MSC), in November 2014; the environmental provisions and MARPOL amendments were adopted during the 68th session of the Marine Environment Protection Committee (MEPC) in May 2015.

Appendix D: Theoretical bases applied during workshops

Theory related to the process of Learning from Failures (Labib, 2014) was outlined, followed by characterisation of Risk and Risk Matrix, followed by small group activities.





Risk Matrix in Risk Assessment:
For a complete Safety Management System

SEVERITY	CONSEQUENCES				INCREASING LIKELIHOOD				
	People	Assets	Environment	Reputation	A	B	C	D	E
					Never heard of in the Industry	Heard of in the Industry	Has happened in the Organisation or more than once per year in the Industry	Has happened at the Location or more than once per year in the Organisation	Has happened more than once per year at the Location
0	No injury or health effect	No damage	No effect	No impact					
1	Slight injury or health effect	Slight damage	Slight effect	Slight impact					
2	Minor injury or health effect	Minor damage	Minor effect	Minor impact					
3	Major injury or health effect	Moderate damage	Moderate effect	Moderate impact					
4	PTD or up to 3 fatalities	Major damage	Major effect	Major impact					
5	More than 3 fatalities	Massive damage	Massive effect	Massive impact					

Figure: Theoretical bases applied during workshops

Beyond risk analysis and learning from failure, organisational resilience theories were considered in order to delve deeper into the case study analysis, which considers the following:

- We use this term to refer to the ability of an organization to anticipate, circumvent threats to its existence and primary goals and rapidly recover (Hale and Heijer, 2006).
- In a more succinct way, the main feature of resilience is underpinned by three capacities; absorptive capacity, adaptive capacity and restorative capacity.
  - **Absorptive capacity**: the degree to which a system can absorb the impacts of system perturbations and minimize consequences with little effort.
  - **Adaptive capacity** is the ability of a system to adjust to undesirable situations by undergoing some changes.
  - **Restorative capacity** is the rapidity of return to normal or improved operations and system reliability (Francis and Bekera, 2014).

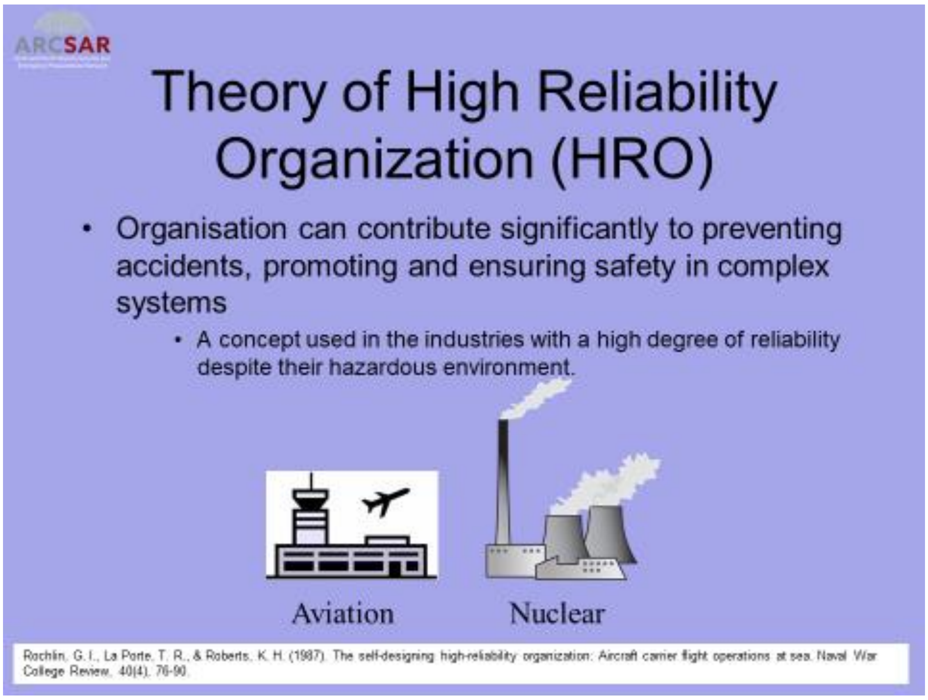
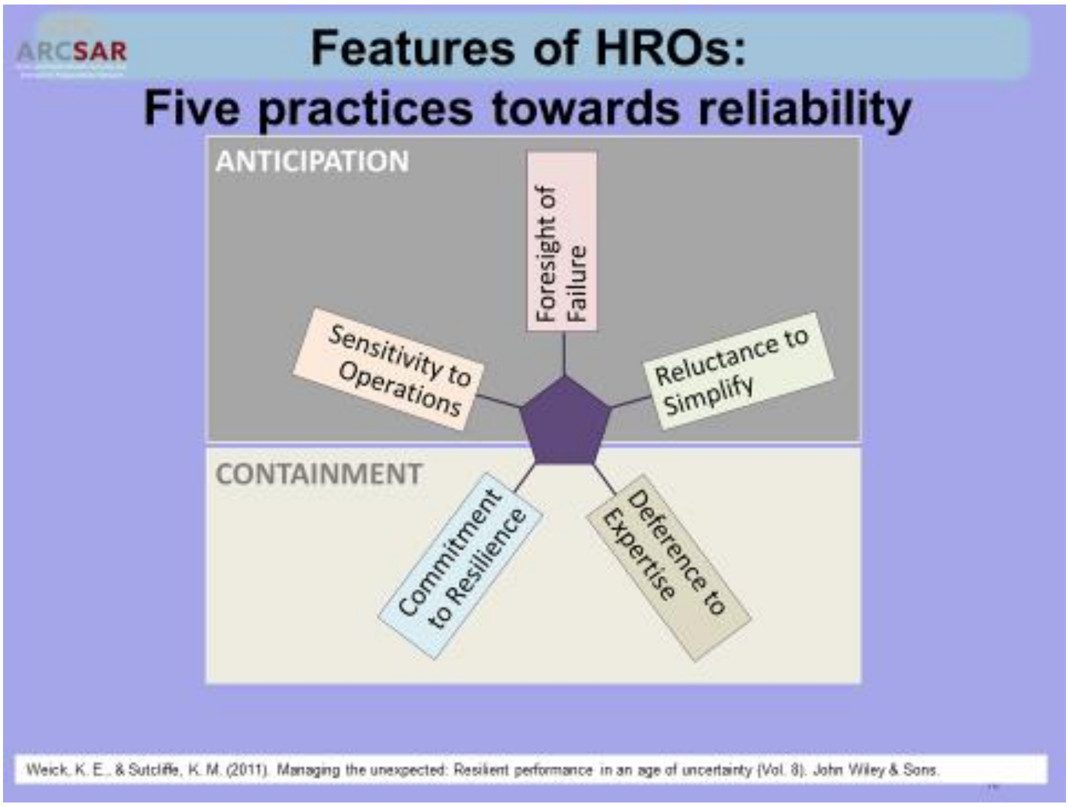


Figure: Theoretical bases for HRO applied during workshops



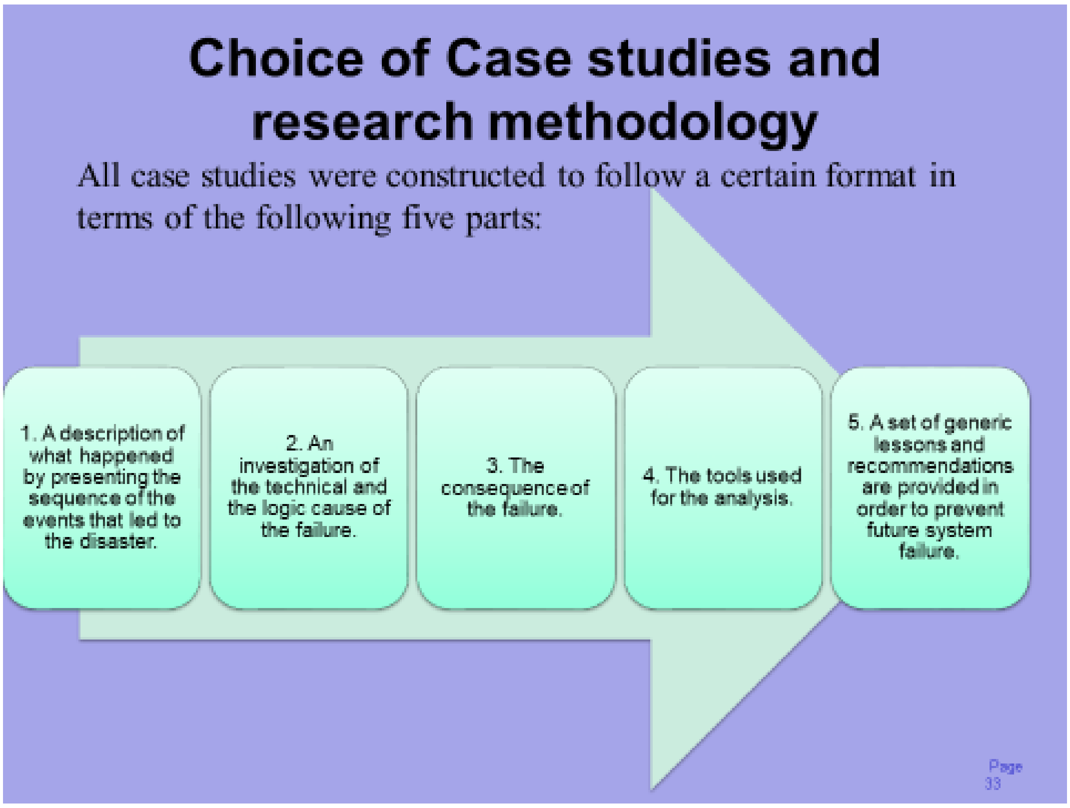


Figure: Case study selection methodology

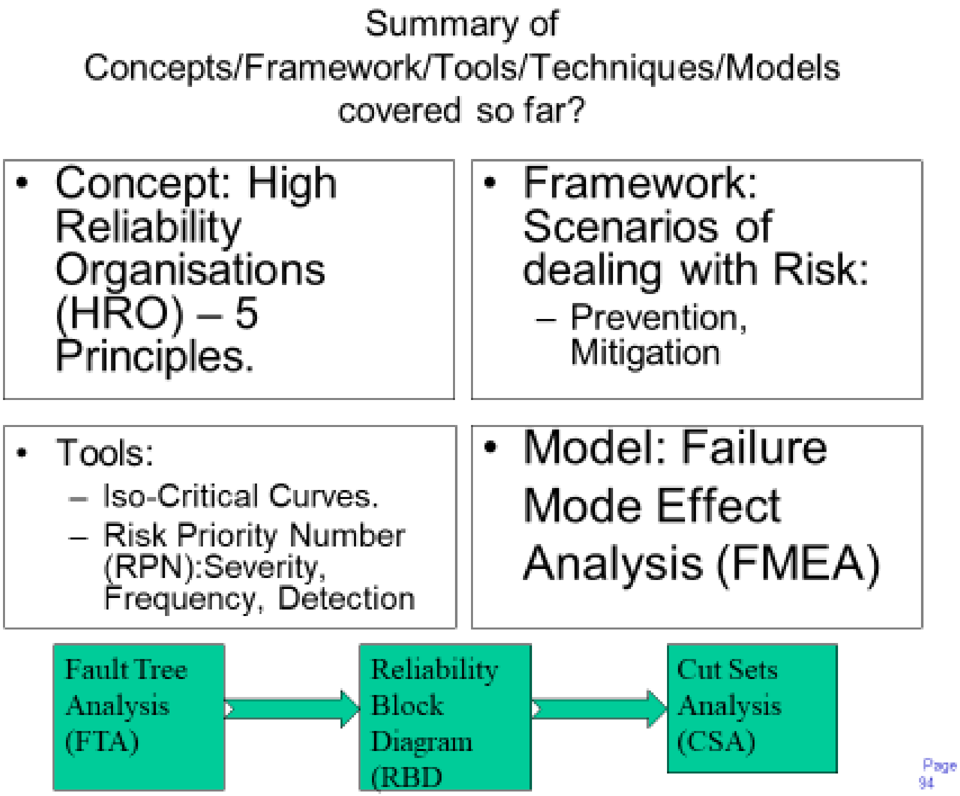


Figure: Overview of root cause analysis models

Mapping the causative factors of the Piper Alpha disaster in terms the 5 HRO Principles				
Preoccupation with Failure	Reluctance to Simplify	Sensitivity to Operations	Commitment to Resilience	Deference to Expertise
Inadequate plant design. Inadequate change management process. Inadequate hazard assessment. Inadequate maintenance procedures. Inadequate safety procedures. Inadequate permit to work system. Inadequate shift handover process.		Poor shift handover Inadequate attention to permit process	Ineffective emergency response procedure	Neighbouring plants waited on hierarchy for shutdown instructions, inadvertently fueling the explosion.

Applications of the 5 Principles of HRO to a famous case study of offshore oil spill (BP, Deepwater Horizon, 2010) in the Gulf of Mexico

Mapping the causative factors of the Deepwater Horizon disaster in terms the 5 HRO Principles				
Preoccupation with Failure	Reluctance to Simplify	Sensitivity to Operations	Commitment to Resilience	Deference to Expertise
Poorly designed cement barrier Poor maintenance procedures. No function test of cement barriers. No function test of safety safety systems. Non functional safety alarms.		Failure to interprete a safety test. Poor communication Inadequate training Poor maintenance practices. Poor crew coordination.	Delay in reacting to signals Inadequate emergency response training. Inadequate supply of lifeboats Poor mustering process	

Appendix E: Stakeholder Engagement Images

Some small groups photos


Group Work

Some photos for groups work